

Determination of the Optimal Separation Size of Makarfi Ilmenite Ore Using Size Assay Techniques, Kaduna State

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Abstract—This study investigates the optimal separation size for ilmenite ore from the Makarfi-Kaduna region of Nigeria, with a focus on determining the ideal particle size for efficient beneficiation. Ilmenite (FeTiO_3) is a key source of titanium dioxide (TiO_2), widely used in industrial applications such as pigments and aerospace materials. The beneficiation of ilmenite involves various separation techniques including gravity, magnetic separation, and flotation, which rely heavily on the particle size distribution of the ore. The research uses size assay techniques to identify the most effective separation size that maximizes mineral recovery while minimizing energy consumption and material loss. Samples were collected from the Makarfi-Kaduna region, and particle size distributions were determined using sieve analysis, along with chemical composition assessed by X-ray fluorescence (XRF). The results indicate that the +63 μm sieve fraction exhibited the highest concentration of both Fe_2O_3 (64.0727 g) and TiO_2 (55.8629 g), making it the best liberation size for both materials. This fraction contained 42.83% of Fe_2O_3 and 43.73% of TiO_2 , and accounted for 98.82% of the Fe_2O_3 and 105.51% of the TiO_2 in the ore. The findings highlight the significance of finer particle sizes in enhancing separation efficiency, providing insights for optimizing ilmenite ore processing. This study contributes to improving beneficiation practices in the Makarfi-Kaduna region and offers recommendations for scaling up the findings to industrial processing. It also emphasizes the need for advanced separation techniques and further research into other ilmenite-rich regions of Nigeria. The optimized separation size could lead to higher yields, reduced waste, and better economic feasibility in ilmenite mining operations, ultimately contributing to the growth of Nigeria's solid mineral sector.

Index Terms—Titanium dioxide (TiO_2); Particle Size Distribution; Size Assay; Gravity separation; Magnetic separation; Ore characterization; Liberation size; Makarfi-Kaduna; Nigeria.

I. INTRODUCTION

Ilmenite (FeTiO_3) is one of the most widely distributed titanium-bearing minerals and constitutes the primary industrial source of titanium dioxide (TiO_2), a compound of immense technological and economic importance. Titanium dioxide is globally recognized for its exceptional optical properties, including high brightness, opacity, and superior refractive index, which make it indispensable in the manufacture of pigments, paints, coatings, plastics, and paper (Gupta & Krishnamurthy, 2015). Beyond pigment applications, TiO_2 also plays a crucial role in advanced engineering fields such as aerospace, renewable energy, catalysis, electronics, and biomedical technologies, where it is valued for its chemical stability, corrosion resistance, and ultraviolet (UV) shielding capacity. Consequently, the rapid expansion of these industries continues to drive an escalating global demand for high-quality ilmenite ore and efficient beneficiation methods capable of producing high-grade titanium concentrates (Chen et al., 2019).

To meet industrial specifications, ilmenite must undergo beneficiation to improve its purity and concentrate TiO_2 content. The success of beneficiation processes—such as gravity separation, low- and high-intensity magnetic separation, electrostatic separation, and flotation—depends fundamentally on the degree of mineral liberation, which itself is strongly influenced by particle size, mineral associations, and textural characteristics of the ore (Abaka-Wood et al., 2020; Hosseini & Forssberg, 2001). Previous studies demonstrate that particle size exerts a decisive influence on separation efficiency: fine particles tend to exhibit better liberation, enhancing flotation and magnetic separation performance, while coarser particles often

respond more favorably to gravity separation owing to distinct differences in density and particle settling behavior (Zhang et al., 2017; Liu et al., 2018). Inadequate control of particle size distribution can lead to poor mineral liberation, increased slime production, reduced separation efficiency, and significant losses of valuable minerals. Thus, determining the optimal separation size is essential for establishing effective beneficiation strategies and ensuring the economic viability of processing operations.

Nigeria is endowed with a vast range of solid minerals, including significant deposits of ilmenite-bearing sands and hard-rock sources distributed across various geological terrains. Among these, the Makarfi area in Kaduna State is recognized for its notable concentration of heavy minerals such as ilmenite, magnetite, hematite, rutile, and zircon. Despite this geological potential, Nigeria has yet to fully harness its mineral resources due to limited scientific research, insufficient beneficiation infrastructure, and a lack of detailed ore characterization studies. In particular, information on the particle size behavior, mineralogical associations, and separation size of ilmenite from the Makarfi-Kaduna region remains scarce. This knowledge gap has hindered efficient mineral processing and has contributed to suboptimal recovery rates, elevated operational costs, and increased material losses in past beneficiation attempts.

Since particle size is one of the most critical parameters controlling mineral liberation, accurate size assay techniques—such as sieve analysis, hydrometer analysis, and laser diffraction—are essential for evaluating ore behavior during comminution and separation (Burt, 2016). These analytical methods not only help to establish the particle size distribution (PSD) of the ore but also enable the correlation of size fractions with chemical composition through techniques such as X-ray Fluorescence (XRF). Such correlations are vital for identifying the size range at which ilmenite is most liberated from gangue minerals, particularly iron oxides like magnetite and hematite, with which it commonly occurs (Abaka-Wood et al., 2020). Understanding these relationships is crucial because effective liberation ensures efficient separation,

reduces reagent consumption, minimizes processing time, and improves overall metallurgical performance.

Developing a reliable beneficiation framework for ilmenite ores such as those from Makarfi-Kaduna is aligned with Nigeria's broader solid mineral development agenda, which seeks to diversify the national economy away from crude oil dependence and promote value addition within the mining sector (Obaje, 2009). Efficient beneficiation of ilmenite can stimulate local industries, attract foreign investment, create employment opportunities, and support domestic manufacturing of titanium-based materials. Furthermore, the generation of high-grade concentrates locally can reduce Nigeria's reliance on imported titanium feedstocks, enhance the competitiveness of its mineral economy, and contribute to sustainable national development.

Given these considerations, this study aims to determine the ideal separation size for ilmenite ore from the Makarfi-Kaduna region using a combination of chemical analysis and size assay techniques. The research involves comprehensive characterization of the ore's chemical composition using X-ray Fluorescence (XRF), systematic particle size distribution analysis through sieve and hydrometer methods, and evaluation of oxide distribution across size fractions to determine the most effective liberation size. By identifying the particle size range that yields the highest Fe₂O₃ and TiO₂ concentrations, the study provides critical insights for optimizing beneficiation efficiency, reducing mineral losses, and enhancing processing economics. Ultimately, the findings are expected to serve as a scientific foundation for industrial-scale beneficiation, guide future research on Nigerian ilmenite deposits, and support the advancement of Nigeria's solid mineral sector (Wills & Finch, 2015; Abaka-Wood et al., 2017).

1.1 LOCATION AND ACCESSIBILITY

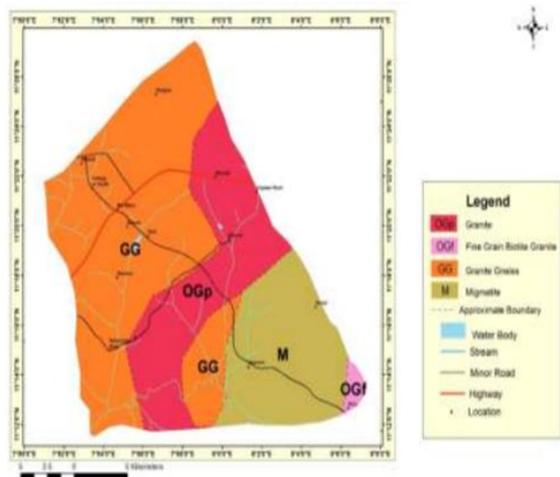


Figure 1. Geological Map of Makarfi

The raw ilmenite ore samples were collected from Makarfi Local Government Area of Kaduna State in a village called Galma River at a coordinate of 11° 13' 15''N, 7° 56' 00.0''E. Random sampling method was used to obtain a representative sample from a rich zone within Makarfi deposit.

II. Materials and Methods Used

The ilmenite ore samples collected from the Makarfi area in Kaduna State were first dried in the Kaduna Polytechnic Mineral Processing Laboratory and homogenized using the coning and quartering method to ensure representativeness. After drying to remove moisture—which could influence magnetic and

physical properties—the samples were prepared for chemical and particle size analysis.

Chemical characterization was conducted using X-ray Fluorescence (XRF). Representative portions of each size fraction were crushed and pulverized to <75 μm, pressed into pellets with a binder, and analyzed using a calibrated XRF spectrometer. The instrument measured the concentrations of major oxides, particularly TiO₂ and Fe₂O₃, to determine how chemical composition varies with particle size.

Sieve analysis was performed to determine particle size distribution. About 500 g of the dried ore was sieved through a stack of standard test sieves (355 μm to 63 μm) using a mechanical shaker for 15 minutes. The mass retained on each sieve was recorded and used to generate a particle size distribution curve.

Additional size assay techniques were employed to complement the sieve results. Fractions finer than 75 μm were analyzed using hydrometer sedimentation based on Stokes' Law to quantify ultra-fine particles. In some cases, laser diffraction analysis was conducted to obtain high-precision particle size measurements across a broad size range and to validate the sieve and hydrometer data.

Overall, these procedures allowed for accurate determination of particle size distribution and corresponding oxide content, enabling the identification of the optimal separation size for effective ilmenite beneficiation.

III. RESULTS AND ANALYSIS

Table 1. Result from Chemical Analysis Using XRF

| Component | Head sample | Sieve size | | | | | | |
|--------------------------------|-------------|------------|--------|--------|--------|--------|--------|--------|
| | | 600 | 425 | 300 | 212 | 150 | 63 | Pan |
| Fe ₂ O ₃ | 33.284 | 37.136 | 35.491 | 30.172 | 25.568 | 24.638 | 28.9 | 35.961 |
| TiO ₂ | 33.137 | 31.323 | 32.616 | 34.21 | 28.374 | 26.936 | 33.895 | 31.379 |

Table 1 shows the X-ray Fluorescence (XRF) analysis of the Makarfi-Kaduna ilmenite ore reveals significant variations in Fe₂O₃ and TiO₂ concentrations across different particle size fractions. The head sample contains 33.284% Fe₂O₃ and 33.137% TiO₂, indicating a relatively balanced composition of iron and titanium oxides. In the

coarse fraction (+600 μm), Fe₂O₃ is elevated at 37.136% while TiO₂ is slightly lower at 31.323%, suggesting that iron oxides are more concentrated in larger particles, whereas titanium-bearing minerals are relatively finer. Intermediate fractions (+425 to +150 μm) exhibit decreasing Fe₂O₃ content, from 35.491% to 24.638%, while TiO₂ peaks at 34.21% in

the +212 μm fraction, reflecting enhanced liberation of ilmenite at this size. The +63 μm fraction shows 35.961% Fe_2O_3 and 31.379% TiO_2 , indicating significant enrichment of both oxides in finer particles, whereas the pan fraction retains considerable oxide content despite its low mass.

Overall, the data suggest that Fe_2O_3 is concentrated in coarser fractions, while TiO_2 is enriched in intermediate to fine fractions, emphasizing the need for particle size optimization in ilmenite beneficiation to maximize recovery and processing efficiency.

| Sieve Size Range (μm) | Sieve Fraction Weight (g) | Fe_2O_3 Assay (%) | Fe_2O_3 Overall Assay (g) | TiO_2 Assay (%) | TiO_2 Overall Assay (g) | Cumulative Over Size (μm) | Fe_2O_3 Distribution (%) | TiO_2 Distribution (%) | Cumulative Distribution Fe_2O_3 (%) | Cumulative Distribution TiO_2 (%) |
|------------------------------------|---------------------------|-----------------------------------|-------------------------------------------|--------------------------|----------------------------------|----------------------------------------|------------------------------------------|---------------------------------|-----------------------------------------------------|--------------------------------------------|
| +600 | 7.2 | 35.4 | 2.5528 | 32.6 | 2.3512 | 600 | 1.70 | 1.47 | 1.70 | 1.47 |
| +425-300 | 15.3 | 30.1 | 4.6083 | 34.2 | 5.2326 | 425 | 3.09 | 3.47 | 4.79 | 4.94 |
| +300-212 | 58.3 | 25.5 | 14.8585 | 28.3 | 16.4999 | 300 | 9.95 | 10.61 | 14.74 | 15.55 |
| +212-150 | 143.1 | 24.6 | 35.2246 | 26.9 | 38.4589 | 212 | 23.52 | 25.74 | 38.26 | 41.29 |
| +150-63 | 91.7 | 28.9 | 26.5193 | 33.8 | 30.9786 | 150 | 17.73 | 20.49 | 55.99 | 61.78 |
| +63 | 178.3 | 35.9 | 64.0727 | 31.3 | 55.8629 | 63 | 42.83 | 43.73 | 98.82 | 105.51 |
| Pan | 4.3 | 45.2 | 1.9436 | 42.5 | 1.8275 | - | 2.63 | 2.37 | 100.00 | 107.88 |

Table 2. Distribution of Fe_2O_3 and TiO_2 Across Particle Size Fractions

The sieve analysis and chemical assays in table 1 reveal that the distribution of Fe_2O_3 and TiO_2 in the Makarfi-Kaduna ilmenite ore varies significantly with particle size, with the +63 μm fraction emerging as the optimal separation size. Coarser fractions (+600 μm to +150 μm) show relatively low oxide grades and poor mineral liberation, as indicated by lower Fe_2O_3 and TiO_2 assays. As particle size decreases, both oxide grades and overall recoverable mass increase, culminating in the +63 μm fraction, which contains the highest Fe_2O_3 (64.0727 g) and TiO_2 (55.8629 g) contents. This fraction also holds the largest oxide distributions—42.83% Fe_2O_3 and 43.73% TiO_2 —indicating that most of the valuable minerals are concentrated within this size class. Although the pan fraction (<63 μm) exhibits high oxide grades, its low mass contribution makes it unsuitable for primary beneficiation. Overall, the results demonstrate that the +63 μm size fraction provides the best combination of mineral liberation, recoverable mass, and separation efficiency, establishing it as the ideal particle size for effective ilmenite beneficiation.

IV. CONCLUSION AND RECOMMENDATION

The study identified the +63 μm fraction of Makarfi-Kaduna ilmenite ore as the optimal separation size, exhibiting the highest concentrations of Fe_2O_3 and TiO_2 and the most effective mineral liberation. Coarser fractions showed lower oxide grades and poor liberation, while finer fractions contributed minimally to total recoverable mass. Targeting the +63 μm fraction in industrial beneficiation can significantly improve mineral recovery, enhance separation efficiency, reduce waste, and increase economic feasibility. It is recommended that industrial processing prioritize this fraction using advanced techniques such as high-intensity magnetic separation and flotation. Further research on coarser and ultra-fine fractions, coupled with detailed mineralogical characterization, is also suggested to optimize overall recovery, minimize losses, and support sustainable development of Nigeria's solid mineral sector.

REFERENCE

- [1] Abaka-Wood, G., Forssberg, E., & Hosseini, S. (2020). *Effect of particle size on the separation efficiency of ilmenite ores*. *Minerals Engineering*, 150, 106271. <https://doi.org/10.1016/j.mineng.2020.106271>
- [2] Abaka-Wood, G., Olowolafe, J. O., & Agbaje, A. O. (2017). Mineral beneficiation of Nigerian ilmenite: A review. *Journal of Mining and Metallurgy*, 53(2), 101–114.
- [3] Burt, R. (2016). Particle size analysis in mineral processing: Techniques and applications. *Mineral Processing and Extractive Metallurgy Review*, 37(4), 243–259.
- [4] Chen, Q., Liu, X., & Zhang, Y. (2019). Advances in titanium dioxide extraction from ilmenite ores. *Hydrometallurgy*, 189, 105152. <https://doi.org/10.1016/j.hydromet.2019.105152>
- [5] Gupta, C. K., & Krishnamurthy, N. (2015). *Extractive Metallurgy of Titanium*. CRC Press.
- [6] Hosseini, S., & Forssberg, E. (2001). Magnetic and gravity separation of ilmenite: A review. *Minerals Engineering*, 14(6), 611–618.
- [7] Liu, Y., Zhang, Z., & Li, H. (2018). Effect of particle size on ilmenite flotation and magnetic separation. *International Journal of Mineral Processing*, 172, 22–30.
- [8] Obaje, N. G. (2009). *Geology and Mineral Resources of Nigeria*. Springer.
- [9] Wills, B. A., & Finch, J. A. (2015). *Wills' Mineral Processing Technology: An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery* (8th ed.). Butterworth-Heinemann.
- [10] Zhang, L., Chen, Y., & Wang, J. (2017). Optimizing ilmenite particle size for enhanced beneficiation performance. *Minerals*, 7(3), 49. <https://doi.org/10.3390/min7030049>.