

PARTICLE SIZE DISTRIBUTION, GRINDABILITY, AND COMMINATION ENERGY ANALYSIS OF YALO SPHALERITE IN ALKALERI, BAUCHI STATE, NIGERIA.

*¹Haile, M. G., ²Seidu, S. O., ²Aramide, F. O. and ²Alabi, O. O.



DOI10.51459/jostir.2026.2.2.0326

¹Manufacturing Industry Development Institute, Woreda 09 Basha welde chilot, Arada subcity, Addis Ababa, Ethiopia.

²Department of Metallurgical and Materials Engineering, Federal University of Technology, P.M.B. 704, Akure, Nigeria.

Correspondence

michaelgirma686@gmail.com

History

Received: 21-05-2026

Accepted: 13-06-2026

Published: August, 2026



<https://www.futa.edu.ng>



<https://jostir.futa.edu.ng>

ABSTRACT

Efficient comminution and particle size control are important factors, which can have direct effect on downstream beneficiation and leaching performance. In this study, the particle size distribution analysis, grindability test, and evaluation of comminution energy for Yalo Sphalerite ore, Alkaleri, Bauchi State, Nigeria were conducted. Based on particle size distribution (PSD) results, 180 μm was selected as an efficient liberation size of grinding for subsequent beneficiation and leaching processes. Particle size characterization result confirmed 90% of the sample were less than 180 μm particle size. The ore exhibited a Bond work index of 18.52 kWh/t and a specific grinding energy requirement of 7.14 kWh/t which indicates moderate resistance to grindability and within industrially acceptable energy ranges.

Keywords: Sphalerite ore; particle size distribution; Bond work index; comminution energy; grindability

1. | Introduction

The comminution process is one of the energy-intensive operations in mineral processing, which has a major role in determining the efficiency of the downstream beneficiation and extraction processes. In extractive processes such as hydrometallurgical and hybrid pyro-hydrometallurgical processes, effective liberation of valuable mineral phases from gangue minerals is strongly dependent on the particle size reduction (Zhang and Subasinghe, 2016). The degree of grinding influences surface area exposure, reaction kinetics, solid-liquid interaction, and ultimately metal recovery efficiency. Among sulfide minerals, sphalerite is the major source of zinc worldwide and it commonly extract through beneficiation followed

by hydrometallurgical or combined pyro-hydrometallurgical process (Hamid *et al.*, 2019). However, the efficiency of these processes largely depends on achieving adequate mineral liberation through a controlled comminution process (Reyes *et al.*, 2018). Insufficient grinding may result in incomplete liberation and poor leaching efficiency, whereas excessive grinding can increase leaching reagent consumption, energy consumption and waste generation that is difficult to separate (Sousa *et al.*, 2018). Particle size distribution analysis is, therefore, an important preliminary characterization step that provides essential information regarding the distribution of particles after crushing and grinding operations and assists in determining the sufficient particle size for subsequent processing stages

(Escalante *et al.*, 2025). Furthermore, grindability evaluation using Bond's work index method enables estimation of the required energy for grinding and hardness property of the ore (Sagzhanov *et al.*, 2025). This Bond work index is widely used in mineral processing to predict the specific energy requirement for the grinding process of the ores. It is represented by kilowatt-hour per ton to indicate the required work index to reduce a material from a theoretically infinite feed size to a product size where 80% passes through a specified screen aperture (Fan *et al.*, 2024). Previously, several researchers have investigated comminution behavior and grindability characteristics of various metallic ores using Bond's method (Yang *et al.*, 2016; Sousa *et al.*, 2018; Pérez-García, Bouchard and Poulin, 2020). These studies support that the work index values provide a valuable insight into ore hardness, grinding resistance, and expected power consumption during processing. Although several studies have reported the sieve analysis, grindability test and energy requirement of various metallic and sulfide ores, limited information is available regarding the comminution behavior of specific Yalo sphalerite deposit in Bauchi State, Nigeria. The lack in particle size distribution data, liberation size suitability limits the design and optimization of downstream beneficiation and hydrometallurgical extraction processes for the specific and other similar ores. Therefore, this study employed investigation of the particle size distribution, grindability characteristics, and specific grinding energy of Yalo sphalerite ore using sieve analysis, particle size characterization, and the modified Bond work index method. The study also provides a baseline comminution data required for process design and suitable grinding conditions for efficient beneficiation and extraction process of similar ores.

2. | Materials and Methods

2.1 | Sample Collection

The sphalerite ore investigated in this study was sourced from Yalo mining area, located at 9°44'23"N, 10°48'49"E within the Alkalari Local Government Area, Bauchi State, Nigeria. The particular area of mining covers a radius of 500 meter around the active mining pits, corresponding to an estimated surface area of about 0.785 km². The reference ore was also collected from host rock in radius of 500 meter to sphalerite ore mining pit.

2.2 | Material Preparation

The bulk ore was first crushed using Jaw crusher to reduce the particle size before the further grinding and homogenization process. To achieve a representative sampling, the crushed ore undergoes mixing and splitting procedures to ensure sample uniformity. The prepared sample was then subjected to grinding process using a ball mill grinding equipment at fixed time interval. The ground material was then homogenized before particle size analysis and grindability evaluation performed to minimize segregation effects and ensure representative sampling during subsequent analyses.

2.3 | Particle Size Analysis

Experimental procedures employed to evaluate particle size distribution, grindability, and comminution energy were as follows:

1. 100 g of sample from each test and reference ore are taken, crushed using Jaw crusher and pulverized.
2. The pulverized sample of the test and reference ore was subjected to sieving separately, with a number of size fractions using automatic sieve shaker for 10minutes.

3. Retain of each sieve size was collected, weighed, and the recorded under the “feed”.
4. The “feed” of test and reference samples were gathered and introduced into laboratory ball mill machine and ground for one hour.
5. The sample from the laboratory ball mill machine were subjected to sieving with different sieve fraction, weighed and recorded as “product”

Particle size analysis was conducted by arranging ten different sieve sizes from 1400 µm to - 63 µm(pan) based on the $\sqrt{2}$ sieve series (Das, 2015) and the sieving operation was carried out using an automatic sieve shaker for a fixed time duration. After sieving, the mass retained on each sieve was carefully measured using weighing balance, recorded, and used to calculate the cumulative percentage retained and cumulative percentage passing. Using semi-logarithmic particle size distribution curves, the resulting data were plotted to determine the 80% passing size. Following the particle size analysis, the ground sample was characterized to confirm the ground sample aligns with the particle size analysis result and to determine the percentage distribution of particles sizes within whole sample.

2.4 | Grindability Testing and Energy Estimation

Grindability test was conducted to evaluate the resistance of the sphalerite ore to the grinding process and estimate the energy required for comminution. The test was evaluated using the modified Bond work index method by comparing the grindability of Yalo sphalerite ore with a reference quartz ore under identical grinding conditions. Feed and product size distributions were determined for both ores, and the 80% passing sizes (F80 and P80) were obtained.

2.4.1 | Determination of Bond Work Index

The Bond work index was determined using the modified Bond equation expressed as:

$$W_i = W_{ir} * \frac{\left(\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}} \right)}{\left(\frac{10}{\sqrt{P_t}} - \frac{10}{\sqrt{F_t}} \right)} \quad (1)$$

Where:

W_i is Bond work index of the test ore (kWh/t)

W_{ir} is Bond work index of the reference ore (kWh/t)

P_r is 80% passing size of the reference ore product (µm)

F_r is 80% passing size of the reference ore feed (µm)

P_t is 80% passing size of the test ore product (µm)

F_t is 80% passing size of the test ore feed (µm)

2.4.2 | Comminution Energy Estimation

The specific comminution energy required for grinding the sphalerite ore was estimated using Bond's energy relationship:

$$E = W_i \left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right) \quad (2)$$

Where:

E is specific grinding energy (kWh/t)

W_i is Bond work index (kWh/t)

F_{80} is 80% passing feed size (µm)

P_{80} is 80% passing product size (µm)

3. | Results and Discussion

3.2 | Particle Size Analysis

The particle size analysis was employed to determine an appropriate grinding condition for sufficient mineral liberation while minimizing unnecessary energy consumption. The diagram in Figure 1 indicates, the cumulative retained and cumulative passing particle size distribution curves for the Yalo sphalerite ore. As shown in the diagram, the ore exhibits a relatively smooth particle size distribution, and according to (Wills and Finch 2016) well-distributed particle size profiles

generally, indicates effective size reduction during comminution process. The curves from cumulative retained and cumulative passing further suggests that approximately 180 μm represents a suitable grinding size for subsequent beneficiation and leaching processes. This particle size was therefore selected as the target grinding condition because it provides a balance between effective mineral liberation and practical grinding efficiency. Similar observations have been reported on literature for sulfide ores, where liberation sizes range between 100 and 200 μm are considered suitable for

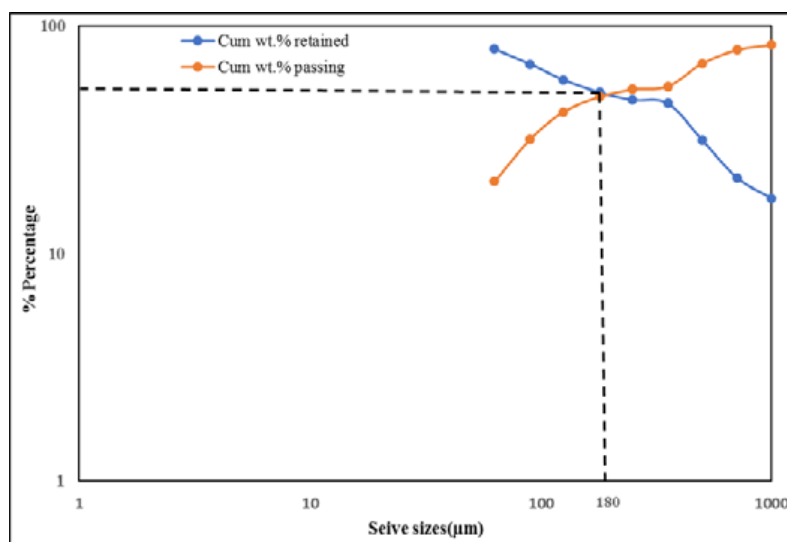


Figure 1 | Plot of cumulative percentage retained and cumulative percentage passing of sphalerite ore (product)

downstream beneficiation and hydrometallurgical processing (Fuerstenau and Han, 2003). On the other side, highly coarse particles often result insufficient liberation of target minerals, whereas ultrafine particles may also negatively affect downstream process (Sousa *et al.*, 2018).

3.2 | Particle Size Distribution characterization of Homogenized Ore

Following the particle size distribution analysis result, the ground and homogenized sample

was characterized to confirm and determine the distribution of each particle sizes within the whole sample. The particle size characterization results are diagrammatically presented in Figure 2 and it is indicated that approximately 90% of the particles are finer than 180 μm , confirming the effectiveness of the selected grinding condition and indicating a relatively narrow particle size distribution suitable for downstream processing. The obtained particle size parameters revealed x50 values between 60 - 63 μm , and x80 values between 153 - 156 μm , which indicates that the majority of the particles are

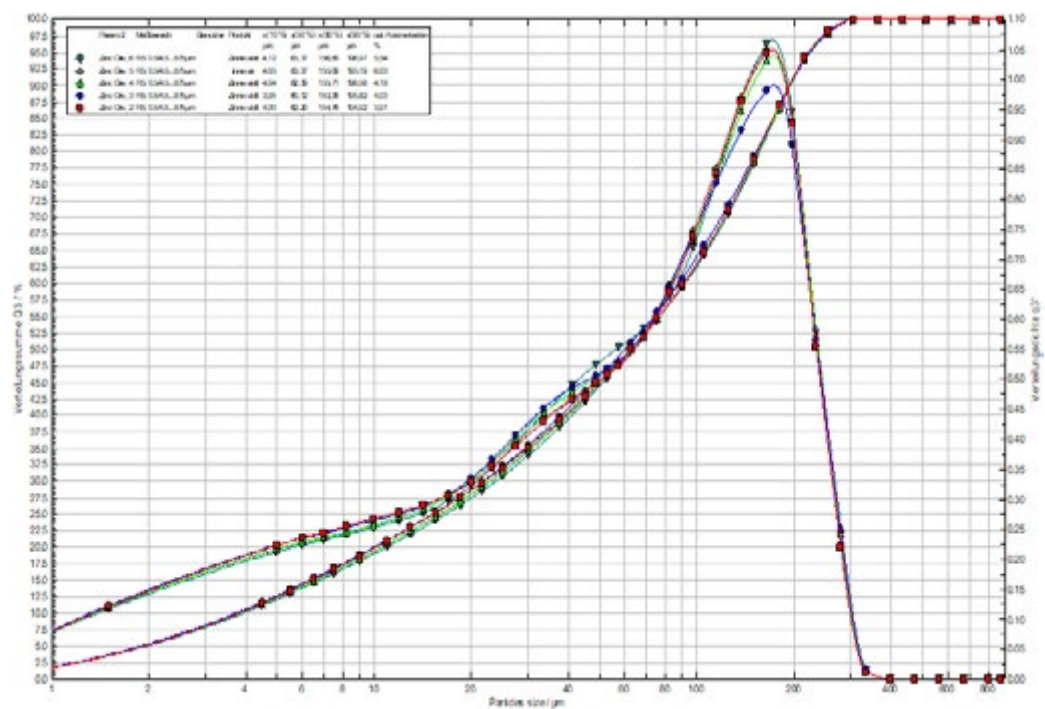


Figure 2 | Grain size distribution curve of homogenized sphalerite sample ready for leaching.

concentrated within the fine particle size below 180 μm .

The dominance of the particles being below 180 μm is advantageous for downstream beneficiation and hydrometallurgical processing, as sufficient liberation of sphalerite from associated gangue minerals is expected at specific range of particle size, which will simplify concentration processes, reduce reagent consumption and waste generation (Habashi, 1999). Furthermore, it will have direct influence on generation of sulfur passivation by enhancing reagent-mineral interaction and metal dissolution rates during leaching, while minimizing mass-transfer limitations and improving zinc recovery. Several studies support our conclusion on improved mineral liberation contribution to enhance the leaching kinetics and metal recovery (Bulatovic, 2007; Reyes *et al.*, 2018). However, ultrafine particle size may increase operating costs related to reagent cost and create difficulties in solid-liquid separation process (Wills and Finch, 2016). Therefore, the obtained particle size in this study appears to be suitable for downstream beneficiation and subsequent leaching

while avoiding the disadvantages associated with excessive coarse and overgrinding.

3.3 | Grindability

The grindability of the sphalerite ore was evaluated using the modified Bond work index approach shown in Equation1, by comparing the grinding behavior of the test ore with that of a reference quartz ore under identical grinding conditions. The calculated particle size parameters obtained from the particle size distribution analysis are presented in Table 1.

Table 1 | Summary of Obtained Values from Particle Size Analysis

Parameter	Value
F_i	664.3 μm
P_t	175.4 μm
F_r	341.5 μm
P_r	88.4 μm

The calculated Bond work index of the Yalo sphalerite ore was 18.52 kWh/t and quartz was used

as a reference ore with bond work index of 13 kWh/t (Adetula *et al.*, 2019). The obtained work index value shows moderate resistance to grinding and hardness and it falls within the typical industrial range reported for sulfide ores previously (Leon, Hogmalm and Bengtsson, 2020). From an industrial process perspective, the obtained Bond work index provides useful information as the moderate work index suggests that, the ore can be processed using non advanced crushing and grinding systems without exceptional high-power requirements. The obtained work index value is compatible with the range commonly reported for some sulfide and base-metal ores. For Instance, (Leon *et al.*, 2020) reported that Bond work index values of sulfide ore usually falls in the range between 10 and 25 kWh/t depending on mineralogical composition and texture. Similarly, (Yang *et al.*, 2016) concludes that the value of work index is strongly affected by mineral associations, grain boundaries, and liberation between minerals and gangue phases.

3.4 | Comminution Energy Requirement

Depending on the Bond work index analysis, the specific comminution energy required to reduce the Yalo sphalerite ore to the target particle size was estimated using Bond's energy formula in equation 2. The calculated result for the estimation of energy requirement was 7.14 kWh/t, indicating that the target liberation size can be achieved with moderate energy consumption. This result provides important information for industrial processing because comminution by itself is one of the largest energy-consuming stage in mineral processing plants (Ballantyne and Powell, 2014). The moderate energy requirement observed in Yalo sphalerite ore suggests that adequate mineral liberation can be achieved without excessive power consumption, which will improve economic feasibility of downstream beneficiation and simplify the hydrometallurgical processing. According to (Napier *et al.* 1996), reducing grinding energy while maintaining

adequate liberation is one of the primary objectives of efficient comminution circuit design.

4. | Conclusion

In this research, the particle size distribution, grindability characteristics, and comminution energy requirement of sphalerite ore were evaluated by employing sieve analysis, characterization of particle size, and the modified Bond work index method. From the particle size analysis, less than 180 μm is selected gridding size for further extraction process. After grinding the sample based on the result from sieve analysis, Particle size characterization was employed and 90% of the particles were confirmed to be finer than 180 μm , and from this 20% of distributed particle is below 10 μm , and 70% is below 100 μm . The estimated the work index for Yalo sphalerite was calculated to be ~ 18.52 kWh/t. The comminution energy requirement for particle size reduction was also estimated to be ~ 7.14 kWh/t, which indicates the Yalo sphalerite ore exhibits moderate resistance to grinding and it is in an acceptable industrial energy demand.

Authors Contribution Statement

Haile, Michael Girma conducted the laboratory experiments, with technical and theoretical support of Saliu Ojo Seidu, Fatai Olufemi Aramidea, Alabi Oladunni Oyelola. All authors read and approved the final version.

References

- Adetula .V, Ozah B, Alabi O, John A, Akoja A. (2019). Determination of Work Index for Iperindo Lode Gold Deposit at Ilesha Goldfield Osun State, Nigeria Using Modified Bond Index. *American Journal of Materials Synthesis and Processing*. 4, 37–42. <https://doi.org/10.11648/j.ajmsp.20190401.15>
- Ballantyne, G.R. and Powell, M.S. (2014). Benchmarking comminution energy consumption for the processing of copper and gold ores. *Minerals Engineering*, 65, 109–114. <https://doi.org/10.1016/j.mineng.2014.05.017>
- Das, S. (2015). Quantitative mineralogical characterization of chrome ore beneficiation plant tailing and its beneficiated products. *International Journal of Minerals, Metallurgy, and Materials*, 22, 335–345. <https://doi.org/10.1007/s12613-015-1078-y>
- Escalante, P., Oliva, J., Anticoi, H., Sampaio, C. H., and Mohanty, K. (2025). Characterization of mineralogical impurities in a carbonate-rich material using MLA. *Minerals Engineering*, 230, 109409. <https://doi.org/10.1016/j.mineng.2025.109409>
- Fan, Y., Zhang, G., Li, S., Zhang, L., Guo, J., and Feng, C. (2024). Mineral Liberation and Concentration Characteristics of Apatite Comminuted by High-Pressure GRU. *Minerals*, 14(11). <https://doi.org/10.3390/min14111148>
- Habashi, F. (1999). Textbook of Hydrometallurgy. *Métallurgie Extractive Québec*. *Minerals Engineering* 13(13) [https://doi.org/10.1016/S0892-6875\(00\)00127-8](https://doi.org/10.1016/S0892-6875(00)00127-8)
- Hamid, S. A., Alfonso, P., Oliva, J., Anticoi, H., Guasch, E., Sampaio, C. H., Garcia-Vallès, M., and Escobet, T. (2019). Modeling the liberation of comminuted scheelite using mineralogical properties. *Minerals*, 9(9). <https://doi.org/10.3390/min9090536>
- Leon, L. G., Hogmalm, K. J., and Bengtsson, M. (2020). Understanding mineral liberation during crushing using grade-by-size analysis—a case study of the penuota sn-ta mineralization, spain. *Minerals*, 10(2). <https://doi.org/10.3390/min10020164>
- Napier-Munn, T.J., Morrell, S., Morrison, R.D. and Kojovic, T. (1996). Mineral Comminution Circuits: Their Operation and Optimization. *Minerals Engineering*, 10(3), 349–350. [https://doi.org/doi:10.1016/S0892-6875\(97\)00011-3](https://doi.org/doi:10.1016/S0892-6875(97)00011-3)
- Pérez-García, E. M., Bouchard, J., and Poulin, É. (2020). A mineral liberation distribution estimator for monitoring and process control applications. *Powder Technology*, 367, 527–538. <https://doi.org/10.1016/j.powtec.2020.04.002>
- Reyes, F., Lin, Q., Cilliers, J. J., and Neethling, S. J. (2018). Quantifying mineral liberation by particle grade and surface exposure using X-ray microCT. *Minerals Engineering*, 125, 75–82. <https://doi.org/10.1016/j.mineng.2018.05.028>
- Sagzhanov, D., Ito, J., Altansukh, B., Godirilwe, L. L., Haga, K., Takasaki, Y., and Shibayama, A. (2025). Lithium Ore Beneficiation: Sustainable Approaches for Efficient Recovery of Lithium from a Low-Grade Spodumene Ore. *Journal of Sustainable Metallurgy*, 11(2), 754–772. <https://doi.org/10.1007/s40831-025-01086-3>
- Sousa, R., Simons, B., Bru, K., de Sousa, A. B., Rollinson, G., Andersen, J., Martin, M., and Machado Leite, M. (2018). Use of mineral liberation quantitative data to assess separation efficiency in mineral processing – Some case studies. *Min-*

erals Engineering, 127, 134–142.

<https://doi.org/10.1016/j.mineng.2018.08.004>

Wills, B.A. and Finch, J.A. (2016). Wills' Mineral Processing Technology. 8th Edition. Butterworth-Heinemann.

Yang, X., Laukkanen, J., Torppa, A., Enkhzul, B., Lkhagvasuren, B., and Margai, D. (2016). Chapter 25 - Mineralogy and Beneficiation of Vein-Type Apatite Rare Earth Element Ore from Mushgia Khudag, Mongolia. In I. Borges De Lima and W. Leal Filho (Eds.), *Rare Earths Industry* (pp. 377–392). Elsevier. <https://doi.org/10.1016/B978-0-12-802328-0.00025-5>

Zhang, J., and Subasinghe, N. (2016). Development of a flotation model incorporating liberation characteristics. *Minerals Engineering*, 98, 1–8. <https://doi.org/10.1016/j.mineng.2016.05.021>.

