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ORIGINAL RESEARCH ARTICLE

Compositional Characterisation and Industrial Suitability Assessment of Talc Ore from Ingawa, Katsina State, Nigeria

Ibrahim Salisu[1,2]*, Aminu Musa[2], Maryam Saddik[2], Hajara Wada Bawa[2], Abdulhamid Murtala[1,2], Abdullahi Nasir Salmanu[1]
[1]Chemistry Unit, Federal University of Transportation Daura, P.M.B 1050, Daura, Katsina State, Nigeria
[2]Department of Chemistry, Umaru Musa Yar'adua University, P.M.B 2218, Katsina, Katsina State, Nigeria

ABSTRACT

This study explores the unique characteristics of talc ore sourced from the Ingawa Local Government Area in Katsina State, with a focus on its potential for diverse industrial applications. Representative samples were analysed using X-ray Fluorescence (XRF), X-ray Diffraction (XRD), and Fourier Transform Infrared (FTIR) spectroscopy to determine elemental composition, mineralogical phases, and structural bonding. XRD analysis confirmed that the ore is a heterogeneous assemblage dominated by Talc (triclinic), with significant amounts of quartz and kaolinite. XRF analysis quantified the chemical composition, revealing deviations from stoichiometric purity, with high silica (SiO_2, 37.23%) and aluminium oxide (Al_2O_3, 26.41%) content. Magnesium oxide (MgO) concentration was found to be (0.91%), which is lower than the theoretical standard for pure Talc of 31.8%. Iron oxide Fe_2O_3 was present at 10.99%, correlating with the observed light-to-dark brown coloration of the samples. A comparative assessment against industrial specifications indicates that the Ingawa deposit is low-to-medium grade. While the high quartz and iron content currently restricts its use in pharmaceuticals and cosmetics, the raw ore is technically feasible for use as a structural filler in the rubber and plastics industries. Advanced beneficiation, specifically to reduce abrasive silica and chromophoric iron oxides, is recommended to upgrade the ore for high-value applications.

ARTICLE HISTORY

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Ore, composition, characterisation, potential, utilisation

INTRODUCTION

Talc (Hydrous Magnesium Silicate), is a soft mineral used in drugs, cosmetics and industrial applications (Durotoye and Ige, 1991). It's widely used commercially due to its lamellar habit, softness, whiteness, fragrance retention, luster and chemical purity. It is also used in a wide variety of products we see every day. It is an important ingredient in rubber and a filler and brightening agent in high quality paints (Akintola, 2017). Pure Talc has the formula $Mg_3Si_4O_{10}(OH)_2$,and chemical composition of 31.88% by weight (wt) Magnesium oxide (MgO), 63.37% Silicon dioxide (SiO_2), and 4.75% water (H_2O). Talc structure is shown in Fig 1. It has the chemical abstract no. (CAS No. 14807-96-6). Industrial deposits often contain associated mineral phases that dictate their end-use suitability (Hecht *et al.,* 1999). Consequently, rigorous mineralogical and geochemical assessment is required to determine economic viability.

Nigeria possesses vast talc reserves; however, the local industry remains underdeveloped, with manufacturers heavily reliant on imported fillers. Although previous studies have characterised various Nigerian talc deposits, data regarding the Ingawa talc deposit remains sparse. Specifically, there is a lack of comprehensive data benchmarking the Ingawa ore against international industrial standards, such as those established by the ASTM or United States Pharmacopeia (USP). This lack of standardised characterisation limits the commercial exploitation of the deposit and hinders import substitution efforts.

This study addresses this research gap by presenting a systematic multi-technique characterisation of the Ingawa talc deposit. By assessing its mineralogical purity and physicochemical properties against global industrial requirements, this research establishes the specific suitability of Ingawa talc for specific industrial applications.

Correspondence: Ibrahim Salisu. Chemistry Unit, Federal University of Transportation Daura, P.M.B 1050, Daura, Katsina State, Nigeria. ✉ ibrahimdaurasalisu@gmail.com.

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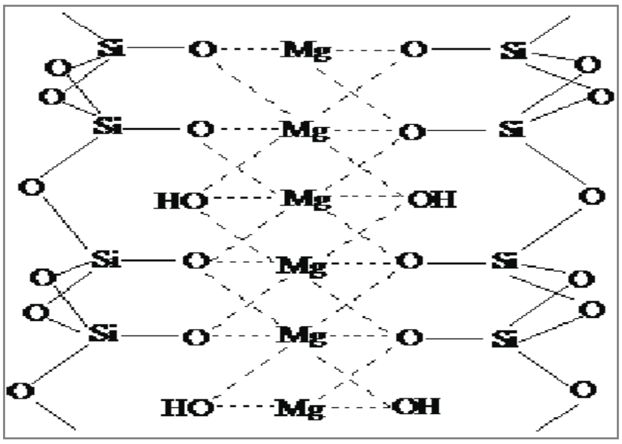

Figure 1: Structure of Talc showing the phyllosilicate layered arrangements of Talc, with alternating tetrahedral (Si-O) and Octahedral (Mg-OH) sheets, held together by weak Van der Waals forces that give Talc its softness, perfect cleavage and greasy feel.

MATERIALS AND METHODS

Sample collection and preparation

Representative bulk samples were collected from the Bidore ward, Ingawa Local Government Area of Katsina State, Nigeria (approximate coordinates $12^{0}38^{1}01^{11}$E). To ensure spatial representativeness and account for geological variability, a gross sampling strategy was employed, by taking 1kg of the talc ore from three different locations, within the vicinity of the location of the ore (Latitude 12.5072587, Longitude 8.1322964). Samples were then resized using coning and quartering method to obtain manageable sizes before taken to the laboratory. Samples were grounded with pestle and mortar due to the softness of the mineral to obtain fine powder. Grounded talc samples were then sieved using a suitable sieve of 200 mesh size to obtain fine particles for analysis and stored in a tightly sealed polypropylene containers prior to analysis. Analyses were performed on all three samples and the mean values are reported. Fig 2 shows the summary of the methodology.

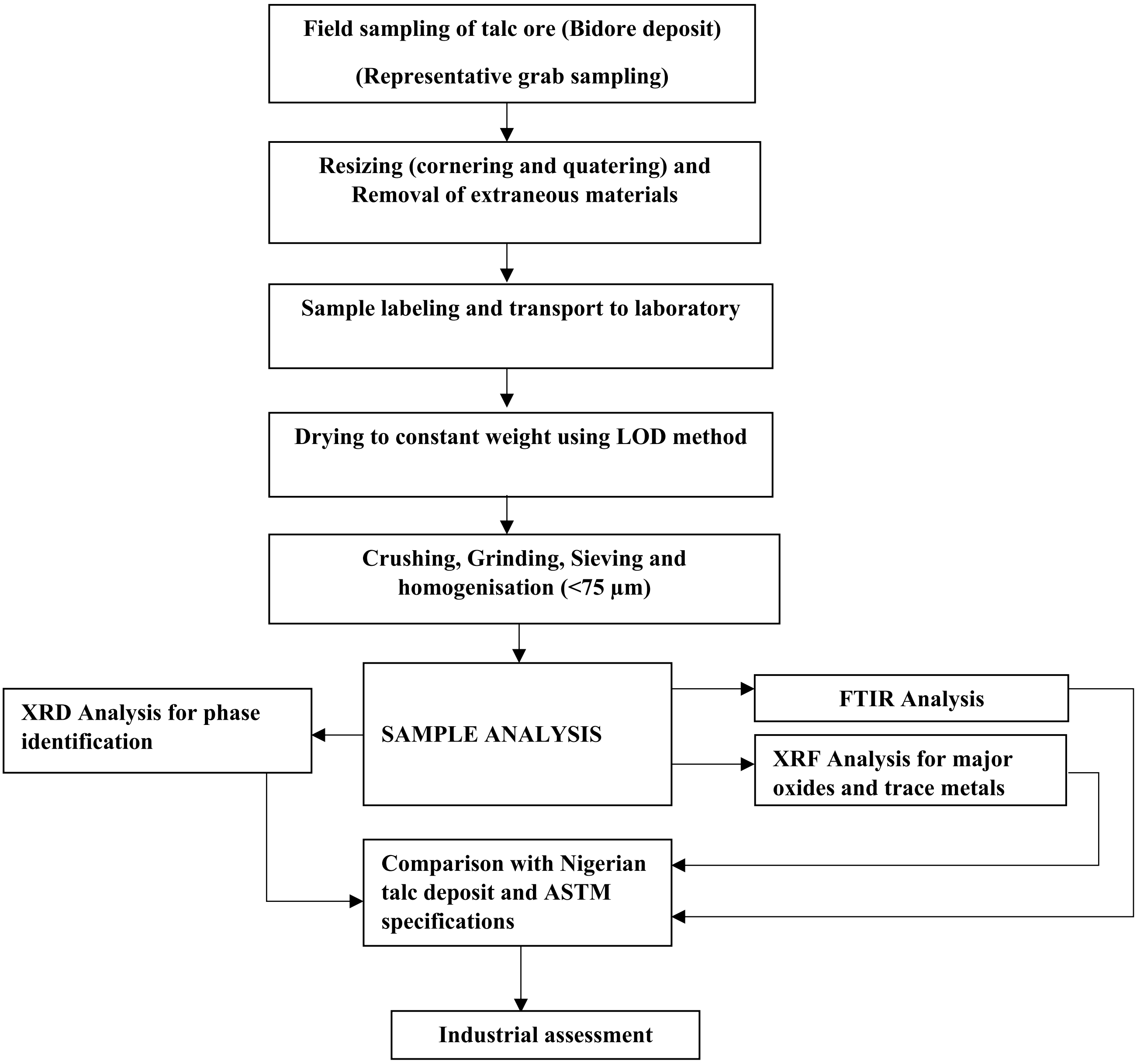

Figure 2: Flowchart of sampling, sample preparation, and analytical workflow adopted for the chemical characterisation of Bidore talc ore

Fourier Transform Infrared Spectroscopy

FTIR spectroscopic analysis (Figure 3) was conducted to characterise the molecular bonding and structural purity of the Talc. Analysis was performed using an Agilent Technologies Cary 630 FTIR spectrometer. Spectra were acquired in the range of (4000–400 cm^{-1}) with a resolution of 4 cm^{-1} and 32 scans per sample. Background spectra were collected and subtracted to eliminate atmospheric interference.

Xray Fluorescence Spectroscopy

The major elemental oxides (Table 1) were quantified using an ARL QUANTX Energy Dispersive X-ray Fluorescence (EDXRF) analyser (Thermo Fisher Scientific, Switzerland; Serial No. 9952120). The instrument was operated at a tube voltage of 20 kV and current of 80 mA under helium atmosphere. Calibration was verified using certified reference materials to ensure quantitative accuracy.

-Xray Diffraction Spectroscopy

Mineralogical phase identification (Figure 4) was performed to identify the talc structure and associated gangue minerals. An Empyrean diffractometer (PANalytical, Netherlands) was utilised with Cu anode radiation (λ= 1.5406 Å). The diffraction patterns were recorded over a scan range of 5^0 to 75^0 2θ and a scan speed of 0.02^0 2θ seconds/step. Crystalline phases were identified by comparing the obtained patterns with standard reference data.

Determination of Moisture Content

The moisture content of the talc sample was determined using the loss-on-drying (LOD) method, following standard oven-drying procedures. Approximately 100 g of the sample was weighed into a pre-dried and pre-weighed container. The sample was then dried in a laboratory electric oven at 105 °C for 30 minutes to remove physically adsorbed moisture. After drying, the sample was allowed to cool to room temperature in a desiccator to prevent moisture reabsorption and then reweighed. The difference between the initial (wet) mass and the dried mass was attributed to moisture loss. All measurements were carried out using an analytical balance, and results were expressed as percentage moisture content.

RESULTS AND DISCUSSION

Table 1: Major and trace elements and their mean elemental oxide compositions of Bidore talc samples (XRF analysis). Average Values expressed as mean ± SD (n = 3) wt.%

Elemental oxides	Sample 1 [conc (wt. %)]	Sample 2 [conc (wt. %)]	Sample 3 [conc (wt. %)]	Mean ± SD (wt.%)
SiO_2	36. 09%	48. 89	26. 72	37.23 ± 11.13
Fe_2O_3	24. 14%	7. 22	1. 61	10.99 ± 11.73
Al_2O_3	24. 52%	35. 92	18. 79	26.41 ± 8.72
MgO	0. 88%	1. 68	0. 17	0.91 ± 0.76
P_2O_5	0.10%	0. 16	0. 10	0.12 ± 0.03
SO_3	0. 25%	0. 25	0	0.17 ± 0.14
Na_2O	0%	0. 12	0. 02	0.05 ± 0.06
TiO_2	2. 2%	0. 68	0. 18	1.02 ± 1.05
MnO	0. 03	0. 05	0. 009	0.030 ± 0.021
CaO	0. 04	0. 14	0. 16	0.113 ± 0.064
K_2O	0. 17	1. 74	0. 17	0.69 ± 0.91
CuO	0. 004	0. 002	0. 001	0.0023 ± 0.0015
ZnO	0. 006	0. 01	0. 003	0.0063 ± 0.0035
Cr_2O_3	0. 018	0	0. 001	0.0063 ± 0.0101
V_2O_5	0. 05	0. 01	0. 004	0.021 ± 0.025
PbO	0. 0006	0. 007	0. 003	0.0035 ± 0.0032
BaO	0. 065	0. 04	0. 02	0.0417 ± 0.0225

The reported standard deviations reflect spatial variability among sampling locations rather than instrumental uncertainty.

Table 2: Comparative geochemical assessment of some elemental oxides of Bidore (Ingawa) talc deposit against the Kagara deposit (Niger State) and established ASTM D605 industrial specifications. Values are reported in weight percentage (wt%).

Parameter (wt. %)	Bidore Talc (This Study)	ASTM Industrial Talc	Kagara Talc Ore (Nigeria)
SiO_2	37.23 ± 11.13	≤ 60	**53.45 – 67.27**
MgO	0.91 ± 0.76	≥ 20	**21.77 – 27.68**
Al_2O_3	26.41 ± 8.72	≤ 10	**1.00 – 2.64**
Fe_2O_3	10.99 ± 11.73	≤ 5	**5.86 – 11.03**
Pb (ppm)	0.0035 ± 0.0032	≤ 20	**Not reported**

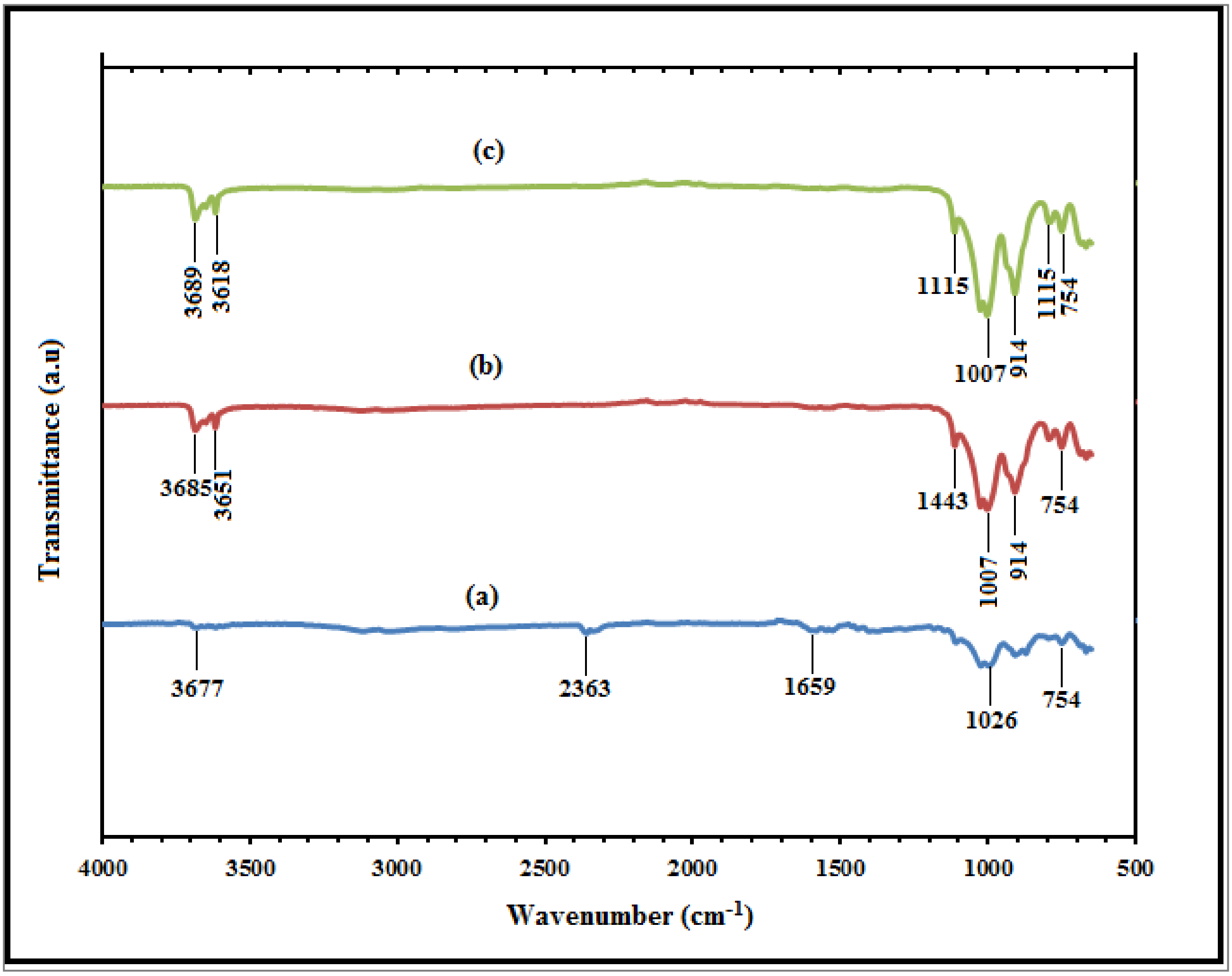

Figure 3: Fourier Transform Infrared (FTIR) spectra of the Ingawa (Bidore) talc samples. The stack plot displays the absorption bands for three replicate samples, labeled (a), (b), and (c). Key functional groups are observed, including the characteristic O-H stretching vibration (3676 cm^{-1}) and Si-O-Si bond vibrations (1016 cm^{-1}) confirming the structural uniformity of the deposit

Table 3: positions of peaks of identified phases and crystal system. The crystal systems identified for Talc, kaolinite, and quartz in the Bidore samples are in excellent agreement with internationally accepted crystallographic standards, confirming the reliability of the phase identification and supporting the mineralogical interpretation of the deposit.

PHASES	POSITION (2θ)	CRYSTAL SYSTEM
Talc	34. 5, 36. 0, 43. 0	Monoclinic
Kaolinite	12. 0, 20. 0, 23. 0, 25. 0, 39. 5, 46. 0, 50. 0, 55. 5, 60. 0, 62. 0	Triclinic
Quartz	21. 0, 27. 0, 39. 5, 46. 0, 50. 0, 55. 5, 60. 0, 68. 0	Trigonal

Moisture Content

The moisture content (MC) of the talc sample was calculated using Equation (1):

$$MC\ (\%) = \frac{Mw}{Md} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where

M_w is the mass of moisture lost during drying,

M_d is the mass of the dry sample.

Alternatively, when container mass is considered:

$$(Mc\ +\ Mw) - (Mc\ +\ Md)/\,(Mc\ +\ Md) - Mc\ x\ 100 \ldots\ldots\ldots\ldots\ldots.(2)$$

Where

Mc is the mass of the container.

Using the experimental data:

Mass of container + wet sample = **109.92 g**

Mass of container + dry sample = **109.57 g**

Mass of empty container = **11.01 g**

$$Mw = 109.92 - 109.57 = 0.35\ g$$

$$Md = 109.57 - 11.01 = 98.56\ g$$

Therefore

$$MC\ (\%) =\ 0.35 \div 98.56 \times 100 = 0.35\%$$

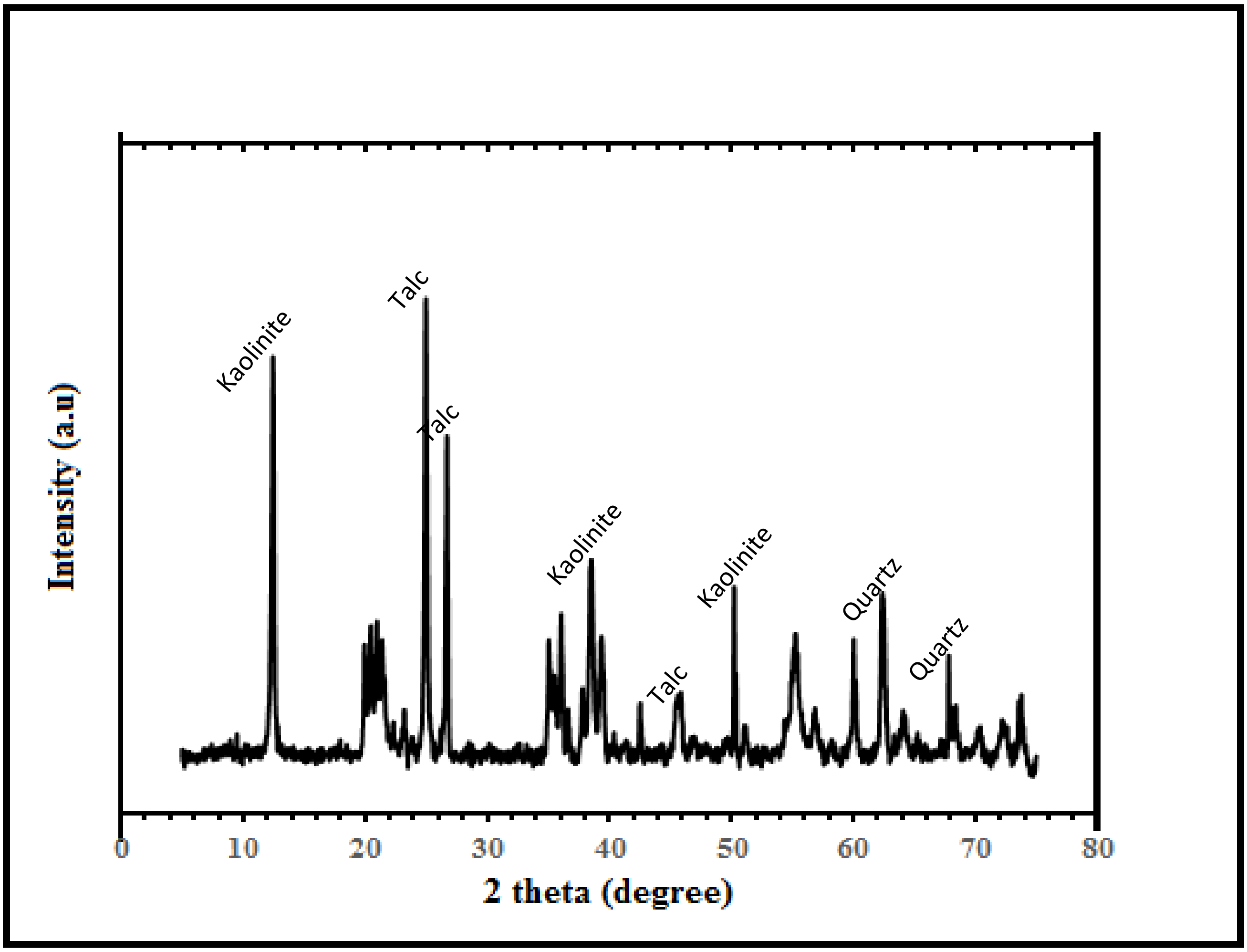

Figure 4: X-ray diffraction (XRD) patterns of the Ingawa talc sample. The diffractogram highlights the characteristic peaks of the identified mineral phases, with Talc indicated as the dominant phase with a triclinic crystal system. Secondary phases (gangue minerals) are marked at their respective theta positions. Peak assignments were verified against the standard crystallographic reference.

X-ray Fluorescence (XRF) Analysis

The major and trace elemental compositions of the talc samples from Bidore Ward are presented in Table 1 as oxide weight percentages. The dominant oxides across all samples are SiO_2, Al_2O_3, and Fe_2O_3, with subordinate MgO, reflecting the mineralogical association of Talc with silicate and aluminosilicate phases. To improve statistical analysis of results, measurements were conducted for all three samples, and a mean ± standard deviation (SD) was calculated. Variations among Samples 1–3 indicate spatial heterogeneity within the deposit, a common feature of Nigerian talc occurrences.

Silica (SiO_2) shows the highest concentration, ranging from 26.72–48.89 wt.%, with Sample 2 exhibiting the maximum value. This elevated silica content is attributed to the abundant quartz gangue, corroborated by XRD results. Similar high SiO_2 contents have been reported for talc deposits in Nasarawa, Niger, and Kebbi States, where quartz commonly occurs as an associated phase (Aderibigbe *et al*., 2016; Ahmed *et al*., 2020). Al_2O_3 concentrations (18.79–35.92 wt.%) are relatively high, indicating significant kaolinite contamination, which is consistent with weathered talc bodies in tropical environments. Comparable Al_2O_3 enrichment has been reported for Talc from Ijero-Ekiti and Kagara, Nigeria (Aroke & El-Nafaty, 2013). MgO contents (0.17–1.68 wt.%) are notably lower than those expected for high-grade industrial Talc (typically >20 wt.% MgO), suggesting that the studied material is low- to medium-grade Talc and requires beneficiation prior to pharmaceutical or cosmetic application. Trace oxides (TiO_2, MnO, Cr_2O_3, PbO, ZnO, CuO) occur at concentrations <1 wt.%, consistent with values reported for Nigerian talc deposits and below critical thresholds specified for industrial Talc in ASTM D2666 and USP–NF guidelines.

Fourier Transform Infrared (FTIR) Spectroscopy

The FTIR spectra of the samples (4000–500 cm^{-1}) exhibit characteristic absorption bands diagnostic of Talc and associated clay minerals. The strong absorption band observed at 3689 cm^{-1} corresponds to the stretching vibration of structural OH groups bonded to octahedral Mg in Talc (Petit *et al*., 2004; Hubicki *et al.,* 2009). The presence of bands at 3651 cm^{-1} and 3618 cm^{-1}, along with the H–O–H bending vibration at 1659 cm^{-1}, indicates adsorbed water, typical of clay-rich materials. The broad band between 1170–1015 cm^{-1} is attributed to asymmetric Si–O–Si stretching, confirming the dominance of silicate phases. Peaks at 914 cm^{-1} are assigned to Al–Al–OH vibrations, supporting the presence of kaolinite, while the band at 754 cm^{-1} corresponds to Al–O stretching vibrations (Besson & Drits, 2010). Overall, the FTIR results correlate strongly with both XRF and XRD findings, confirming a talc–kaolinite–quartz mineral assemblage (Fig 3).

X-ray Diffraction (XRD) Analysis

XRD patterns were recorded over a 2θ range of 5–75°, and the identified crystalline phases are summarised in Table 2. The major phases detected include Talc, kaolinite, and quartz. Talc reflections were observed at 34.5°, 36.0°, and 43.0° (2θ), consistent with the monoclinic Talc reported by Bish (1991) and Antao et al. (2008) as shown in Table 3. Kaolinite peaks occur at 12.0°, 20.0°, 23.0°, 25.0°, and 39.5°, confirming a triclinic structure, while quartz exhibits prominent trigonal reflections at 21.0°, 27.0°, 39.5°, 50.0°, 60.0°, and 68.0°.

The relative intensities of quartz and kaolinite peaks exceed those of Talc, explaining the elevated SiO_2 and Al_2O_3 concentrations observed in the XRF results. Similar mineralogical dominance of quartz and kaolinite over talc has been documented for talc deposits in Kagara, Wurno, and Dutsen-Wai, Nigeria (Aderibigbe *et al.*, 2016).

Moisture Content

The talc sample exhibits a low moisture content of 0.35%, indicating minimal physically adsorbed water. This value is consistent with reported moisture contents of Talc from northern Nigerian deposits, which typically range below 1% due to Talc's hydrophobic nature and low water affinity. Low moisture content is advantageous for industrial applications such as ceramics, paint fillers, and polymer additives, as it minimises processing challenges related to drying and agglomeration (Aroke & El-Nafaty, 2013; Ogunniyi *et al.*, 2018)

INDUSTRIAL ASSESSMENT

Based on the above determinations of chemical and physical characteristics, the Ingawa talc ore is assessed functionally, thus:

Ceramics Industry

In the production of wall and floor tiles, white wares, and enamels, Talc is used as an additive to enhance translucency and increase product toughness. Mitchell (1975) specified a good firing colour (white) and an average CaO concentration of 6% to act as a flux, lowering the maturing temperature of the ware. The Ingawa talc, with a significantly low CaO content of 0.11%, falls below this threshold, limiting its utility as a primary fluxing agent. However, its high silica content suggests it could serve as a filler in stoneware bodies where high purity is less critical, provided standard fluxes (feldspar) are added to compensate for the calcium deficiency

Paints Industry

When pulverised Talc is added during the manufacture of paints, it reduces the risk of cracks in paint films, paper, and hard rubber goods. It also acts as an inert filler and extender. According to ASTM D605 (Severinghaus, 1975), paint-grade Talc should have a good white colour, be free of hard particles, and have a particle size with at least 97% passing through a 325-mesh screen. In addition, Al_2O_3 should be ≤2%, MgO + SiO_2 ≥75%, and pH range 8–10. The Ingawa talc fails to meet these criteria primarily due to its brownish coloration caused by elevated Fe_2O_3 (10.99%) and the presence of abrasive quartz grains (associated with high SiO2). Unlike the Kagara deposit, which exhibits higher whiteness suitable for topcoats, the Ingawa ore in its raw state is restricted to use in dark-colored, anti-corrosive primers or undercoats where color fidelity is non-critical.

Rubber Industry

Talc offers greater tear and abrasion resistance and stiffness in the manufacture of rubber. It is also a highly valued dusting agent to lubricate moulds. Severinghaus (1975) specified that the Talc should be off-white, free of gritty particles, and have low MnO and CaO values. This sector represents the most viable application for the raw Ingawa deposit, since the industry prioritises mechanical reinforcement and cost reduction over strict chemical purity or whiteness. Low MnO and CaO values of Ingawa talc (average 0.065%) are advantageous, as high concentrations of these oxides can degrade rubber-curing catalysts. Consequently, Ingawa talc can function effectively as a dusting agent and reinforcing filler without extensive beneficiation.

Paper Industry

Talc is useful as filler and extender in paper manufacture. It also acts as a coating pigment, providing smoother, glossier surfaces for high-quality print paper and magazines. IARC monographs and Okunlola *et al.* (2002) report that suitable paper-grade Talc must be white, fine-grained, mica-free, and have very low Fe_2O_3 and CaO (<5%). The Ingawa talc does not meet these specifications, as it contains appreciably high average Fe_2O_3 content (10.99%), which is responsible for the mineral's colouration tendency.

Refractory Materials

When Talc is added to high-alumina clay and fired to 1250–1400 °C, it produces low thermal expansion, high thermal shock resistance, and good electrical properties. These qualities make it useful for the production of electrical coils, water boiler insulators, fire bricks, and burners. ASTM specifications (ASTM D605; IARC, 2010) require Talc for this purpose to have low fire shrinkage, CaO <1%, Fe_2O_3 <1.5%, SiO_2 <6%, MgO <30%, and (Na_2O+K_2O) <0.4%. Although the Ingawa talc meets the low CaO requirement (0.11%), its average iron oxide content (10.99 %) significantly exceeds the 1.5% limit established by ASTM D605.

Plastics

In the polymer industry, particularly for polypropylene (PP) and polyamide composites, Talc is utilised to increase stiffness, heat distortion temperature, and dimensional stability. While general requirements include a fine particle size and a low specific gravity (Okunlola et al., 2002), the filler's abrasiveness and colour are the critical limiting factors. It is technically feasible as a reinforcing filler where structural rigidity is the priority. The off-white to brownish coloration, attributed to the elevated Iron Oxide content, renders it unsuitable for light-colored or white consumer plastics (e.g., household appliances) without bleaching or rigorous magnetic separation.

Pharmaceuticals, cosmetics and the food industry

Talc is widely used in pharmaceuticals, cosmetics, and food processing—for creams, powders, odour absorption in soaps, as a dusting agent for tablets, in wound dressings, as a food additive, as a colour absorbent, and as a polishing agent. For these specialised applications, USP standards and CIR safety assessments specify that Talc must be odourless, grit-free, pure (≥90% talc), white, with a LOI of ~5%, pH 8–10, and CaO around 1.6% (Fiume *et al.,* 2015). The Ingawa talc is chemically unsuitable for these sectors due to its low mean MgO content (0.91%) relative to the required (>30%) and high quartz content. Without rigorous purification (froth flotation and acid leaching) to meet the USP standards for total heavy metal content and purity, the direct use of Ingawa talc in cosmetics or pharmaceuticals is not feasible.

CONCLUSION

This study, to the best of our knowledge, provided the first systematic multi-technique characterisation of the Ingawa talc deposit using FTIR, XRF, and XRD analyses. The mineralogical assessment confirms that the ore is a talc-quartz-kaolinite assemblage. Geochemically, the deposit deviates from purity, exhibiting elevated silica and aluminium oxide levels, along with lower magnesium oxide concentrations, due to quartz and clay impurities. Based on these physicochemical properties, the Ingawa talc in its raw, unprocessed state is technically feasible for use as a structural filler in the rubber and plastics industries, where high purity is less critical than mechanical reinforcement. This presents an immediate opportunity for regional manufacturers to substitute imported low-grade fillers with locally sourced Ingawa talc. However, the presence of abrasive quartz and high level of iron oxides currently limits its application in high-value sectors such as cosmetics, pharmaceuticals, and coatings. To unlock these markets, beneficiation strategies, specifically froth flotation, to depress quartz and magnetic separation to reduce iron content, are requisite. Future resource development should focus on optimizing these processing routes to upgrade the Ingawa ore to meet ASTM and USP standards.

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