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Comparative Mineralurgical Phase Examination of Selected Locally Sourced Ceramic Raw Materials Using X-Ray Diffractometry (XRD)

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ABSTRACT: The ceramics industry is shifting nippily due to globalization, consumer trends, and consumption patterns. This is in turn driving up manufacturing costs locally and consequently increasing the volume of imported goods because local ceramic products sell for relatively high prices comparative to their unit weight, making importation an economically viable option, thereby hurting the local market. Since Nigeria is blessed with an abundance of solid minerals that can be used to produce all of the ceramic goods it needs, it is imperative to create a local competitive climate in order to ensure that the country's ceramic industry achieves global positioning. Consistent quality improvement therefore, and product innovation in local ceramic manufacture are important factors for making locally made goods competitive with imported ones. The goal of this paper is to compare the mineralogical components of the chosen local raw materials in terms of both qualitative and quantitative examination. If production has to be precise in order to meet the standard of imported goods, then this phase composition component of raw materials cannot be overstated. The study aims to utilize X-Ray Diffractometry (XRD) in order to ascertain the Mineralogical phase composition of sample that were chosen. The common phases that were present in the examined samples but obviously at varying quantities were Kaolinite, Quartz, Illite, Kyanite, Sillimanite, Muscovite, Montmorillonite, Halloysite, Pyrophyllite, Pseudobrookite and Anatase. Their percentage presence in the samples eventually determined individual qualities and respective application to ceramic products.

KEY WORDS: phase, diffractometry, kaolinite, characterization and ceramics.

1. STUDY BACKGROUND

Ceramic products are composed of nonmetallic and inorganic constituents that commonly occur in the earth crust. According to Denis and John (2009), traditional ceramics contain oxides of aluminum, silicon, magnesium, calcium, iron, and alkali metals along with trace quantities of other elements. Adjusting the composition or mineral constitution and increasing the amount or degree of vitrification in firing are means of achieving low porosity, high mechanical strength and high resistance to chipping in ceramic manufacturing (Catherine, 2008). With respect to composition of minerals, strength can be achieved in clay-based ceramics. Further improvements in strength are obtained when Aluminium oxide also called Alumina (Al_2O_3) or other minerals such as Zirconium oxide also called Zirconia (ZrO_2) are added to the composition, (Basu & Balani 2011; Aramide, 2014).

Problem Statement

Globalization, consumer trends and consumption patterns are causing rapid changes in the ceramics economic sector all over the world, it is in turn placing pressure on local manufacturing costs, making the volume of imported products grow rapidly, and since the selling price of local ceramic products is relatively high compared to the unit weight of the product, importation is next economically feasible option thereby putting the local market at disadvantage, (EPINA, 2014 & Oaikhinan, 2015).

Aim and Objective

Nigeria is rated the 13th Highest importer of ceramic products in the world, it is therefore now very essential to create a local competitive climate to ensure that Nigerian ceramic industry attains global positioning, since the nation is endowed with abundant solid minerals that can be harnessed for the production of all ceramic its needs.

For locally made products to favorably compete with the imported ones therefore, sustained quality improvement and products innovation in local ceramic production is a major influence. This paper is geared towards comparative examination of mineralogical constituents of the selected local raw materials in both qualitative and quantitative capacity. This phase composition of raw materials cannot be overemphasized, if precision is to be the goal of production in order to match the standard of imported products. This in turn is capable of revamping Nigeria's ceramic industry, given the strategic importance of many of the industry's products to substantively deplete the level of ceramics importation. The objective of the study is to employ the X-Ray Diffractometry (XRD) to determine the Mineralogical phase composition of each of the selected samples.

Selected Samples and Study Area

The raw materials selected for this research study are kaolin from Ekiti, Osun, Ondo and Edo States which covers the SouthWest (SW) and SouthEast (SE) Geo-Political Zones (GPZ) of the country. Ekiti, Osun and Ondo from SW, while Edo from SE GPZ. These were carefully selected in order to harness and maximize the solid minerals available within ample proximity to the research locale (Akure).

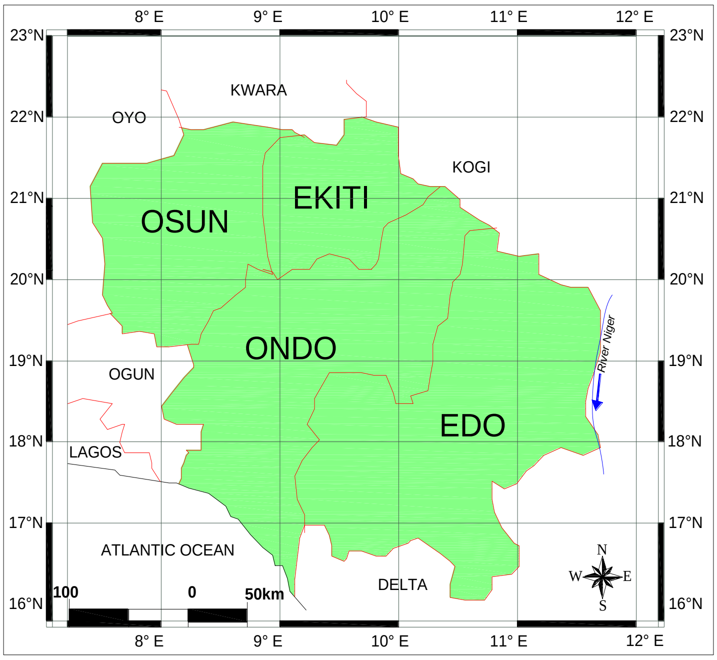

Fig. 1: Map of the Study Area in its Regional Setting

2. KAOLIN DEPOSITS AND THEIR SOURCING

Kaolin is a hydrated aluminum silicate with the chemical formula, $Al_2\ Si_2O_5\ (OH)_4$, a specific gravity of 2.2-2.6 and hardness (Mohs' scale) of 2. It is also referred to as primary clay or china clay. It is a friable, non-plastic material and rather coarse. When present in ceramic body, kaolin opens up the plastic clay in the body so that it dries more easily. It is an indispensable material in the formulation of ceramic bodies to enhance strength and whiteness; and helps to control vitrification in the bodies. According to American Elements (2015), kaolin is used as refractories due to its extremely high fusion point, low water content and high green strength.

It is the principal raw material needed for the production of technical ceramics items such as refractory crucibles, as opined by Kashim, 2011; and gives plasticity to enable the body to be shaped and gives adequate unfired strength so that it may be handled between the shaping and firing process. To substantiate the indispensability of kaolin in ceramic body processing, it remains the main versatile industrial raw material of wide application in ceramic industry.

Grim as cited by Kashim (2011) revealed that kaolin is formed by a process called kaolinisation in which kaolinite is formed from the decomposition of potassium feldspar, granite and alumina silicate, occurring in three ways viz: crumbing and transformation of rock due to the effect of climatic factors, transformation of rock due to hydrothermal effect and formation by climatic and hydrothermal effect. Badmus and Olatinsu (2009) explained that the iron content in each type of kaolin clay determines its colours and that other colours such as purple, bleach brown, etc., are due to the impurities in the material.

Okpanachi (2004) claimed that Nigerian kaolin is to have purity as high as 90% and an estimated reserve of three (3) billion metric tonnes distributed in various parts of the country where it is found. Badmus and Olatinsu (2009) posited that kaolin deposits are wide spread throughout Nigeria and almost every state in Nigerian has at least one deposit of kaolin. According to Raw Materials Research and Development Council, as cited by Kashim (2011), one of the major deposits of very high grade quality kaolin in Nigeria is found in Ikere Ekiti in Ekiti State where one of the kaolin samples for this research was sourced. Atanda, Oluwole and Oladeji (2012) produced electrical porcelain using Ikere Ekiti kaolin and have thereby proven its suitability for the production of refractories.

3. MATERIALS AND METHODS

Kaolin samples used in this research were sourced from selected locations in Southern Nigeria, namely: Okpela in Edo state, Alagbaka in Ondo state, Ikere in Ekiti state and Awo in Osun state respectively as shown on the following plates 1 to 12. This was because these mining locations had been geographically identified found viable and have been used by previous researchers with promising results.

Sourcing of Raw Kaolin and Processing

The raw kaolin samples were sourced from established locations in the Southern part of Nigeria, namely: Okpela in Edo state, Alagbaka in Ondo state, Ikere in Ekiti state and Awo in Osun state respectively. The samples was soaked in water for three (3) days to dissolve and to form slurry for ease of processing. The slurry was sieved to remove the unwanted materials and other foreign substances. The filtrate was allowed to settle down and the water decanted. The decanted slurry was poured into Plaster of Paris (P.O.P) moulds to further drain the water out of the filtrate kaolin completely.

The resulting kaolin was sun dried and subsequently dried in the drier at 110ºC for about 24 hours at the Department of Industrial Design, Federal University of Technology, Akure. Finally, the dried kaolin samples were crushed and milled to an average particle of 300µm. Processing line was as shown on plates 15 to 20.

Plate 1: Soaked Kaolin

Plate 2: Sieving of Kaolin Sample

Plate 3: Decanting

Plate 4: Draining of Kaolin Sample

Plate 5: Sun Drying of Sample

Plate 6: Awo Kaolin Deposit

Plate 7: Ikere Kaolin Deposit

Plate 8: Ikere Kaolin

Plate 9: Alagbaka Kaolin Deposit

4. X-RAY DIFFRACTOMETRY (XRD) RESULTS OF RAW KAOLIN SAMPLES

The samples were prepared for XRD analysis using back loading preparation method. They were analyzed and the relative phase amounts (in weight percentage) were estimated using the method (Autoquan Program). Amorphous phases were not taken into consideration in the quantification.

The samples were crushed, and sieved to a particle size ≤ 75µm. The sieved samples now in powdered form were used for X-ray diffraction analysis (XRD). Analysis of X-ray diffraction was performed on the sample by a Shimadzu XDS 2400H diffractometer with Cu anode, λ_{CU} = 1.54056 [A°], on uncompressed powders in order to collect the maximum of the diffraction lines and a better identification of the phases. The prepared sample was placed in a lucite holder on the goinometer of the instrument which was configured with a graphite monochromator. The diffraction beam monochromator operated at 40 KVA and a current of 30 mA with the 2θ range of 3–100 ºC and at a scan speed of 2º C/minute with step size of 0.02º for 120 minutes to create x- ray patterns with enough intensity to produce lines to identify minerals at the **2θ** angles. Components were identified using the JCPDFWIN software of the Joint Committee on Powder Diffraction Standard (JCPDS), and ICDD reference for the XRD on kaoline sample. The receiving slit was placed at 0.040°. The counting area was from 7 to 60° on a 2θ scale. The count time was 1.5s.

The various results of the XRD tests are hereby as displayed on Tables 1 to 5 and Figure 2 following below:

Table 1: XRD Diffraction Pattern of Ikere Kaolin

Peak	2θ/degree	d-Valve (A˚)	Plane	Symbol	Name	Chemical Formulae
1	11.59	6.67	002	M	Montmorillonite	(Na,Ca)0,3(Al,Mg)2Si4O10(OH)2•n(H2O)
2	19.32	4.59	020	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
3	28.11	3.16	023	Q	Quartz	SiO_2
4	28.42	3.12	102	Q	Quartz	SiO_2

5	29.79	3.09	114	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
6	29.56	3.02	113	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
7	31.98	2.78	112	Q	Quartz	SiO_2
8	32.70	2.74	024	Ky	Kyanite	Al_2SiO_5
9	34.26	2.58	130	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
10	35.58	2.52	200	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
11	38.25	2.32	116	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
12	43.25	2.13	026	S	Sillimanite	Al_2SiO_5
13	44.01	1.98	222	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
14	46.11	1.89	225	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
15	47.56	1.85	136	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
16	49.28	1.80	223	Q	Quartz	SiO_2
17	49.95	1.78	226	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
18	50.62	1.76	224	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
19	50.84	1.75	008	Q	Quartz	SiO_2
20	53.14	1.67	313	Mu	Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$
21	58.19	1.53	215	K	Kaolinite	$Al_2Si_2O_5(OH)_4$

Table 2: XRD Diffraction Pattern of Okpela Kaolin

Peak	2θ/degree	d-Valve (A˚)	Plane	Symbol	Name	Chemical Formulae
1	11.59	6.67	002	M	Montmorillonite	(Na,Ca)0,3(Al,Mg)2Si4O10(OH)2•n(H2O)
2	18.16	4.89	110	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
3	19.32	4.59	020	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
4	28.11	3.16	023	Q	Quartz	SiO_2
5	28.42	3.12	102	Q	Quartz	SiO_2
6	28.79	3.09	114	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
7	29.56	3.02	113	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
8	31.98	2.78	112	Q	Quartz	SiO_2
9	32.70	2.74	024	Ky	Kyanite	Al_2SiO_5
10	34.26	2.58	130	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
11	35.21	2.52	025	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
12	35.58	2.52	200	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
13	37.25	2.38	006	Q	Quartz	SiO_2
14	43.25	2.13	026	S	Sillimanite	Al_2SiO_5
15	46.89	1.89	225	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
16	47.10	1.88	044	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
17	50.10	1.78	226	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
18	50.86	1.75	008	Q	Quartz	SiO_2
19	51.19	1.74	045	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
18	58.19	1.53	215	K	Kaolinite	$Al_2Si_2O_5(OH)_4$

Source: Researchers' fieldwork, 2024

Table 3: XRD Diffraction Pattern of Awo Kaolin

Peak	2θ/degree	d-Valve (A˚)	Plane	Symbol	Name	Chemical Formulae
1	11.59	6.67	002	M	Montmorillonite	(Na,Ca)0,3(Al,Mg)2Si4O10(OH)2•n(H2O)
2	19.32	4.59	020	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
3	26.45	3.36	112	H	Halloysite	$Al_2Si_2O_5(OH)_4$
4	28.11	3.16	023	Q	Quartz	SiO_2
5	28.42	3.12	102	Q	Quartz	SiO_2
6	29.79	3.09	114	K	Kaolinite	$Al_2Si_2O_5(OH)_4$

7	29.56	3.02	113	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
8	30.18	2.94	212	Py	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$
9	31.98	2.78	112	Q	Quartz	SiO_2
10	32.70	2.74	024	Ky	Kyanite	Al_2SiO_5
11	34.26	2.58	130	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
12	35.28	2.52	025	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
13	35.58	2.49	200	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
14	36.13	2.46	022	At	Anatase	TiO_2
15	37.86	2.38	006	Q	Quartz	SiO_2
16	41.74	2.13	116		Montmorillonite	$(Na,Ca)0,3(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot n(H_2O)$
17	43.25	2.13	026	S	Sillimanite	Al_2SiO_5
18	44.01	1.98	222	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
19	46.11	1.89	225	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
20	47.10	1.88	044	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
21	47.56	1.86	136	P	Pseudobrookite	Fe_2TiO_5
22	49.95	1.78	226	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
23	50.86	1.75	008	Q	Quartz	SiO_2
24	53.14	1.67	313	Mu	Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$

Source: Researchers' fieldwork, 2024

Table 4: XRD Diffraction Pattern of Alagbaka Kaolin

Peak	2θ/degree	d-Valve (A˚)	Plane	Symbol	Name	Chemical Formulae
1	11.59	6.67	002	M	Montmorillonite	(Na,Ca)0,3(Al,Mg)2Si4O10(OH)2•n(H2O)
2	19.32	4.59	020	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
3	28.11	3.16	023	Q	Quartz	SiO_2
4	28.42	3.12	102	Q	Quartz	SiO_2
5	29.79	3.09	114	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
6	29.56	3.02	113	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
7	31.98	2.78	112	Q	Quartz	SiO_2
8	32.70	2.74	024	Ky	Kyanite	Al_2SiO_5
9	34.26	2.58	130	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
10	35.58	2.52	200	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
11	43.25	2.13	026	S	Sillimanite	Al_2SiO_5
12	44.01	1.98	222	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
13	46.11	1.89	225	I	Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
14	49.28	1.80	223	Q	Quartz	SiO_2
15	49.95	1.78	226	K	Kaolinite	$Al_2Si_2O_5(OH)_4$
16	50.86	1.75	008	Q	Quartz	SiO_2
17	53.14	1.67	313	Mu	Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$
18	58.19	1.53	215	K	Kaolinite	$Al_2Si_2O_5(OH)_4$

Source: Researchers' fieldwork, 2024

Table 5: Mineralogical Phases Detected in All Tested Samples

Mineral Phases	Okpela Kaolin (wt. %)	Awo Kaolin (wt. %)	Ikere Kaolin (wt. %)	Alagbaka Kaolin (wt. %)
Kaolinite	60.23	21.64	61.80	19.72
Quartz	2.75	58.73	23.62	51.58
Illite	10.92	3.79	6.31	6.64
Kyanite	4.21	1.08	0.57	4.21
Sillimanite	12.43	3.42	1.39	5.40
Muscovite	-	3.81	3.92	7.92
Montmorillonite	5.64	2.59	2.06	2.74
Halloysite	-	0.62	-	-
Pyrophyllite	-	1.47	-	-
Pseudobrookite	-	0.89	-	-
Anatase	-	1.19	-	-

Source: Researchers' fieldwork, 2024

Table 6: General Information on the Mineralogical Phases Examined

Mineral Phases	Category	Chemical Formula	Crystal System
Kaolinite	Phyllosilicates	$Al_2Si_2O_5(OH)_4$, or in oxide notation: $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	Triclinic
Quartz	Silicate mineral	SiO_2	α-quartz: trigonal β-quartz: hexagonal
Illite	Mica- phyllosilicates	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$	Monoclinic
Kyanite	Nesosilicate	Al_2SiO_5	Triclinic
Sillimanite	Nesosilicate	Al_2SiO_5	Orthorhombic
Muscovite	Phyllosilicate	$KAl_2(AlSi_3O_{10})(F,OH)_2$	Monoclinic
Montmorillonite	Phyllosilicates	$(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$	Monoclinic
Halloysite	Phyllosilicates	$Al_2Si_2O_5(OH)_4$	Monoclini
Pyrophyllite	Silicate minerals	$Al_2Si_4O_{10}(OH)_2$	Monoclinic or triclinic
Pseudobrookite	Oxide mineral	Fe_2TiO_5	Orthorhombic
Anatase	Oxide minerals	TiO_2	Tetragonal

Source: Researchers' fieldwork, 2024

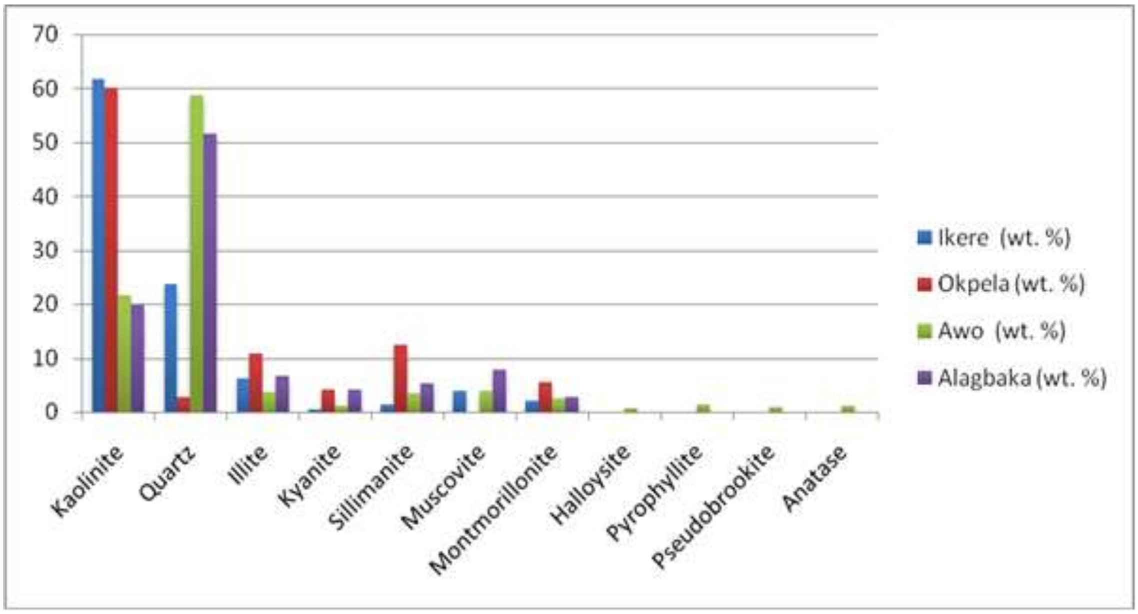

Fig. 2: Histogram of X-Ray Diffractometry (XRD) of Tested Kaolin Samples

Discussion and Conclusion of the Mineralogical Phases Present on XRD Test on Samples

'Phase' of a mineral is a physically different molecular or crystal structure induced by a set of conditions (i.e. temperature, pressure). Phases may possess similar chemical properties but definitely exhibit different physical properties, (opengeology.org, sciencedirect.com, wikipedia.org & google.com; retrieved Feb., 2024). From the XRD tests as summarized on Table 1 to 5 and Fig. 2, the most common mineralogical phases detected in the four samples were Kaolinite, Quartz, Illite, Kyanite, Sillimanite, Muscovite and Montmorillonite. Others, common to Awo kaolin alone, were Halloysite, Pyrophyllite, Pseudobrookite and Anatase.

The dominant mineral phase present in the four samples was Kaolinite with approximately 60%, 22%, 62% and 20% in Okpela, Awo, Ikere and Alagbaka samples respectively. Quartz phase stood at 2.75%, 58.73%, 23.62% and 51.58% by weight respectively.

Sillimanite phase ranked second to Kaolinite phase in the samples, it was taken as 12%, 3%, 1% and 5% respectively. The Illite phase found were 10.92%, 3.79%, 6.31% and 6.64% too. Montmorillonite phase follows with 5.64%, 2.59%, 2.06% and 2.74% respectively. The Kyanite phases contained in the samples were 4.21%, 1.08%, 0.57% and 4.21% respectively. Muscovite phase was not present in Okpela kaolin but present in Awo, Ikere and Alagbaka samples at 3.81%, 3.92% and 7.92% respectively.

Halloysite, Pyrophyllite, Pseudobrookite and Anatase phases were peculiar to Awo kaolin and present in 0.62%, 1.47%, 0.89% and 1.19% respectively.

Declaration

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REFERENCES

1. Ajala, A. (2010), 'Studies on the Production of Earthenware Glazes from Eucalyptus Leave Ash and Cullet', Unpublished M. Tech. Thesis, Industrial Design Programme, Abubakar Tafawa Balewa University, Bauchi.
2. Ajala, A. O. (2019), Production of Gas Burner with Zirconia-Based Nozzle from Locally Sourced Materials in Southern Nigeria. Unpublished Ph.D Thesis, Department of Industrial Design, Federal University of Technology, Akure - Nigeria.
3. American Elements (2015): www.americanelements.com /kaolin. Retrieved 19th January, 2024
4. Aramide, F. O. (2014), 'Development of Mullite-Zircon-Zirconia Refractory Ceramic Composite from Selected Clays in South West Nigeria', Unpublished PhD. Thesis, Metallurgical and Materials Engineering Department, Federal University of Technology, Akure - Nigeria.
5. Atanda, P. O., Oluwole, O. O., and Oladeji, T. A. (2012): Electrical Porcelain Production from Selected Kaolin Deposits in Southwestern Nigeria Using Slip Casting. International Journal of Materials and Chemistry, 2012, 2(3): pp86-89
6. Badmus, B. S. and Olatinsu, O. B. (2009): Goephysical Evaluation and Chemical Analysis of Kaolin Clay Deposit of Lakiri Village, Southwestern Nigeria. *International Journal of Physical Sciences,*Vol. 4. (10) pp. 592-606
7. Basu, B. and Balani, K. (2011): Advanced Structural Ceramics, 1st ed., John Wiley and Sons, New Jersey, USA
8. Catherine, S. (2008), 'Oxford English Mini Dictionary', Seventh Edition. Oxford University Press Inc. New York.
9. Denis, A. B. and John, P. S. (2009): 'Fine Ceramic Products: Industrial Minerals and Rocks'. West Conshohocken
10. Epina (2014); Ceramic market projected to reach $408B by 2018 globally. Epina Technologies Limited, Foundry Building, Federal Institute of Industrial Research, Oshodi, Lagos. www.vanguardngr.com/201408/ceramic-market-project-reach-408bn-2018-globally
11. https://www.google.com, 2024
12. https://opengeology.org/petrology/8-igneous-phase-diagrams-and-phase-equilibria/&ved=2ahUKEwjbxJ6h7LqFAxU7UkEAHZHbAm4QFnoECBMQAw&usg=AOvVaw0ISOJUgiGSuREqOKI1HFom, 2024

13. https://www.sciencedirect.com/topics/engineering/mineral-phase&ved=2ahUKEwjbxJ6h7LqFAxU7UkEAHZHbAm4QFnoECCsQAQ&usg=AOvVaw0RCRPv8vqsdhmtBQ3r1r-b, 2024
14. https://en.wikipedia.org, 2024
15. Kashim, I. B. (2011): Solid Mineral Development in Sustaining Nigeria's Economic and Environmental Realities of the 21st Century. Journal of Sustainable Development in Africa, Vol. 13, No. 2
16. Oaikhinan, E. P. (2015): How to Revamp Nigeria's Moribund Ceramic Industry. Published in the Guardian Newspapers of Thursday 21 April 2016
17. Okpanachi, U. M. (2004): *The Economics of Solid Minerals Development.* A Paper presented at a Seminar on Solid Minerals Exploration and Exportation at the Hill Station Hotel Jos, Organised by The Shippers' Council of Nigeria on 22nd July, 2004