

INVESTIGATION OF THE PROPERTIES AND CHARACTERIZATION OF ETSAKO FELDSPAR FOR SUITABLE INDUSTRIAL APPLICATIONS

¹Oladiji A. O., ²Asafa T. B., ³Apata A. O. and ⁴Alabi A. A.

¹Mechanical Engineering Department, Oyo State College of Agriculture and Technology, Igboora, Nigeria;

²Mechanical Engineering, Ladoko Akintola University of Technology, Ogbomoso, Nigeria; ³Metallurgical and Material Engineering Technology, Federal Polytechnic, Idah, Nigeria; ⁴Civil Engineering Department, Oyo State College of Agriculture and Technology, Igboora, Nigeria.

Abstract

The properties and characterization of feldspar found in Etsako deposit, Edo State was determined. The test carried out include, Linear Shrinkage, Loss on Ignition, Water Absorption, Bulk Density, Porosity, Moisture Content, Tensile Strength, Electrical Conductivity, Thermal Conductivity and Chemical Composition Analysis using Atomic Absorption Spectrometer. Mineralogy using X-ray diffraction, and Scanning Electron Microscopy for two different size samples of 150 μm and 250 μm . The physical properties of the Etsako feldspar for the two different size samples of 150 μm and 250 μm respectively are 11.49% shrinkage, 2.36% moisture content, 0.33% loss of ignition, 2856 kg/m^3 bulk density, 0.66% water absorption, 2.75% Porosity, 2.8 specific gravity, 760.0 Mpa Tensile strength, 1.648W/m-K thermal conductivity, 5.8 μSm Electrical conductivity and 11.42% shrinkage, 1.79% moisture content, 0.27% loss of ignition, 2903 kg/m^3 bulk density, 0.81% water absorption, 0.95% Porosity, 2.9 specific gravity, 760.3 Mpa Tensile strength 1.646 W/m-K thermal conductivity and 5.4 μScm Electrical conductivity respectively. The characterization of the Etsako feldspar showed that the feldspar contains the following constituents for 150 μm sample, 65.15% SiO_2 , 17.0% Al_2O_3 , 0.1% Fe_2O_3 , 0.01% TiO_2 , 0.05% CaO , 11.0% K_2O , 0.01% MnO , 0.06% MgO , 0.8% Na_2O and 250 μm sample, 65.75% SiO_2 , 19.25% Al_2O_3 , 0.2% Fe_2O_3 , 0.01% TiO_2 , 0.06% CaO , 13.0% K_2O , 0.01% MnO , 0.07% MgO , 1.1% Na_2O . The result obtained compared with standard values shows that the Feldspar from Etsako, Edo State, is of a good, suitable quality and can be used for many industrial purposes such as in the production of refractories for lining ovens, porcelain insulators, mortar and pestle, sanitary wares, tiles, etc. The SiO_2 content in the Etsako feldspar (65.75%) lies within the acceptable quantity in commercial ceramic grade feldspar (75%) and has considerable amount of 11%-13% K_2O .

Keyword: Feldspar, characterization, porcelain insulators, refractories, Etsako

How to Cite: Oladiji A. O.; Asafa T. B.; Apata A. O. and Alabi A. A. (2025). Investigation of the properties and characterization of etsako feldspar for suitable industrial applications. *OYSCATECH Journal of Engineering and Environmental Studies*, 3(1), 42-50. <https://oyscatechpublications.org/>

Introduction

It is estimated that insulation accounts for over 20% of the total cost of a conventional electrical transmission and distribution system, with porcelain insulators being the most prominent component. In Nigeria, nearly all insulating materials used in the power

sector are imported, largely from Asian countries, with porcelain insulators occupying a major share (Anih, 2005). This highlights the potential of locally available feldspar as a valuable raw material for the nation's power industry, in addition to its wide industrial applications.

Feldspar represents the most abundant group of minerals in the earth's crust, constituting about 60% of terrestrial rocks. These minerals are essential constituents of igneous, metamorphic, and sedimentary rocks, and in fact, the classification of several rock types is based on feldspar content. Chemically, feldspars are aluminosilicates containing sodium, potassium, calcium, iron, or barium, either singly or in combination (Kathy, 2014; Mazen & Mohammad, 2014). Since different feldspars exhibit varying behaviors, their chemical composition must be determined before industrial use. The general chemical formula is expressed as $x\text{Al}(\text{Al},\text{Si})_3\text{O}_8$, where "x" may represent sodium, calcium, and/or potassium. Of the nearly 20 recognized feldspar species, only nine are commonly found, which are broadly classified into two groups: alkali feldspars (rich in Na and K) and plagioclase feldspars (containing Ca and Na) (Justin, 2016).

Feldspar is widely integrated into daily life, being a vital ingredient in products such as drinking glasses, protective glass, fiberglass for insulation, ceramic tiles, sanitary ware, and household tableware. In ceramics and glass production, feldspars function as fluxing agents, lowering the melting temperature of quartz, regulating viscosity, and reducing production costs due to their alkali content (IMA-NA, 2015; Ajayi & Owoeye, 2014). They also enhance the strength, durability, and toughness of ceramic bodies. The glass and ceramic industries account for approximately 95% of feldspar consumption (Adindu *et al.*, 2014). Beyond these, feldspar is utilized in bonded abrasives, paints, cements, concretes, fertilizers, roofing materials, plastics, rubber, pharmaceuticals, and welding rod coatings. In sanitary ware, feldspar optimizes vitrification, while in tableware, it promotes fusibility and defect-free products. Additionally, it supplies alumina and alkalis in glaze formulations.

The term "feldspar" was first introduced by Johan Gottschalk Wallerius in 1747, derived from the earlier "fieldspar," as some

specimens were originally discovered in fields. "Spar" is a generic term for non-metallic minerals with a glassy luster and distinct cleavage surfaces (Kathy, 2014).

Nigeria remains a significant consumer of ceramic products, including sanitary ware, spark plugs, porcelain items, and ceramic tiles, despite abundant indigenous raw materials with potential for ceramic manufacturing (Oaikhinan, 2014). The limited number of domestic ceramic industries operate well below installed capacity due to challenges associated with raw material processing. To maximize the usability of Nigerian feldspar, particularly in glass and ceramics for thermal and electrical purposes, it is necessary to assess its chemical, mineralogical, and physicochemical properties.

Kumar *et al.* (2009) defined characterization as the general process of determining the structure and properties of a material, while Oslen (2020) emphasized the importance of evaluating mechanical and physical properties to guide material selection for industrial applications. Although extensive studies have been conducted on foreign feldspar deposits, limited attention has been given to Nigerian deposits, restricting their application in local industries. This research, therefore, aims to investigate the properties and characterization of feldspar from Etsako, Edo State, Nigeria, with emphasis on electrical and thermal applications, as well as the influence of particle size on these properties. Etsako is situated in Etsako West Local Government Area, with its headquarters in Auchi, covering an area of approximately 945.3 km².

Materials and Methods

Materials

The following materials were used namely, the raw grounded (powdered) feldspar, furnace, sample bag was used carry and to store the samples collected at field. Shrinkage Dish, Polyethylene Centrifuge Bottle, Evaporating Dishes, Mercury Dish, Trowel or Shovel,

Sieves, Oven, Desiccators, Weighing Balance, Sieve (150 and 250microns), Spring Balance, Shrinkage Mold, Universal Testing Machine, Digital Electronic Bulk Density Apparatus, Cassagrande's Apparatus, Thermal Conductivity Meter, Electrical Conductivity Meter Beakers, Atomic Absorption Spectrophotometer (AAS), Scanning Electron Machine (SEM) and X-Ray Diffraction Machine XRD.

Methods

a. Collection and Preparation of feldspar

The grounded feldspar gotten from Etsako, Edo State was soaked in water for at least 72 hours. it absorbs water and dissolves. Soaking for a period of 72 hours allow the mineral to dissolve and detach from any sand particles, more fresh water was added to form a lighter paste like mixture, which was then poured through a sieve of 150 µm and 250 µm. The sandy elements remain on the sieve (residue) was removed and discarded. The feldspar paste was dried on a hot cement slab placed in the sun heat. When the feldspar was fully dried it was removed and stored in a sack and kept in a dry place.

The sourced feldspar sieved using 150 microns and 250 microns sieves were taken for test at University of Ibadan central Laboratory where the properties and the characterization of the material samples were carried out

b. Physical Properties

Bulk Density

The density of each sample was carried out using Quick Digital Electronic Bulk Density Apparatus (Model: DA-300M) and recorded.

$$\text{Density, } \rho = \frac{\text{mass}}{\text{volume}} \quad (1)$$

Moisture Content

Each samples' moisture content was determined using the Cassagrande's Apparatus by deriving its Liquid and Plastic limits.

% Moisture Content =

$$\frac{\text{Difference in weight}}{\text{Original Weight}} \times \frac{100}{1} \quad (2)$$

$$\frac{(W_w - W_d) \times 100\%}{W_d}$$

W_w = Initial wet weight

W_d = Final dry weight

Linear Shrinkage

The shrinkage was also done using the Cassagrande's Apparatus. Sample mixed with enough water to make a paste was transferred into a shrinkage mould 128mm in length. The paste was leveled into the rim of the mould, and the surface smoothened. After oven-drying for 24hours, the length of the resulting cast which has shrunk considerably was measured against that of the shrinkage mould, using a Vernier caliper. The difference in value calculated in percentage as below, is the linear shrinkage:

The following equation shows the derivation of the linear shrinkage:

$$\text{Linear Shrinkage} = \frac{128 - X}{128} \times 100 \quad (3)$$

$$P = L.L - P.L$$

P.I = Plasticity index,

P.L = Plastic limit and L.L = Liquid limit

Length of Shrinkage mould = 128 mm

Length of sample after oven drying = X mm

Sample was reduced in length by (128–X) mm

Water absorption

The water absorption was tested using the water absorption analyzer and the result is discussed in the following chapter.

$$\text{Water Absorption} = \frac{W_1 - W_2}{W_1} \times 100 \quad (4)$$

Where: W_1 = wet weight

W_2 = dry weight

Porosity

The porosity of each sample was measured by carrying out manual analysis.

The formula used is:

$$\text{Porosity (\%)} = \frac{v_p}{v_b} \times 100, \quad (5)$$

$$\begin{aligned} V_p &= \text{Pour Volume} \\ V_b &= h r^2 = \text{Bulk volume} \end{aligned}$$

Luster

The feldspar sample was identified by looking at the images from its structural formation. It could be metallic, earthy, vitreous, waxy or pearly luster.

c. Characterization of Feldspar

Chemical Analysis

Chemical analysis of the sourced feldspar samples was carried out using (Flame-Atomic Absorption Spectrometer) F-AAS type A Analyst 200 machine by Perkin Elmer to check for the presence of certain metals or metallic oxides present in the samples in their percentage

$$\begin{aligned} \% \text{ Chemical Composition} = \\ \frac{\text{Molar mass of component element}}{\text{Relative molecular mass}} \times 100 \end{aligned} \quad (6)$$

Loss on Ignition.

It was calculated alongside the chemical analysis. When the feldspar was heated, there was a loss in its weight due to the escape of water and carbonaceous matter. The difference in weight of the raw samples and the fired samples gives the loss on ignition at that particular temperature and it is calculated as a percentage of original weight. All samples were accurately weighed before and after firing. The difference gives the loss on Ignition which was determined at a temperature of 870°C.

For Sample A (150Microns)

$$\begin{aligned} \% \text{ Loss Ignition} \\ = \frac{\text{Initial Loss of Sample A}}{\text{Initial weight of Sample A}} \times 100 \end{aligned} \quad (7)$$

For Sample B (250Microns)

% Loss Ignition =

$$\frac{\text{Initial Loss of Sample B}}{\text{Initial weight of Sample B}} \times 100 \quad (8)$$

d. Mineralogy

X-Ray Diffractometer (XRD).

X-ray diffractometer (Mini Flex Rigaku D/Max-IIIc) developed by the Rigaku Int. Corp. Tokyo, Japan was used to determine the phase compositions, Texture and Morphology of the two feldspar samples of 150µm and 250µm.

Scanning Electron Microscope (SEM).

Electron Microscope [SEM (JEOL JSM-7600F)] was used for the two samples of feldspar 150µm and 250µm

e. Mechanical Properties

Abrasion Test

The abrasiveness and surface luster of the samples were evaluated by examining polished sections of the fired rock. The results revealed a vitreous to pearly appearance along cleavage planes, with occasional iridescence on cleavage surfaces. The abrasion test was performed in accordance with ASTM D4966 standards.

Tensile stress test.

The tensile stress test was done on each size sample of sourced feldspar using the Universal Testing Machine (Model: Zugfestigkeit 440gu Philips) with tensile load ranging from 0 N to 150 N. the results for both 150µm and 250µm samples were as shown in table 3

$$\begin{aligned} \text{Tensile strength } (\sigma_t) = \\ \frac{\text{Peak load}}{\text{Cross-sectional area}} \end{aligned} \quad (9)$$

Compressive Stress Test

The compression test was done on each size sample of the sourced sample using the Universal Testing Machine (Model: Zugfestigkeit 440gu Philips) under compressive loads (e.g. crushing) ranging from 0 to 200 N. The results were as recorded for both 150µm and 250µm samples in Table 3

$$\sigma_c = \frac{P_{\max}}{A} \quad (10)$$

where:

σ_c = Compressive strength (MPa or N/mm²)

$P_{\max}$ = Maximum load before failure (N)

A = Cross-sectional area (mm²)

f. Thermal Properties

Thermal conductivity

The thermal conductivity of the samples was measured using a Thermal Conductivity Meter. Tests were conducted at different temperatures ranging from 50 °C to 300 °C, in intervals of 50 °C. The results were recorded,

and the average thermal conductivity values were calculated. The computed mean values are presented in Table 3.

g. Electrical Properties

Electrical conductivity

The Electrical Conductivity Meter was used to measure its electric conductivity.

Results and discussion

Results

a. Physical Test

Table 1: Summary of Results of Physical Test Done on Etsako Feldspar

Properties		Physical Properties				
	Moisture content %	Linear Shrinkage %	Density Kg/m ³	Specific Gravity	Water Absorption %	Porosity %
150µm	3.36	11.49	2856	2.8	0.66	0.75
250µm	2.79	11.42	2903	2.9	0.81	0.95

b. Chemical Analysis

Table 2: Chemical Composition Analysis Using Atomic Absorption Spectrophotometry

Sample constituents		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	K ₂ O	MnO	MgO	Na ₂ O	LOI
Percentage (%)	150 µm	65.15	17.0	0.1	0.01	0.05	11	0.01	0.06	0.8	0.33
	250 µm	65.75	19.25	0.2	0.01	0.06	13	0.01	0.07	1.1	0.27

Loss on Ignition at 1100 °C`

c. Mineralogical Test

X-Ray Diffractometer (XRD)

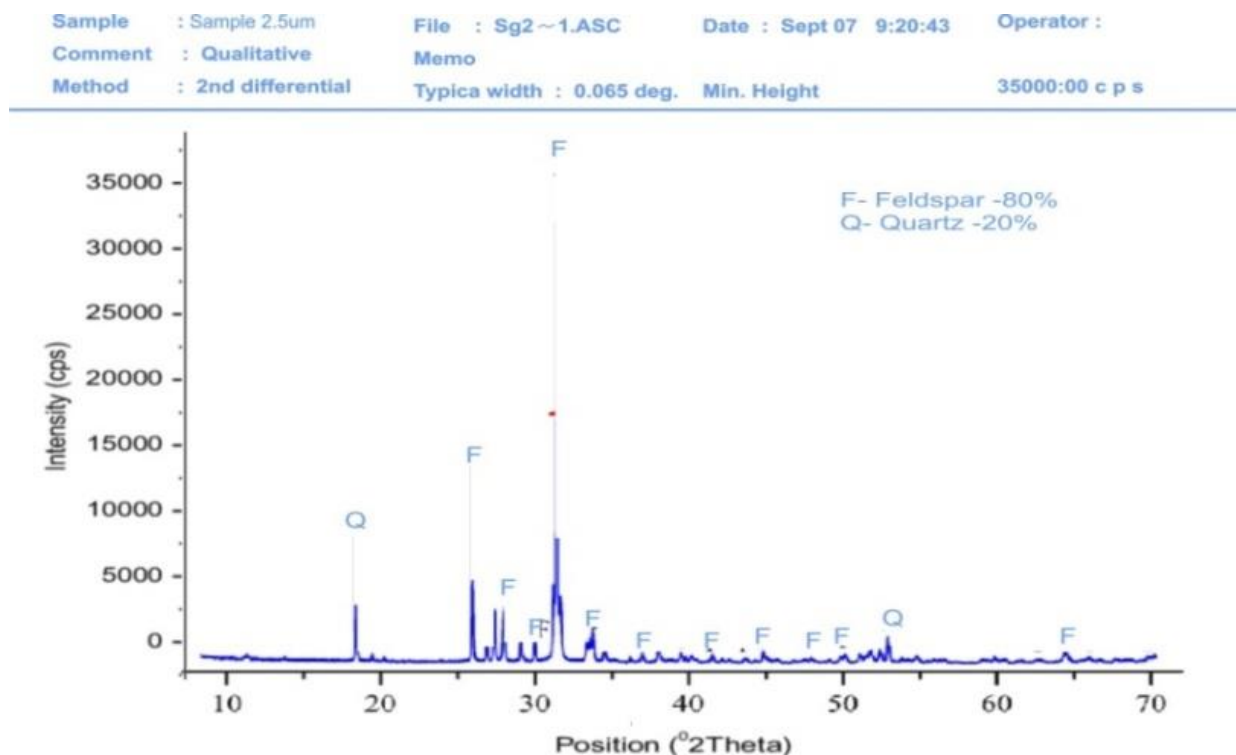


Fig 1a: XRD for 150micron sample

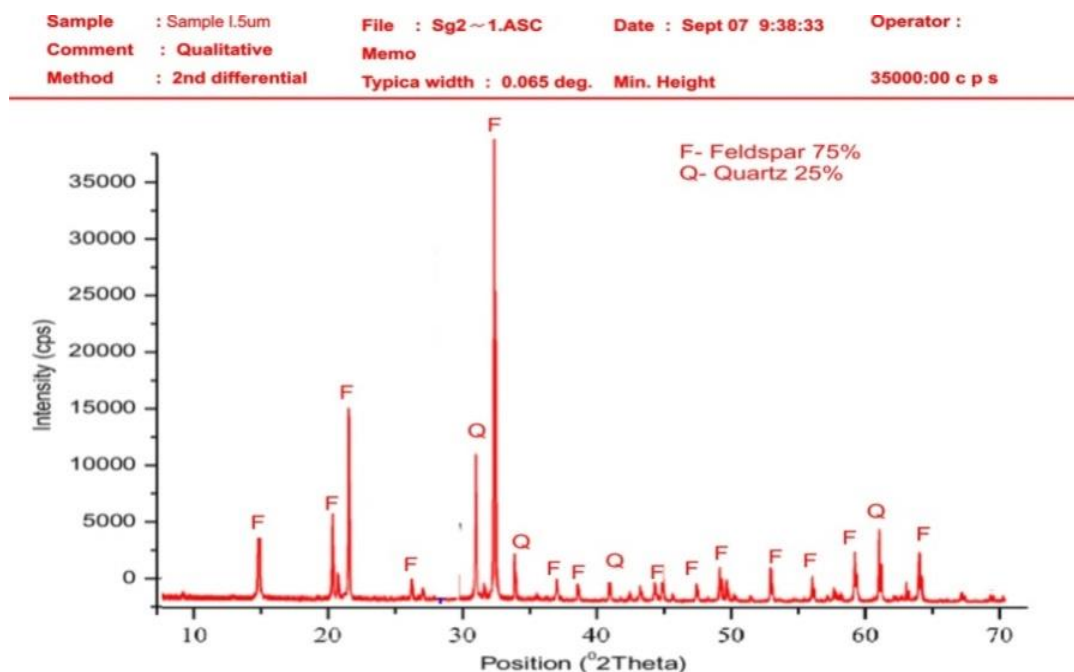


Fig 1b: XRD for 250micron sample

3.3.2 Scanning Electron Microscope (SEM).

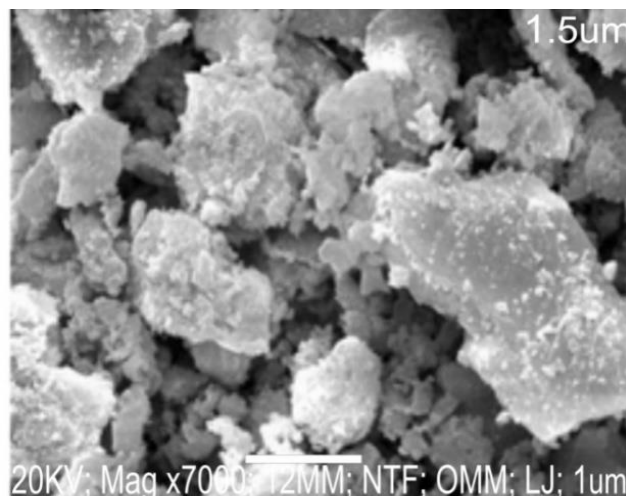
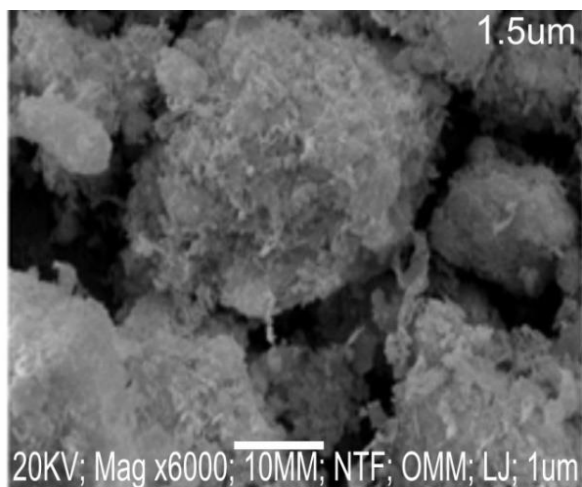


Plate 1: SEM images of 150micron sample

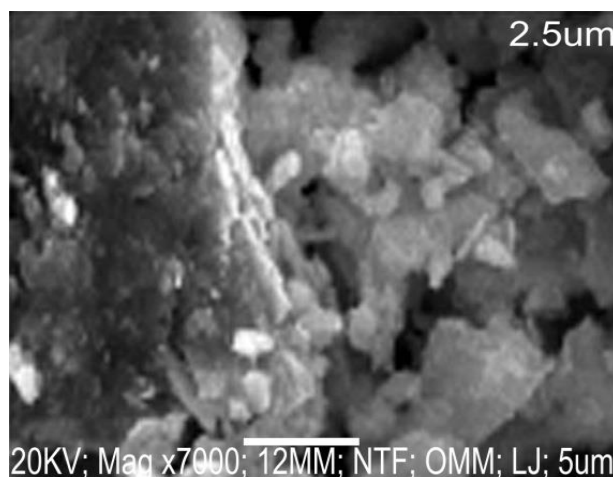
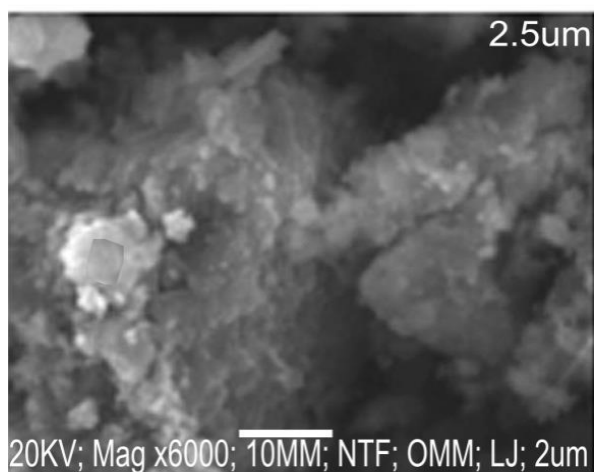


Plate 2: SEM image of 250micron sample

d. Summary of Mechanical, Thermal and Electrical Properties

Table 3: Summary Mechanical, Thermal and Electrical Test of each Sample

Test	Abrasive Test					Tensile strength Mpa	Thermal Conductivity Mean (W/m-K)	Electrical Conductivity (uS/m)
Properties /Sample	Color	Hardness	Grain shape	Fracture	Cleavage			
150 µm	White	6.4	Triclinic	Uneven + Splintery	Prismatic parallel	76.0	1.648	5.8
250 µm	Grey	6.0	Monoclinic	Uneven + Splintery	Prismatic parallel and basal parallel	76.3	1.646	5.4

Discussion

a. Physical Properties of the Feldspar

The physical properties of Etsako feldspar lies between the required physical properties for commercial grade

b. Characterization of Etsako feldspar

Comparison with Commercial Ceramic-Grade Feldspar

As shown in Table 2, the Etsako feldspar contains appreciable amounts of potassium and aluminium, the two major components that enhance its suitability for use in various downstream industries (IMA-NA, 2015). The critical oxides influencing ceramic processing and final product quality include K₂O, Na₂O, Al₂O₃, SiO₂, and Fe₂O₃. The chemical composition of a standard commercial ceramic-grade feldspar is presented in Table 4.

Table 4. Principal chemical constituents of commercial ceramic-grade feldspar (Mohammad and Mazen, 2014)

Constituent (%)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	Na ₂ O
	75	15	0.3	3.3	4.5

A comparison of the major constituents of raw Etsako feldspar with commercial ceramic-grade feldspar is presented in Table 4. The results show that the chemical composition of the Etsako deposit meets the requirements for use as a raw material in ceramic industries. Specifically, the Fe₂O₃ content was found to be 0.1% and 0.2% for the 150 µm and 250 µm samples, respectively, which fall within the maximum allowable limit of 0.3%. Furthermore, the Etsako feldspar is classified as an alkali feldspar (K-feldspar), a category of particular significance for industrial applications (IMA-NA, 2015).

Conclusion

The chemical analysis of feldspar samples from the Etsako deposit demonstrates their suitability as raw materials for ceramic industries. They can be utilized in the manufacture of refractories for furnace linings, porcelain mortars and pestles, sanitary ware, tiles, as well as fillers in glass, paints, and in the production of insulators for both

thermal and low-voltage electrical applications, owing to their low conductivity. The abundance of the deposit and its favorable properties suggest strong potential for economically viable feldspar production to support ceramic applications in both thermal and electrical sectors.

Reference

- Adindu, C.I. Moses, J. Thaddeus, C. A. and Tse, D.T. 2014. Exploring Ceramic raw materials in: Nigeria and their Contribution to Nation's Development. *American Journal of Engineering Research (AJER)*. Vol. 3, No. 9: pp 127-134.
- Ajayi, B.A. and Owoeye, S.S. 2014. Characterization of Okpilla Feldspar Deposit for Glass and Ceramic Production. *International Journal of Science and Research (IJSR)*. Vol. 3, Issue. 11.
- Anih, L.U. 2005. Indigenous Manufacture and Characterization of Electrical Porcelain Insulator. *Nigeria Journal of Technology*. Vol. 24: No. 1: p 42.
- Hans Lüschen (1979), Die Namen der Steine. Das Mineralreich im Spiegel der Sprache (2nd ed.), Thun: Ott Verlag, p. 215, ISBN 3-7225-6265-1.
- Hu, H. Li, H. Dai, L. Jiang J. 2014. Electrical conductivity of K-feldspar at high temperature and high pressure. *Mineralogy and Petrology*.
- Industrial Mineral Association North America-IMA-NA (2015): What is Feldspar. Retrieve September 10, 2021. from https://www.ima-na.org/page/what_is_feldspar
- Justin R. (2016). Why should anyone care about feldspar. September 22, 2021 from <https://czo-archive.criticalzone.org/national/blogs/post/why-should-anyone-care-about-feldspars/>
- Kalemtas, A. 2010. MME391 Ceramic Materials. Bursa Technical University, Metallurgical and Materials Engineering Department.
- Kathy F. (2014). Earth Sciences Museum: Feldspar; Retrieve October 6, 2021. from <https://uwaterloo.ca/earth-sciences-museum/resources/detailed-rocks-and-minerals-articles/feldspar>
- Kauffman, R.A. and Dyk, D.V. (1994). Feldspar. In: *Industrial Minerals and Rocks, 6th Ed.* P 478.
- Kumar, Sam Z. Lin L. Ashok (2009). Materials characterization techniques. Boca Raton: CRC Press. ISBN 978-1420042948.
- Liu, S. Han, C. Liu, J. 2019. Study of K-Feldspar and Lime Hydrothermal Reaction: Phase and Mechanism with Reaction Temperature and Increasing Ca/Si Ratio. *Minerals*. Vol. 9, No. 46.
- Mohammad, A. and Mazen, A. (2014). Characterization of the Jordanian Feldspar Raw Materials for Application in the Ceramic and Glass Industries. *International Journal of Mining Engineering and Mineral Processing*, 2014. Pp 28-31.
- Oaikhinan E.P. 2014. We are committed to reviving Nigeria ceramics Industry. BusinessDay. Retrieved Sept. 8, 2021. From <https://www.google.com/amp/s/businessday.ng/entrepreneur/article/we-are-committed-to-reviving-nigeria-ceramics-industry/amp/>
- Oladiji A. O., Asafa T. B., Apata A. O.(2022) Properties and Characterization of Feldspar for Electrical and Thermal Application. *Proceeding of 6th National Engineering Conference*. School of Engineering. The Federal Polytechnic Idah. Kogi State. 16th - 19th March, P. 154-161
- Oslen, D. 2020. How to Evaluate Materials-properties to Consider? MediaTek International Blog. Retrieved Sept. 14, 2020. From <https://www.mediatek.com/blog/how-to-evaluate-materials-properties-to-consider/>
- Othman, S.S. Jumal, J. Harun, F.W. Ali, B.J. Abdul Rahman, M.B. 2018. Immobilization of enzyme using natural feldspar for use in the synthesis of oleyl oleate. In: *AIP Conference Proceedings*. June 2018.