

Characterization of a Feldspar Mineral from Adogo, Ajaokuta Deposit

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Abstract

This study considered the suitability of Adogo feldspar deposit in Kogi State, Nigeria for glass and ceramic production. The feldspar's sample was characterised through analysis of its physical, chemical and mineralogical properties. The results of the physical analysis showed that the mineral has a bulk density of 1.3551 g/cm³ and tapped density of 1.5209 g/cm³, which was used to determine the compressibility index and Hausner ratio. The index shows that the powdered mineral has a good flow character. The result also revealed that the mineral has a very low percentage of moisture content (1.75%) and clay content of 2.9%. Meanwhile, the chemical analysis showed that the feldspar mineral has dominant elements of Silicon (70%) and Aluminium (20%), with 73% and 23% oxides of silicon and aluminium respectively, negligible values of other elements and oxides in the feldspar. The mineralogical analysis revealed that the feldspar deposit was of low-grade soda feldspar, while the phases present showed that the mineral was a low-grade feldspar Albite Feldspar. Though, the physical and chemical properties of the feldspar revealed the potential of the feldspar as a suitable raw material in ceramics and glass industry but further beneficiation was needed to meet suitability for the production of ceramic and glass.

Keywords

Albite, Characterization, Diversification, Feldspar, Flowability, Muscovite,

1. Introduction

The need for diversification of Nigeria's economy from oil and gas to other great potential economic and abundantly available resources, like mineral

resources, agriculture, renewable and non-renewable natural resources, among others is greatly desired for economic transformation to a greater height (Nkuda, 2021; Hassan *et al.*, 2020; Chris *et al.*, 2015; Suberu *et al.*, 2015; Esu and Udonwa, 2015). The Nigerian economy has been in a leaned and **unsafety** conditions for decades due to over dependence on oil (Chris *et al.*, 2015; Suberu *et al.*, 2015). In 2020, Nigeria economy crumbled and entered the deepest recession for the first time since the 1980s due to a combination of drastic fall in global crude oil price and consequence of COVID-19 (The World Bank, 2020a; The World Bank, 2020b; African Development Bank, 2021). Though, the country's economic status has not been on the sustainable part before this time due to over-dependence on oil as its major economic source (Chete *et al.*, 2017; Sanusi 2010; Pinto, 1987). Meanwhile, Nigeria is endowed with different resources (such as marble, feldspar, gold, iron ore, soil, lead, zinc, coal, columbine, tin, limestone, among others) in large quantities, that are have great potential in developing the country economy, if adequately utilized (Ajudua *et al.*, 2021; Mike & Taiwo, 2020; Metu *et al.*, 2020; Raw Material Research and Development Council, 2010). Unfortunately, records show that these resources have not been adequately used for industrial and economic developments (Oxford Business Group, 2021; Nkuda, 2021; Ajudua *et al.*, 2021; Shuaib-Babata *et al.*, 2019; Shasore, 2018; Shuaib-Babata *et al.*, 2018a; Shuaib-Babata *et al.*, 2018b; Shuaib-Babata *et al.*, 2017; Godwin & Ubong, 2015; Ajayi & Owoeye, 2014).

Feldspar, an essential raw material used in glass and ceramic industries, is known to be in the group of most abundant minerals found on the earth crust (Aljaradin & Amaireh, 2014; Klien, 2001). It can be an essential material in batches for making glass, fine ceramic products like hardware, china wares, porcelain, tiles, shower basins, tableware and other ceramics products due to its fluxing properties; as filler and extender in paint, plastics and rubber, and as a highly significant input in agricultural and pharmaceutical sectors. In the production of glass, feldspar provides alumina, which improves the hardness, durability, and ability of glass to resist chemical corrosion. Feldspar is mostly utilized in ceramic bodies and glazes in the ceramic industry. As a flux, feldspar lowers the melting temperature of a ceramic body during firing and forms a glassy phase in the body (Kauffman & Van Dyk, 1994).

The usefulness and application of feldspar and quartz can be found in minor construction works, abrasive, glass and ceramic industries (Elueze *et al.*,

2004). Feldspars may contain considerable amounts of quartz and iron oxide, which are used in a wide range of applications including the production of tiles, sanitary and technical porcelains, in the production of tableware, electrical and sanitary porcelain, glazes, porcelain enamels and frits (Opoku, 2003).

Considerable records have revealed the presence of feldspar deposits across Nigeria in appreciable quantities (Ministry of Mines and Steel Development, 2022; Badmus *et al.*, 2013; Grema, 2004; Elueze *et al.*, 2004;). This is due to the abundant rock deposits in Nigeria since feldspar is formed in rocks (Mineral Education Coalition, 2022; Holbart, 2022; Parsons, 2020). The application and utilization of feldspar like other natural resources in Nigeria have not been adequately harnessed for the country's industrial and economic developments (Ajayi & Owoeye, 2014, Opoku, 2000). Hence, in this study the sample of feldspar from Adogo feldspar deposit in Ajaokuta, Kogi State was characterised to establish its suitability for ceramic and glass production and other relevant industrial applications that will assist in the economic diversification program of Nigerian government and proffer a solution to the problem of unemployment through the establishment of small and medium scale entrepreneurship.

2. Material And Methods

2.1 Material

The principal material used in this study is the feldspar sample (Figure 1) obtained at the deposit in Adogo, Ajaokuta, Nigeria.



Figure 1: Large crystal of the Feldspar mineral obtained at Adogo, Ajaokuta.

2.1.1 Location of the study area

The Adogo Feldspar deposit falls within Ajaokuta Local Government Area of Kogi State and is located within the following coordinates - latitudes $07^{\circ} 30' 57''$ N and longitudes $06^{\circ} 52' 30''$ E. The surrounding settlements are inhabited mainly by Ebiras, Igalas, Bassas and the Hausa, Ibo, Tivs and Yoruba migrants in some cases. The main occupations are crop farming, animal husbandry, fishing and petty trading.

2.2 Methods

2.2.1 Sample Preparation

The sample of the feldspar was collected in boulder form from the deposit site. It was sun-dried for 30 hours, reduced to smaller particle sizes using a sledgehammer, local mortar and pestle at a Foundry Workshop, Department of Materials and Metallurgical Engineering, University of Ilorin, Ilorin, Nigeria. Necessary precautions were taken to avoid contamination of the sample. The sample was then sieved at the Soil Laboratory, Department of Civil Engineering, University of Ilorin, Ilorin, Nigeria and sorted to separate the particle sizes.

2.2.2 Characterization of the Samples

The pulverized sample of the feldspar was characterized through the determination of its physical properties (such as bulk and tapped density, moisture content and clay content), compositional and phase analysis. Chemical and physical properties of feldspar are significant in determining the grade and specifications for its application in ceramic and glass industries (Amaireh & Aljaradin, 2014).

2.2.2.1 Bulk Density and Tapped Density

(a) Bulk density

The bulk density test of the pulverized feldspar sample was carried out at the Soil Laboratory, Department of Civil Engineering, University of Ilorin, Ilorin following the ASTM D6683 guidelines. The weight of the empty measuring cylinder (W_1) was measured. The pulverized sample was then poured into the measuring cylinder (Figure 2), the calibrated volume (V_o) that the sample filled was noted and weighed on the electronic weighing machine to determine the net weight of the sample (W_2). The bulk density of the sample was then calculated using Equation 1.

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{W_2 - W_1 (g)}{V_0 (cm^3)} \quad (1)$$

Where: W_1 is the weight of the measuring cylinder, W_2 is the weight of the measuring cylinder + sample, V_0 is the bulk volume of the sample



Figure 2: Pulverized sample shown in the graduated cylinder

(b) Tapped Density

Sequel to the bulk density determination, 10, 500 and 1250 manual taps was carried out on the powder sample to determine the tapped density. The corresponding volumes V_{10} , V_{500} and V_{1250} were then read to the nearest graduated unit. Since the difference between V_{500} and V_{1250} is less than 2 ml, V_{1250} is recorded as the tapped volume (V_t). The tapped density of the sample is calculated using Equation 2.

$$\text{Tapped Density } \left(\frac{g}{cm^3} \right) = \frac{W_2 - W_1 (g)}{V_t (cm^3)} \quad (2)$$

Where: W_1 is the weight of the measuring cylinder, W_2 is the weight of the measuring cylinder + sample, V_t is the tapped bulk volume of the sample

The compressibility index and the Hausner ratio is determined using the relations in Equation 3 and 4 respectively (Carr, 1965).

$$CI = \frac{100 (V_o - V_f)}{V_o} \quad (3)$$

Where: V_o = unsettled apparent volume, , V_f = final tapped volume.

$$HR = \frac{V_o}{V_f} \quad (4)$$

Where: V_o = unsettled apparent volume, , V_f = final tapped volume.

(c) Moisture Content

The moisture content of the powdered feldspar sample was determined at the Department of Materials and Metallurgical Engineering Material Testing Laboratory, University of Ilorin, Ilorin using British Standards (BS 1377:1990) with further guidelines adopted by Shuaib-Babata *et al.* (2016). Some portion of the pulverized feldspar was mixed thoroughly with water until it got saturated and air-dried for 48 hours was then weigh on the electronic weighing balance, the weight of the wet sample was recorded (W_2). The sample is then placed in a pre-heated muffle furnace (Figure 3) at a temperature of 105°C with a range accuracy of $\pm 5^\circ\text{C}$ as shown in Figure 4, the sample was then removed from the oven and allowed to air-cool and then weighed (W_3) as shown in Figure 5. The moisture content was then determined using Equation 5 (Reeb & Milota, 1999). The test was carried out three times and the average value was calculated.

$$W_{content} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (5)$$

Where: W_1 is weight of the container, W_2 is weight of the container and weight of the wet sample, W_3 is weight of the container and weight of the dry sample



Figure 3: The Sample placed in the Muffle Furnace



Figure 4. Temperature of the Furnace



Figure 5: Dry Sample Weighed on the Weighing Balance

(d) Clay content

The clay content of the sample was determined using the procedures earlier adopted by Tasmia *et al.* (2013). Some samples of the pulverized feldspar were poured into the measuring cylinder and water was added along with 5g NaCl to aid the separation phase. The mixture was then shaken thoroughly and allowed to settle down as shown in Figure 6 for 24 hours after which different layers were showed on the calibrated tube (Figure 7). The solution formed four layers in the measuring cylinder. These layers included water at the top (V_1), followed by the silt (V_2), then the clay (V_3) and lastly, the silicate sand at the bottom (V_4). The test was carried out three times and the average value of the test results was calculated. The clay content is determine using Equation 6 (Tasmia et al., 2013)

$$\text{Clay content} = \frac{V_2 - V_3}{V_3 - V_4} \quad (6)$$

Where: V_1 = Water layer, V_2 = Silt layer, V_3 = Clay layer, V_4 = Silicate layer



Figure 6: Agitated sample for clay content test



Figure 7: Settled sample after 24 hours

(e) Compositional Analysis

The chemical analysis of the feldspar mineral was carried out at the Spectra Laboratory Service, Kaduna. The Elemental/chemical constituents of the powdered feldspar sample were determined using X-ray Fluorescence (XRF) Spectrometer (Thermoscientificadvent'x 1200 model), according to ASTM E1621 standard.

(f) **Phase Identification**

The phase identification of feldspar mineral sample was determined with a general purpose X-ray diffractometer (XRD-6000, Shimadzu, Japan) at the Umaru Musa Yar'adua University, Katsina, Nigeria. XRD is used for phase analysis, crystalline variants and to study the grain size of nanomaterials (Thomas *et al.*, 2021). LibreTexts (2022) also affirmed that XRD is a common technique used to determine a sample's crystalline structure or composition, such crystallinity, composition and phase purity. One of the most powerful qualitative and quantitative crystalline phase analysis (such as minerals) methods is X-ray Diffraction (Uhlig *et al.*, 2008).

The X-ray powder diffraction pattern is plot of peaks intensity relative to weight fraction ratio of each phase in the specific binary which was observed with different angles (5-700 Bragg's angle) and angle 2theta (2θ) detector position at scanning speed of 0.030/min. The particles were then settled in water to obtain 2 micrometer particles. The Sample is treated with ethylene glycol and was then prepared as an oriented mount on a glass slide.

3. Results And Discussion

(a&b) **Bulk Density and Tapped Density**

The results of bulk density and tapped density for the feldspar sample are shown in the Table 1.

Table 1: Result of Bulk density, Tapped density, Compressibility index and Hausner ratio

Tests	Mass of cylinder (g)	Mass of cylinder + powdered sample (g)	Mass of powdered sample (g)	Volume of powdered sample (cm ³)	Volume of powdered sample (tapped) (cm ³)	Density of untapped sample (g/cm ³)	Density of tapped sample (g/cm ³)	Compressibility index (%)	Hausner Ratio
1	66.53	180.55	114.02	84	74	1.3574	1.5408	11.9	1.1351
2	66.53	195.37	128.84	95	85	1.3562	1.5158	10.5	1.1176
3	66.53	171.96	105.43	78	70	1.3517	1.5061	10.3	1.1143
Average						1.3551	1.5209	10.9	1.1223

The bulk density of the mineral is 1.3551 g/cm³ which makes it lighter as compared to the standard density that ranges between 2.5 – 2.8 g/cm³ (King, 2019) and the compressibility index shows that the powdered form of the mineral has a good flow characteristic. The compressibility index and Hausner ratio are measures of the products ability to settle and permit an assessment of the relative importance of inter-particulate interactions. From the results in Table 1, the feldspar sample exhibited a compressibility index and Hausner ratio of 10.9% and 1.1223 respectively. Each of this value falls between the values that characterized the material as a material with good flow character (Table 2).

Table 2: Flow characteristic Table (Carr, 1965)

Compressibility index (%)	Flow character	Hausner Ratio
1-10	Excellent	1.00-1.11
11-15	Good	1.12-1.18
16-20	Fair	1.19-1.25
21-25	Passable	1.26-1.34
26-31	Poor	1.35-1.45
32-37	Very poor	1.46-1.59
>38	Very very poor	>1.60

(c) **Moisture Content**

Water insolubility of fluxing agents in ceramics and glass production makes them more suitable for compositions of traditional porcelain tile produced by the wet route. The strength of ceramics decreases rapidly with increasing moisture content because of existing surface bonds only (Banaszak, 2013). The moisture content test carried out three-time gave the average value of 1.75% as presented in Table 3. This shows that the feldspar mineral has a very low moisture content which will not further add to the amount of moisture content already present in the ceramic body, thereby making it suitable for the production of all sorts of ceramics.

Table 3: Water Content result

Tests	Weight of can (g) W_1	Weight of can + wet sample (g) W_2	Weight of can + dry sample (g) W_3	W_{content} (%)
Test A	338	538.0	535.0	1.50
Test B	338	538.0	534.0	2.00
Test C	338	538.0	534.5	1.75
Average				1.75

(d) Clay Content

Table 4 shows the clay content, the average clay content value in percentage is given as 2.9% . This shows that the feldspar mineral is deficient in clay content which is due to the high percentage of silicate in the mineral (Opoku, 1999). The clay content of fluxes also determines its suitability in use for the production of traditional porcelain (Opoku, 1999). Knowing the percentage of clay influxes to be added during the production process is important so as not to exceed the percentage of clay needed in ceramics production.

Table 4: Clay content results of the feldspar mineral

Tests	Clay content (%)
Test 1	2.8
Test 2	2.9
Test 3	3.0
Average	2.9

(e) Compositional Analysis

Table 5 and Table 6 show the results of the chemical analyses of the feldspar mineral elemental and oxides, respectively in weight percentages. Table 5 shows that Silicon is the predominant element in the mineral, constituting about 71% of the total weight, followed by Aluminium 20% of the constitutes and other minor elements.

Table 6 shows the oxides present in the mineral in weight percentages. Predominantly, SiO_2 and Al_2O_3 are the most enriched oxides constituting above 95% of the oxides in the ore, indicating the presence of Silica (clay mineral) and Quartz. This is in consonance with the assertion of Ibisi (1992) and Ajayi & Owofe (2014) that these oxides are predominant in feldspar

minerals. However, the chemical analysis shows a higher percentage of SiO₂ (73%) in the present study as compared to the results obtained by Ajayi & Owwoeye (2014) and Ibisi (1992) with 41% and 70% respectively. The Al₂O₃ (23%) is lower compared to the value obtained by Ajayi & Owwoeye (2014) (34%), but is higher than the value obtained by Ibisi (1992). However, the presence of magnesium oxide in the feldspar mineral samples suggests the presence of a talc phase, which could also account partly for the presence of the iron oxide (Marcos & Rodríguez, 2010). Albite has triclinic symmetry, which is common for the "low temperature" alkali feldspar and albite-rich plagioclase with ordered aluminium and silicon in the tetrahedral sites (Aramide *et al.*, 2014). The iron oxides impurities present in form of Fe₂O₃, MgO, TiO₂ and ZnO are very low and negligible.

Table 5: Elemental Composition of Sample using X-Ray Fluorescence (XRF) Cu-Zn Method

Elements	Percentage weight (%)
Si	70.631
Al	20.355
Bal	6.674
Fe	1.046
K	0.985
Ca	0.975
Sr	0.111
Ti	0.099
Ba	0.011
Zn	0.009

Table 6: Oxide Composition Using X-Ray Fluorescence (XRF) Cu-Zn Method

Major constituents oxides	Percentage weight (%)
SiO ₂	73.35
Al ₂ O ₃	23.67
MgO	0.219
CaO	0.065
Fe ₂ O ₃	0.166
TiO ₂	0.032
ZnO	0.011

(f) **Phase Identification**

Figure 8 shows the X-ray diffractograms of feldspar mineral. In the figure, the dominant mineral phases in the mineral are more accurately identified to be muscovite ($\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$ "green", and albite ($\text{NaAlSi}_3\text{O}_8$) "blue". A larger peak of muscovite phase is shown in the figure. Table 7 shows a higher percentage of muscovite (63%) and albite taking the remaining 37%, an indication that the feldspar is a low-grade soda feldspar (Ibisi, 1992). In most industrial applications, the feldspar comprising albite and orthoclase is of particular interest (Ajayi & Owoeye, 2014). For production of thermal and electrical insulators muscovite is found useful (Holbart, 2022). Therefore, Adogo feldspar can find its usefulness in glass and ceramic industries.

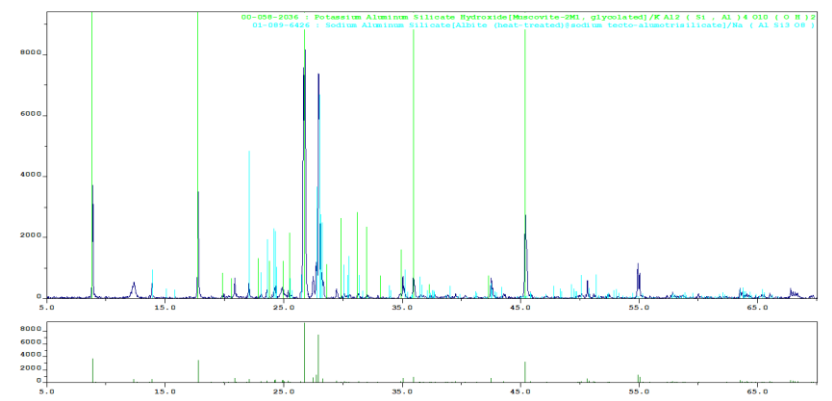


Figure 8: XRD pattern for Feldspar Mineral

Table 7: XRD Result of the feldspar mineral showing the quantity of different phases Present

Phases	Percentage	Ratio
Muscovite	63	0.854
Albite	37	0.492

4. Conclusion

From the results of physical, chemical and phase analysis carried out on the feldspar mineral, the following conclusions are drawn:

- i. The bulk density of the mineral is 1.3551 g/cm^3 and the compressibility index shows that the powdered form of the mineral has a good flow characteristic.
- ii. The feldspar sample exhibiting a moisture content lesser than 3% is an indication that the powdered mineral has a very low moisture content.
- iii. The results of this study also revealed low content of clay in the sample implies a low percentage of clay requirements during ceramics production.
- iv. Chemical analysis shows high percentages of Silica and Alumina in the mineral and the mineral belongs to a low-grade soda feldspar (Albite) as revealed in the XRD analysis.
- v. In conclusion, though Adogo feldspar has the potential as a raw material in glass and ceramic industries, but will require further beneficiation to actually meet the suitable standards for the production of glass and ceramic bodies.
- vi. The information from this study will provide part of data to form a reliable and compressive data bank that will assist in setting up minerals production industries by individuals or government of Nigeria.

5. Recommendations

- i. Further research can be done by further beneficiation and separation techniques to separate the Muscovite from the Albite to archive a pure Feldspar (Albite).
- ii. Further research can also be done by carrying out the practical procedure of mixing the powdered minerals during ceramics or glass production to find out more about their compatibility in ceramics and glass production

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