Investigating the Characterization and Grindability Behaviour of Farin-Lamba Cassiterite Toward Effective Tin Oxide Production

ABSTRACT

The Modified Bond's grindability test is a method used to determine the Work Index which is crucial in the estimation of the energy needed to grind an ore. This is very crucial during mineral processing as a slight deviation would affect the operating expenditure (OPEX) of a company. This study investigates the work index for Farin-Lamba cassiterite with reference to silica sand sourced from Igbokoda. Thetest ore (cassiterite) was analyzed using Energy Dispersed X-ray fluorescence spectrometer (ED-XRS), Petrographic Analysis, and Scanning Electron Microscope equipped with an Energy Dispersive Spectrum (SEM-EDS) to understand their chemical and mineralogical characteristics in relation to their grindability. Both the test ore and the reference material (silica sand) underwent comminution using 500g of each to a 100% passing 500 μm array of sieves arranged in (√2) series from 500μm to 63μm onto an automatic sieve shaker. The chemical and mineralogical analysis revealed the presence of gangue such as SiO_2 and $Al_2O_{3,}$ whichincreases the energy needed during communition; further, the presence of rough and large grain size in the ore also increases the energy needed for communition. The results were subjected to Gaudin Schuman's equation to determine the work index of the ore,which was 14.664 KWh/ton for the test ore, which is standard for cassiterite, which ranges from 10-15 kWh/ton. Further, the energy needed for comminution was calculated to be 33.7272 Kwh, providing valuable insights into the energy efficiency of the grinding process. The evaluation of the grindability of Farin-Lamba cassiterite in relation to the reference ore not only contributes toward understanding the ore processing dynamics but also provides information needed for the optimization of energy consumed during the process of tin oxide production.

Keywords:Cassiterite, Grindability, Work Index, Bonds Equation, Optimization

1. INTRODUCTION

Tinstone, also known as cassiterite, is a heavy mineral that is translucentin its pure form but turns brownish-blackish when iron, aluminium, and silica impurities are present. Cassiterite has a 78.6% tin oxide percentage when chemically pure, which is uncommon. However, when it is impure, the tin content can range from 40 % to 55%. Two basic kinds of deposits contain cassiterite; firstly, it is present in veins and fissures in the granite and adjacent country rock, and it is the principal accessory ingredient of some late-stage granitic intrusions. Secondly, the deposit occurs in secondary origin and can be found as detrital, placer, or alluvial deposits. Tin oxide (SnO2) is a substance that is utilized in many different sectors throughout the world, including electronics, ceramics, and coatings. It is a necessary component of modern technology(Liu et al. 2011; Angadi et al. 2015).

Nowadays, the majority of cassiterite's sources are alluvial deposits containing weathered grains rather than primary deposits; the Malay states, Bolivia, Indonesia, Belgium, Congo, and Nigeria account for the majority of the world's supply of tin ore. Cassiterite has been an important source of tin for one and is still the greatest source of tin today.

The exploitation of mineral resources has become a top priority in many developing nations. Nigeria, for example, has abundant mineral resources that have significantly increased the country's gross domestic product (GDP), which has brought about socioeconomic benefits(Gitau et al. 2024). The production of tin oxide depends on the efficient beneficiation of cassiterite, which must first go through a comminution process that involves ore crushing and grinding. Therefore, knowing the ore's grindability is an important step toward the efficient and effective production of tin oxide(Oyelola et al. 2024).

The goal of the comminution circuit in mineral processing is to prepare the ore as a suitable feed for separation processes, which upgrade the material by rejecting the particles that do not contain economically significant amounts of the target mineral. Comminution theory deals with the relationship between energy input into particle size reduction and the particle size distribution made from a given feed size. In contrast, grindability tests seek to estimate the energy consumption of grinding and to give parameters for the sizing of the grinding mill using various test methods. The significance is that the communition process converts the ore from a population of particles with a relatively uniform grade to particles with a range of compositions that allow them to be separated into low-grade and high-grade streams(Angadi et al. 2015; Lehmann 2021).

Insufficient mineral liberation during the separation phases of an ore is a result of grinding it to excessively coarse particle size. However, too fine a grinding of the mineral results in higher grinding costs and possibly low final recovery. Thus, one of the most important components of effective mineral processing is efficient grinding. Energy consumption drives the cost of grinding. Extensive grinding might not always be a bad thing because the earlier steps might compensate for the higher energy use. While the main goal of grinding is to achieve the economic degree of release, grinding is also occasionally employed to enhance the surface area of minerals(Yang et al. 2021).

The most energy-intensive step in mineral processing is grinding, which comes at the end of the comminution process and can cost a mineral processing plant more than half of its operating expenses. The economic degree of liberation of the target mineral is the goal of grinding. Thus, whether running a mineral processing facility or carrying out a feasibility assessment, understanding an ore's comminution qualities is crucial(Olatunji et al. 2010).

While tumbling mills have reached a high level of mechanical efficiency and dependability, there is ongoing discussion on their energy efficiency. The main issue with tumbling mills, as well as all other crushing and grinding equipment, is that very little of the energy input is actually used to break the ore because the equipment consumes the majority. Less than 1% of the entire energy input is available for actual size reduction, with the majority of the energy being used to produce heat, as demonstrated by Wills et al. (2006).

The primary objective of this research is to understand the mineralogical and chemical characteristics and evaluate the grindabiltybehavior of Farin-Lamba cassiterite using the modified Bonds Index. By understanding the grindability and the ore composition can pave the way for the optimization of processing circuits in order to enhance sustainable tin oxide production.

2. MATERIALS AND METHODS

2.1 Materials

The study's samples came from Farin-Lamba mines, which are situated in Plateau State, Nigeria's Jos South Local Government Area, collected from different pits tagged Pit LC-1, LC-2, LC-3, LC-4, and LC-5.

2.2 Methods

A Denver Laboratory Milling Machine (D-12) was used to grind the samples in order to determine their liberation size and conduct mineralogical and elemental analysis of the crude material. After crushing and grinding, the reference ore, Igbokoda silica, and the test ore were charged into a set of sieves and left on an automatic sieve shaker for 20 minutes. Weighing the sieve fractions of the test and reference ore that was retained allowed us to record the feed product's value for work index calculations.

The processed samplesunderwent mineralogical characterization by utilization of an X-ray Diffractometer (XRD), a Scanning Electron Microscope equipped with a Dispersion Spectrum (SEM-EDS), and a Petrological Analyzer. Finally, the modified Bond's Equation(Alabi et al. 2015)was used to determine the theoretical work index of cassiterite,which involves using reference material such as silicawhose grindability is known shown in Equation 1-2.

$$\text{Wit} = \text{Wir}\left(\frac{10}{\sqrt{\text{P}}} - \frac{10}{\sqrt{\text{F}}}\right) \qquad (1)$$

$$\text{Wit} = \text{Wir}\left(\frac{\frac{10}{\sqrt{\text{Pr}}} - \frac{10}{\sqrt{\text{Fr}}}}{\frac{10}{\sqrt{\text{Pt}}} - \frac{10}{\sqrt{\text{Ft}}}}\right) \qquad (2)$$

Where Wit is the test ore Work Index, Wir is the reference ore Work Index, Pr is the reference ore where 80% of the materials pass 100μm, Pt is the test ore diameter where 80% of the materials pass 100μm, Fr is the reference ore diameter where 80% of the feed pass 100μm, Ft is the test ore diameter where 80% of the feed pass 100μm, Wr is the reference ore work input and Wt is the test ore work input (Valerevich Lvov et al. 2019).

3. RESULT AND DISCUSSION

3.1 Results

3.1.1 Elemental analysis of the cassiterite sample

Table 1: Chemical Composition of the Crude Cassiterite

Compounds	Al_2O_3	SnO_2	Ta_2O_5	SiO_2	Fe_2O_3	BaO	SO_3	ZrO_2	TiO_2	Nb_2O_3	CaO
Composition %)	5.450	24.720	0.667	49.980	3.500	2.136	1.651	2.550	4.600	1.036	1.785

3.1.2 Mineralogical characterization examination using a scanning electron microscope with an energy-dispersive spectrum (SEM-EDS0

a. SEM micrograph of crude cassiterite

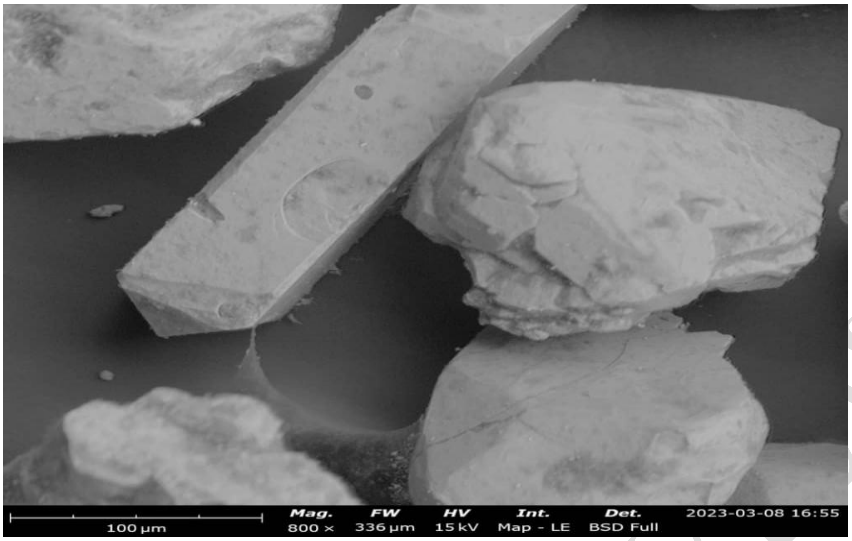

Figure 1: Scanned Electron micrograph of crude cassiterite sample

b. EDS phase diagram of crude cassiterite

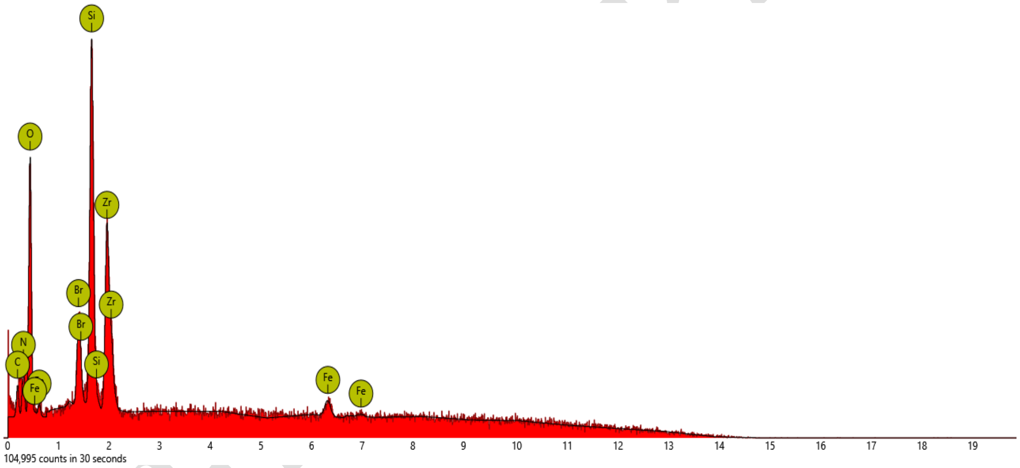

Figure 2: EDS of crude cassiterite at 500 µm Magnification

3.1.3 Petrological analysis

The minerals contained in the test ore were identified using optical techniques in both cross-polarized light (XPL) and plane-polarized light (PPL), as shown in Figure 3.

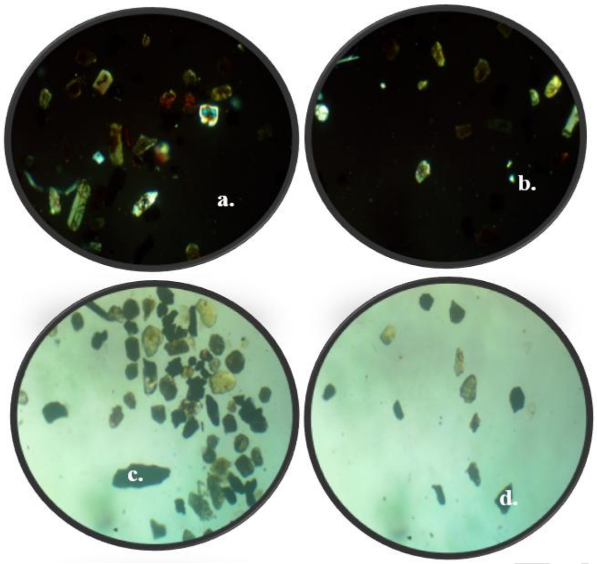

Figure 3: Petrographs of crude cassiterite at 500 magnification in PPL and XPL

3.1.4 Particle Size Analysis

The sieve analysis plots of the test (cassiterite) and reference ore (silica sand) feed to the ball mill are displayed in Figures 4–7. They plot different varied sieve sizes against the cumulative percentage of the ore retained, and the cumulative percentage of the ore passed.

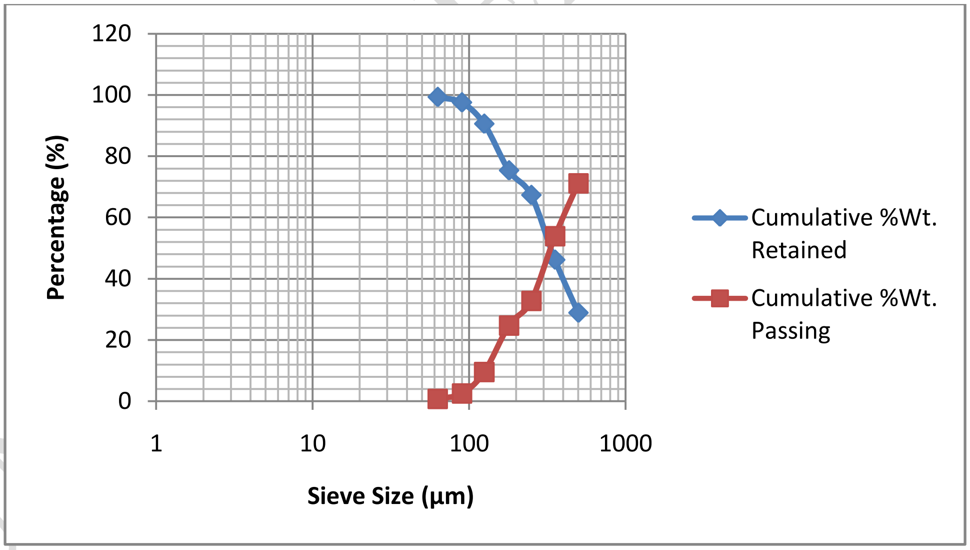

Figure 4: Plot of % cumulative retained and passing against sieve sizes (test ore fed to the ball mill)

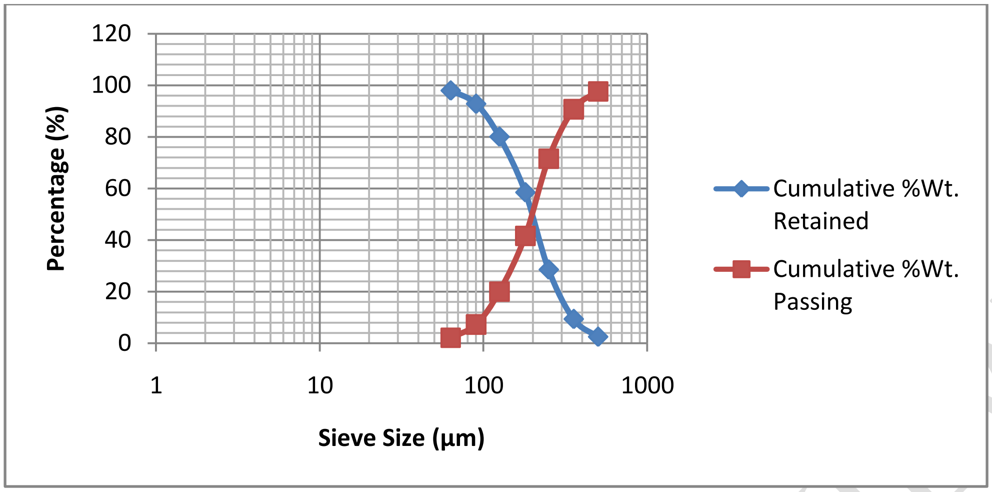

Figure 5:Plotof %cumulative retained and passing particles against sieve sizes (reference ore fed to the ball mill)

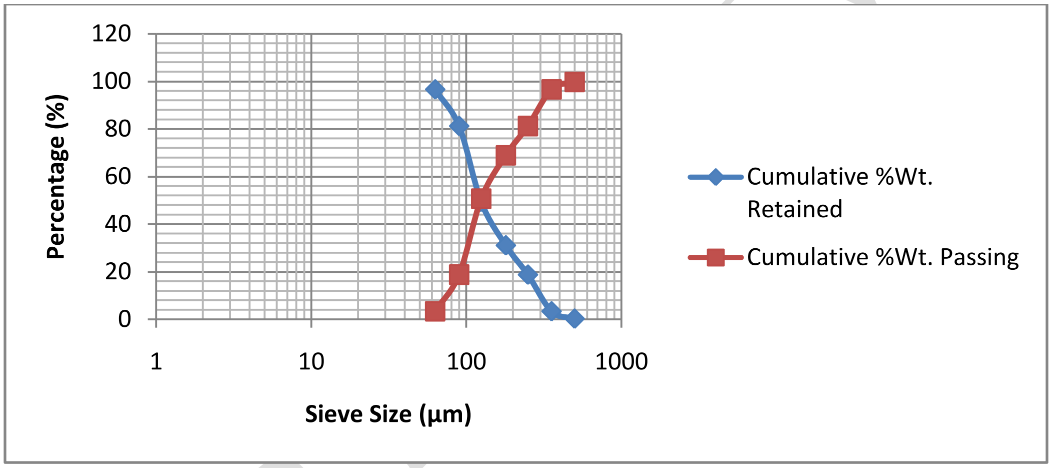

Figure 6: Plot of cumulative % retained and passing against sieve sizes (test ore product from ball mill)

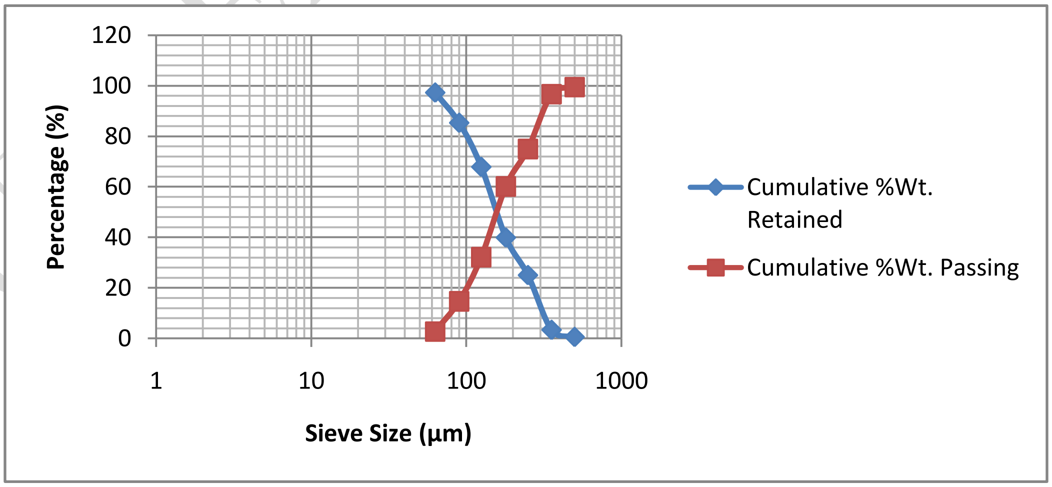

Figure 7: Plot of cumulative% retained and passing against sieve sizes (reference ore product from ball mill)

3.1.5 Grindability Evaluation

Equation 4 was used to evaluate the grindability of the cassiterite.

$$R = \frac{F}{P} \qquad 4$$

Where R is the reduction ratio, F is the feed particle diameter, and P is the product particle diameter.

Utilizing Gaudin Schumann's expression as shown in Equations 5-7.

$$P\ (X) = 100\ (X - K)^{\alpha} \qquad 5$$

$$\alpha = \frac{\log P\ (X2) - \log P\ (X1)}{\log(X2) - (X1)} \qquad 6$$

$$Sieve\ 1 = \frac{\%\ Passing\ \ in\ Sieve\ 1}{\%\ Passing\ \ in\ Sieve\ 2}\text{*sieve 2} \qquad 7$$

Where X is the sieve size with 80% particle passing

InordertoevaluatetheFarin Lamba Cassiterite grindingprocess,equation3.3wasapplied to determine the result in Table1.

Table 2: 500 µm and 250 µm mesh sizes of sieves having an 80% particle size pass rate.

Samples	80% Passing Feed µm (F)	80% Passing Milled Productµm (P)
Test Ore (Cassiterite)	592.13	238.66
Reference Ore (Silica Sand)	660.20	250.44

3.1.6 WorkIndexDetermination

According tothe literature, the Work Index of Silica sand is between 2.65 Kwh/t - 16.46Kwh/t(Alabi et al. 2016). Taking 14.1 as the Work Index of Silica sand. Therefore, the determination of the work index involved inputting the values obtained from Table 1 into Equations1 and 2, resulting in a Wir of 14.664KWh/ton.

WhereWir =14.1Kwh/ton

$$Wit=14.1\times\left(\frac{\frac{10}{\sqrt{250.44}}}{\frac{10}{\sqrt{238.66}}} - \frac{\frac{10}{\sqrt{660.20}}}{\frac{10}{\sqrt{592.13}}}\right) = 14.664\ \text{Kwh/ton}$$

3.1.7 energyused during grinding

The energy used to obtain the optimal liberation size during the communition process was determined by substituting the test work index in Equation 1.

$$Wt = 10\ \times 14.664 \times \left(\frac{1}{\sqrt{238.66}} - \frac{1}{\sqrt{592.13}}\right) = 33.7272\ \text{Kwh}$$

3.2 Discussion

The chemical composition of the crude cassiterite ore revealed 24.72% SnO_2(tin oxide),as shown in Table 1, which is the main mineral of interest. There are also considerable amounts of gangue, such as SiO_2 (49.98%) and Al_2O_3 (5.45%), among others. Elements such as SiO_2 contribute to the formation of hard and abrasive grains due to the presence of minerals such as quartz that increase the energy needed during communition and increases also increase the wear and tear during grinding, thereby reducing the grindability of the cassiterite ore.

Figures 1-2 show a SEM image at 100 µm with 800 magnification, as well as an EDS qualitative analysis of the Farin - Lamba Cassiterite deposit at 500 magnification for Spectrum 1. The SEM morphology reveals that the minerals in the ore matrix are closely packed, allowing for simple liberation via grinding, which is a key and result-determining step in mineral processing, and all subsequent downstream processes in the beneficiation chain rely totally on it (Matsanga et al. 2023). The EDS qualitative analysis of the image revealed that the primary elemental elements of minerals in the ore matrix are *Fe, Sn, O, K, Ca, Al*, and *Si.*

SEM-EDS examines the composition and microstructure of samples at a scale and gives valuable insights into the mineralogical composition of the ore, including the distribution of different mineral phases and the presence of minerals and their gangue constituents in the ore matrix. This information is critical for understanding ore and gangue composition, mineralogy, and texture impact of the grindability of the ore. The presence of abrasive and coarse minerals within the ore affects its grindability by increasing the energy consumption and wear rates of the communition equipment. On the other hand, the absence of such minerals indicates better grindability of the ore (cite).

There also exists a relationship between ore petrography (Figure 3) and cassiterite grindability. Petrological analysis helps to understand various mineralogical associations, such as particle shape and agglomeration within the ore, which affect liberation. The ore generally displays isotropic characteristics under crossed polarized light microscopy, revealing subhedral grain shape within a network of Si and Fe intrusions within the host rock. The arrangement of the grain also appears to be loosely packed within the ore matrix, justifying the low energy used during grinding. Though the cassiterite exhibits a subhedral shape and generally does not exhibit a complex structure, thus allowing easy grindability,however, the presence of silica and iron gangue may consequently affect the grindability and increase the energy for liberation.

The sieve analysis results revealed that the 80% passing particle size fractions for the reference (Fr) and test ore (Ft) fed into the ball mill were 632.25 µm and 312.5 µm, respectively, and the 80% passing particle size fractions for the products that came out of the ball mill were 242.25 µm and 284.55 µm, respectively. The plateau condition Farin-Lamba Cassiterite was found to have a work index of 14.664 Kwh/ton and grindability energy of 33.7272 Kwh. This suggests that reducing one ton of the plateau state Farin-Lamba Cassiterite from 80% passing size requires 33.7272 Kwh of energy.

4. CONCLUSION AND RECCOMENDATIONS

The chemical composition analysis shows the presence of tin oxide with the 24.72% assay in the ore; there are also high amounts of SiO_2 with a composition of 49.98%, which influences ore grindability. The petrological analysis and SEM/EDX study show that the cassiterite mineral was found interlocking in quartz, iron, aluminium, and other gangue. The grains of the minerals within the matrix of the ore are also loosely packed, interlocking with quartz along the grain boundaries. Farin-Lamba cassiterite work index was computed to be 14.664 Kwh/ton, utilizing a grindability energy of 33.7272 Kwh. The actual work needed to grind an ore is usually less than 1%, as the remaining energy is dissipated as vibration, noise, and heat(Bouchard et al. 2017). Therefore, this justifies the less energy used in cassiterite grinding as the ore is brittle and soft, as revealed in the mineralogical characterization. This parameter serves to help the development of a process for the beneficiation of Farin-Lamba cassiterite ore to the economic and technological development of a nation.

Effective beneficiation depends on the use of effective mineral separation processes that are based on the petrological features of the ore. The utilization of flotation, magnetic separation, and gravity separation techniques can aid in the focused elimination of gangue minerals, thus increasing the cassiterite concentration. Furthermore, energy efficiency must be closely monitored throughout the beneficiation process, which calls for a cautious assessment of the grinding parameters and reduction of heat, noise, and vibration-related energy losses by optimization. The beneficiation of Farin-Lamba cassiterite ore can promote economic development and help achieve the larger objectives of sustainable resource management and technological advancement by taking a comprehensive approach that combines technical optimization with environmental care.

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6. DATA AVAILABILITY

The data used in this research is available upon request.