EVALUATION OF ORE CRUSHING AND GRINDING PERFORMANCE FOR LITHIUM RECOVERY FROM UDAWA PEGMATITE KADUNA STATE

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History
Received: 14/01/2025
Accepted: 22/04/2025
Published: 30/05/2025

ABSTRACT

This study evaluates the crushing and grinding performance for lithium recovery from the Udawa pegmatite deposit in Kaduna State, Nigeria. The primary objective was to determine the optimal conditions for comminution to liberate lithium-bearing minerals. Ore characterization, including mineral liberation size, modal mineralogy and textural properties, was carried out using various laboratory techniques. Crushing was initially performed using the BICO Braun Chipmunk VD67 Jaw Crusher, followed by grinding in the SEPOR Ball Mill. The grindability and work index of the ore were determined to assess the ease of grinding and energy requirements for size reduction. Particle size analysis, using sieve analysis and SEM-EDX, revealed that an optimal mill speed of 15 RPM (300 revolutions) achieved the desired particle size of 1151 µm with 80% passing. The work index was calculated at 14.43 kWh/ton, indicating moderate energy consumption for grinding. The lithium content of the ore was found to peak at 3.63% in the -250 μm to +125 μm size range, suggesting that finer grinding would enhance lithium liberation. The study concludes that efficient grinding at 300 RPM is optimal for lithium recovery, and further exploration of beneficiation methods, including flotation and concentration, is recommended for maximizing recovery.

Keywords: Lithium recovery, Udawa pegmatite, comminution, grindability, work index, particle size analysis, SEM-EDX, beneficiation.

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1 | Introduction

The characterization of ore and plant feeds is essential in modern digital mine planning, plant design and mineral processing operations. Textural parameters such as mineral liberation size, mineral association, and modal mineralogy significantly influence the processing conditions and recovery rates (Gu, 2003). Developing an effective process flowsheet, a critical component of mineral processing plants, requires extensive laboratory investigations and pilot plant trials. The selection of equipment and operating conditions is based on empirical data and practical experience, while scaling up from pilot plant to full-scale commercial operation involves careful consideration of factors such as equipment size, operating conditions, and process control (Prasad, 2007). Plant layout also plays a crucial role in mineral processing, needing to be designed within the constraints of available space, topography, and

https://doi.org/10.51459/jostir.2025.1.1.012

integration with other plants. It must ensure efficient material flow, minimize transportation costs, and allow sufficient space for equipment maintenance and repair (Prasad, 2007).

In mineral processing plants, various sections and units are developed based on careful metallurgical tests, and these units are systematically integrated into a single, efficient flowsheet to produce mineral concentrates and other products (Shoemaker, 2003). The design of a processing plant necessitates the creation of a detailed design criteria document, which includes information on ore characteristics, mining plans, operational capacity, comminution tests, recovery tests, and equipment selection (Ajaka, 2015). As minerals of interest are often chemically and physically bound with the host rock, mineral processing aims to remove unwanted gangue to increase the concentration of valuable minerals in an economically viable manner. One of the greatest challenges in mineral processing is to consistently produce high-grade concentrates with maximum recovery from the ore body. To quantify recovery, it is essential to have a clear understanding of the initial concentration of minerals in the ore, which requires reliable sampling procedures to represent the ore body accurately (Gupta & Yan, 2006).

Nigeria is home to a diverse array of industrial minerals, including abundant lithium-bearing pegmatites. Lithium minerals found in Nigeria's pegmatites include spodumene, lepidolite, kunzite, amblygonite, and petalite, with many more potentially undiscovered deposits (Goodenough, 2021). These lithium resources, when appropriately exploited, could significantly contribute to the country's national income and economic development. Characterizing and assessing the lithium content of these pegmatites, such as those in the Udawa deposit in Kaduna State, is vital for optimizing extraction methods and maximizing the economic potential of these mineral resources.

2.0 | Materials and Methodology

The materials and methods employed for crushing and comminution in the study of lithium recovery from the Udawa pegmatite ore were designed to effectively reduce the ore to a suitable particle size for further beneficiation. The Jaw Crusher (BICO Braun Chipmunk VD67) was used as the primary equipment for initial ore crushing, while the SEPOR Ball Mill (8″ ID x 9.75”) and Wilfley Shaking Table played a critical role in liberating and concentrating the lithium-bearing minerals. The SEPOR 8.9 x 8.3 Jones Riffler and the SEPOR W.S TYLER RO-TAP 12" Endecotts sieve set and shaker were used for sample preparation and particle size classification, which are essential in determining the optimal conditions for beneficiation. To assess the physical properties of the ore, the Okhard 2000 Universal Testing Machine (UTM) was employed, and the HKNC-500 Multifunctional Laboratory Rock Cutting Machine was used for sample sectioning in Mining Engineering Lab FUTA. All equipment and materials were used following specific procedures to ensure the reliability and reproducibility of the results in the assessment of lithium content and optimization of recovery from the Udawa pegmatite deposit.

2.1 | Sample Preparation for Grindability Test

The crushed samples were prepared through extensive coning and quartering method, from which a sample size weighing 40 kg was obtained which was further homogenized by the use of a Jones Riffle Sampler, dividing the sample into two equal parts. A small sample weight was used for particles size analysis and the remaining sample

https://doi.org/10.51459/jostir.2025.1.1.012

kept for the various experimental tests in this research.

2.2 | Grindability and Work Index Determination Test

Grinding was carried out as grindability test with Jaw crusher product using SEPOR 8″ ID x 9.75 Stainless Steel Ball Mill. The grindability tests were carried out to determine the Bonds work index for the ore and thus the ease of grinding the ore. The media assisted tests were carried out with 45% media (ball) charge (Wills, 2016). The constant mass of 500 g was used in the entire grinding test. The tests were carried out with +250 um size using the constant mass charge by addition of difference with the SEPOR Stainless Steel Ball Mill at speed of 100, 200, 300 and 400 Revolutions, i.e 5, 10, 15 and 20 revolution per minute (RPM) respectively. The content of the mill was discharge and weighed after each run. The sieve size analysis of the product was carried out and the weight of material retained on each sieve was measured with a digital weighting machine SEPOR HCB 1002 weighing Balance and the cumulative percent mass passing each sieve size was calculated. The cumulative percent mass passing each sieve size was plotted against particle size to determine the 80% passing size. The -250 µm fraction of the product was remove and new feed equivalent to its weight added for another run. The grindability for each mill speed was repeated twice and the average value recorded. The grindability was calculated using (Equation 1). The average grindability was calculated and used to determine the work index employing Bond's

$$G = \frac{Weight\ (W_{250})}{Numberofrevolution} \quad (1)$$

Model.

Bond work index (BWI - *w*i) was determined using the expression in Equation 1

$$(W_i) = \frac{44.5}{P_1^{0.23} X G^{0.82} (\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}})} \quad (2)$$

where Pi is the aperture of the limiting screen (um),

G is the net mass of screen undersize produced per mill revolution (g),

P is the d_{80}size of the mill product (um), and

F is the d_{80} size of the mill feed (um).

3.0 | Results And Discussion

3.1 | Particle Size Analysis

Fractional Sieve analysis was adopted to determine the particle size distribution and liberation size of Udawa lithium ore. Approximately 500 g sample of the ground head sample was weighed and charged onto the upper sieve (5000 µm) of set of sieves ranging from 5000 – 45 µm arranged to conform with √2 series (Wills, 2016). The set of sieves was agitated for 30 minutes using Endecotts sieve shaker such that undersize particles fall through successive sieves until they are retained on a sieve having an aperture less than the particles diameters (Wills, 2016). After agitation, the sieves were separated and weight retained on each sieve was measured and recorded. The result obtained was used to plot a log – log graph of percentage cumulative retained and passing against sieve sizes.

3.2 | Liberation size analysis

The liberation size of the minerals in the ore samples was determined from the results of Scanning Electron Microscopy/Energy Dispersive X-ray (SEM-EDX) morphology micrographs and particle size assay analysis. The aim of the liberation test was to determine the particle size at which the valuable minerals are completely free

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from the gangues which was very useful for the design of comminution and concentration processes.

Table 1 shows a result of particle size analysis after crushing to 80% passing, the crushed material is 1197.21 microns. The effect of grinding is better explained with the result of grindability test. The crushing result show that the ore require an average energy for communition and this can be done at relatively low cost.

Sieve analysis results are presented in Figure 1- 5 present the results of the particle size analysis for the grinding test by addition of difference at 100, 200, 300 and 400 revolutions. The 80% passing was determined from Figures 1 - 5 as shown in Table 1. This, implies that due to continuous grinding operation where grains get weaker internally and at the peripheral after each revolution.

From Table 1 the grinding process is influenced by

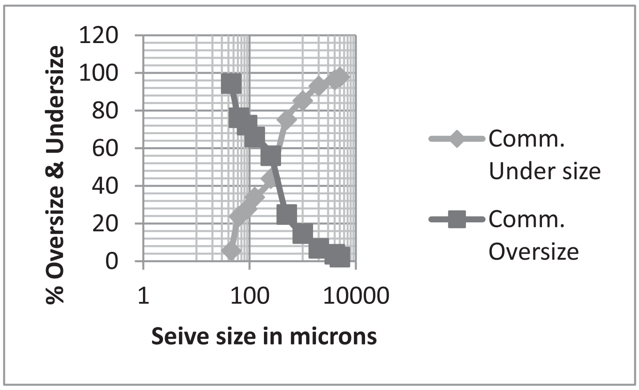

Figure 1 | Plot of Cumulative % Weight Retained and Passing against Sieve Size (μm) after crushing

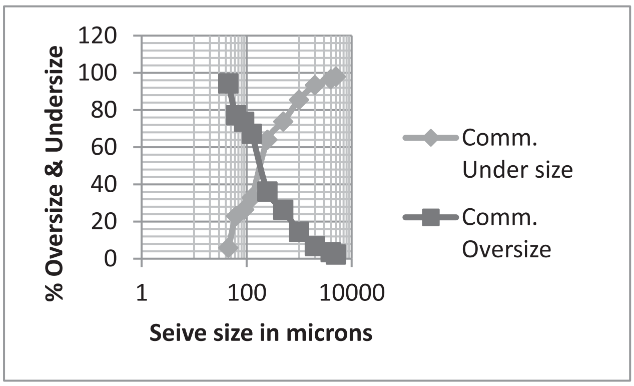

Figure 2 | Plot of Cumulative % Weight Retained and Passing against Sieve Size (μm) Milled at 100 Revolutions

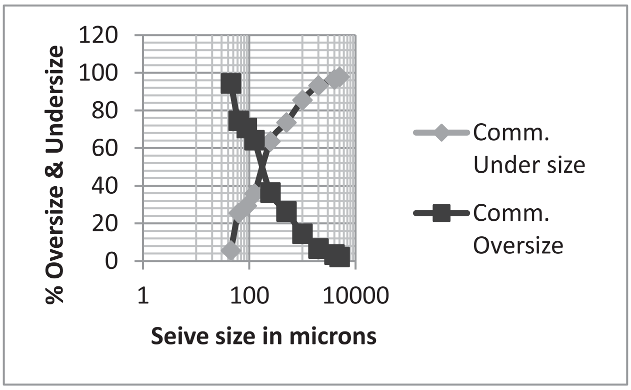

Figure 3 | Plot of Cumulative % Weight Retained and Passing against Sieve Size (μm) Milled at 200 Revolution

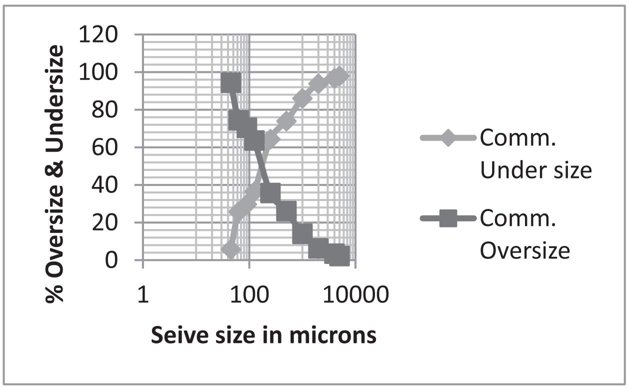

Figure 4 | Plot of Cumulative % Weight Retained and Passing against Sieve Size (μm) Milled at 300 Revolution

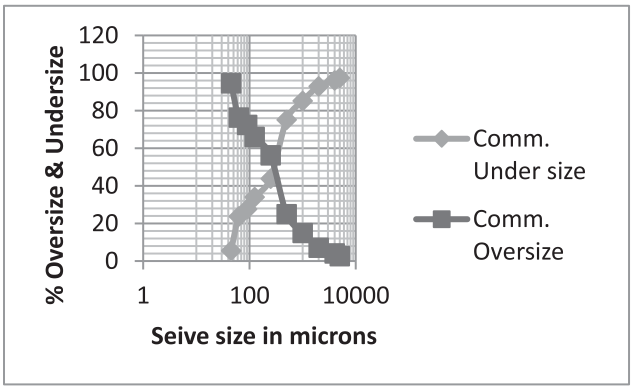

Figure 5 | log-log plot of cumulative % weight retained and passing against sieve size (μm) Milled at 400 Revolution

https://doi.org/10.51459/jostir.2025.1.1.012

Table 1 | 80% Passing Size for Selected Mill Speed

No. of Revolution	Mill Speed (RPM)	80 Percent Passing
100	5	1160μm
200	10	1168μm
300	15	1151μm
400	20	1203μm

the number of revolutions and mill speed. The data suggests that increasing the number of revolutions and mill speed does not necessarily lead to a consistent decrease in particle size. Instead, the 80% passing size fluctuates, indicating that other factors are at play. The highest 80% passing size (1203 μm) was observed at 400 revolutions, which may indicate over-grinding at this stage. On the other hand, the lowest 80% passing size (1151 μm) was observed at 300 revolutions, suggesting that this may be the optimal point for achieving the desired particle size distribution. Based on the data, the optimal mill speed for grinding appears to be 15 RPM (300 revolutions), as it resulted in the lowest 80% passing size. This suggests that operating the mill at this speed will provide the most efficient grinding process. Further investigation into the effects of feed rate, grinding media size, and material properties is warranted to fully understand the grinding process and optimize its performance.

3.3 | Results of Grindability Test and Work Index Determination

Grindability test results are presented in Table 1, utilizing Equation 1, for 100 to 400 revolutions at 20-minute intervals. The addition of difference mode is applicable in continuous grinding operation where grains get weaker internally and at the peripheral after each revolution. Although the tests were carried out at +250 microns, the results can be applied to grinding to finer sizes, especially in regrind mills. From the result, the grindability values decrease sharply with increasing number of revolutions as shown in Figure 3. The grindability value represents the ease of grinding a material. A lower value indicates easier grinding, while a higher value indicates more resistance to grinding. Based on the provided data, the better grindability value for communication in mineral processing would be the lowest value, which is 540,000 g/ton/rev. This indicates that the material with this grindability value is the easiest to grind and process (Kumar *et al.,* 2024).

The ball mill work index of the ore was calculated using Equation 2 which gives 14.43 kWh/ton. The work index is a measure of the energy required to reduce the size of the material through grinding or crushing. It is an important parameter in mineral processing and is used to determine the power required for size reduction operations (Peltoniemi *et al.,* 2020). This is very significant because energy is very expensive and grinding is the most energy intensive operation in mineral beneficiation (Alabi *et al.*, 2016).

Table 2 | Grindability Test Result

Mill Speed RPM	Mass produced (g)		Grindability		Average g/rev
	1st	2nd	1st	2nd	
5	367.0	366.9	3.67	3.66	3.665
10	367.3	366.8	1.83	1.83	1.83
15	320.6	321.5	1.09	1.07	1.08
20	219.0	215.0	0.55	0.53	0.54
		Average			**1.77875**

3.4 | Findings

Comminution tests, including particle size distribution and grindability analyses, revealed that an optimal mill speed of 15 RPM (300

https://doi.org/10.51459/jostir.2025.1.1.012

revolutions) produced a particle size of 1151 µm with 80% passing. Grindability tests quantified the ore's work index at 14.43 kWh/ton, which corresponds to efficient lithium liberation, particularly in the -250 µm to +125 µm size range, where lithium content peaked at 3.63%.

4.0 | Conclusion and Recommendation

The study on the evaluation of ore crushing and grinding performance for lithium recovery from the Udawa pegmatite, Kaduna State, has provided critical insights into the comminution and beneficiation of lithium-bearing minerals. The particle size distribution and grindability analysis of the ore indicate that an optimal mill speed of 15 RPM (300 revolutions) produced the finest particle size, with an 80% passing size of 1151 µm. This finding suggests that 300 revolutions is the optimal point for achieving a suitable particle size distribution for lithium recovery, and operating the mill at this speed ensures efficient grinding.

The grindability test results, quantified by the work index of 14.43 kWh/ton, revealed that the ore requires moderate energy for size reduction, implying that lithium liberation can be achieved with relatively low energy input compared to other ore types. Furthermore, the ore exhibited its highest lithium content (3.63%) in the -250 µm to +125 µm size range, which is crucial for the efficient concentration of lithium during mineral processing.

The laboratory-based results should be confirmed through pilot plant trials to assess the scalability and practical application of the findings in large-scale operations. Further investigation should be conducted on other parameters such as feed rate, grinding media size, and ore hardness to fine-tune the grinding process for optimal lithium recovery. Given the high energy cost associated with grinding, continuous efforts should be made to optimize the milling process to reduce energy consumption while maintaining high recovery rates. Environmental impact assessments should be carried out to evaluate the sustainability of the lithium extraction process and ensure that waste management practices are in place to mitigate any potential negative effects.

Acknowledgement

I would like to express my sincere gratitude and also appreciate the insightful comments and suggestions of the pre-paper reviewers, which significantly enhanced the quality of the manuscript. Special thanks are extended to Prof. E.O. Ajaka (Department of Mining Engineering, Federal University of Technology Akure, Nigeria), Prof. A.O. Adebayo (Department of Chemistry, Federal University of Technology Akure, Nigeria), and Dr. O.O. Alabi (Department of Metallurgical and Materials Engineering, Federal University of Technology Akure, Nigeria) for their invaluable guidance, technical input, and support throughout the research. Lastly, I acknowledge the Federal University of Technology Akure for providing the necessary resources and conducive environment for this work to be completed.

References

Ajaka, E. O., Chukwuna O..C (2015). Promax2100: A computer programme for design and optimization of mineral processing plant. *Journal of Engineering and Engineering Technology FUTAJEET*, vol 7 (II).

Alabi, O.O. (2016). Development of a process

https://doi.org/10.51459/jostir.2025.1.1.012

route for the beneficiation of Gyel columbite ore Gyel Village Jos South Local Government Area of Plateau state to metallurgical grade; Department of Metallurgical and Materials Engineering Ahmadu Bello University (Ph.D Thesis), Zaria.Pp 74 – 140.

Goodenough, K. (2021). *Lithium-bearing Pegmatites in Nigeria: Exploration and Mining Potential*. Journal of Geological Studies.

Gu, Y., 2003. Automated scanning electron microscope based mineral liberation analysis. *Journal of Minerals and Materials Characterization and Engineering 2, 33–41.*

Gupta and Yan (2006). Mineral Processing Design and Operation, Perth, Australia, January 2006.

Gupta, A., & Yan, D. (2006). *Mineral Processing Design and Operation: An Introduction*. Elsevier.

Kumar, R., Thakur, A. K., Chaudhari, P., & Kancharlapalli, C. P. (2024). Nanoparticle preparation of pharmaceutical compounds via wet milling: Current status and future prospects. Powder Technology, 467, 113-123.

Mohr, S. H., Mudd, G.M. and Giurco, D. (2012). Lithium resources and production: a critical global assessment and global projections. Mineral 2. 65-84.

Peltoniemi, M., et al. (2020). *Work Index and Energy Consumption in Mineral Processing*. International Journal of Mining Science and Technology.

Prasad, R. (2007). *Mineral Processing Plant Design: Fundamentals and Applications*. Wiley.

Shoemaker, W. (2003). *Mineral Processing and Metallurgy: Unit Operations*. McGraw-Hill.

Wills, B.A. (2016). *Wills' Mineral Processing Technology: An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery* (8th ed.). Elsevier.

https://doi.org/10.51459/jostir.2025.1.1.012