engineering proceedings

Proceeding Paper

Grindability, Energy Requirements and Gravity Separation of Quartz from Blast Furnace Ironmaking Slag by Shaking Table and Falcon Concentrator †

Itumeleng Kohitlhetse [1,*], Hilary Rutto [1], Kentse Motsetse [1] and Malibongwe Manono [2]

[1] Clean Technology and Applied Materials Research Group, Department of Chemical and Metallurgical Engineering, Vaal University of Technology, Private Bag X021, Vanderbijlpark 1911, South Africa; email1@email.com (H.R.); email2@email.com (K.M.)
[2] Centre for Minerals Research, Department of Chemical Engineering, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa; email3@email.com (M.M.)
* Correspondence: itumelengk@vut.ac.za; Tel.: +27-16-950-7869
† Presented at the 2nd International Electronic Conference on Processes: Process Engineering—Current State and Future Trends (ECP 2023), 17–31 May 2023; Available online: https://ecp2023.sciforum.net/.

Abstract: This study aims to evaluate the grindability and energy requirements for the liberation of quartz from blast furnace ironmaking slag. Furthermore, the study investigates the efficiency of gravity concentration method by using a shaking table and Falcon concentrator for the separation of quartz from the slag. The grindability of the slag was evaluated using the Bond's Work Index (BWI) method. The energy required for the liberation of quartz was determined using a Modified Bond's Work Index (MBWI) method. The results showed that the BWI of the slag was 13.5 kWh/t and the MBWI of the quartz was 22.3 kWh/t. Gravity separation tests were carried out using a shaking table and a Falcon concentrator. The results showed that the shaking table was able to recover 91.2% of the quartz with a grade of 99.5% SiO_2. The Falcon concentrator was able to recover 98.3% of the quartz with a grade of 99.7% SiO_2. In contrast, the study found that the quartz in blast furnace ironmaking slag can be physically separated using gravity separation techniques such as shaking table and Falcon concentrator. The study also provides valuable information on the grindability and energy requirements for the liberation of quartz from the slag, which can be used in the development of more efficient separation processes.

Keywords: ironmaking slag; grinding energy requirements; shaking table concentrator; falcon gravity concentrator; physical separation of quartz

Citation: Kohitlhetse, I.; Rutto, H.; Motsetse, K.; Manono, M. Grindability, Energy Requirements and Gravity Separation of Quartz from Blast Furnace Ironmaking Slag by Shaking Table and Falcon Concentrator. *Eng. Proc.* **2023**, *5*, x. https://doi.org/10.3390/xxxxx

Published: 17 May 2023

1. Introduction

Ironmaking slag is a by-product of the iron and steelmaking industry, and it is a significant source of environmental pollution due to its high content of heavy metals and unreacted minerals [1]. Quartz is one of the most abundant minerals present in ironmaking slag, and its removal from the slag is crucial for environmental and economic reasons. Gravity separation techniques have been widely used for the separation of quartz from ironmaking slag, and recent studies have shown that shaking table and Falcon concentrator are effective methods for this purpose [2,3].

The grindability of quartz is an essential parameter in the gravity separation of quartz from ironmaking slag. Grindability refers to the ease with which a material can be ground to a specified size for further processing. Several studies have investigated the grindability of quartz, and it has been shown that the Bond work index (BWI) is an appropriate measure of the grindability of quartz. The BWI is defined as the energy required to reduce a unit mass of material from an initial size to a final size, and it is typically measured using a standard laboratory ball mill [4,5].

Gravity separation techniques rely on the differences in the densities of the minerals present in the feed material. The energy requirements for gravity separation depend on several factors, including the specific gravity of the minerals, the particle size distribution, and the feed rate. Several studies have investigated the energy requirements for gravity separation of minerals, and it has been shown that the energy required for separation decreases with increasing particle size and feed rate [6,7].

Shaking table and Falcon concentrator are two gravity separation techniques that have been widely used for the separation of quartz from ironmaking slag. The shaking table is a simple and effective method for the separation of minerals based on their specific gravity, while the Falcon concentrator uses centrifugal force to separate minerals with different densities. Several studies have shown that shaking table and Falcon concentrator are effective methods for the separation of quartz from ironmaking slag, and these techniques have the potential to be used on an industrial scale.

A major use of the Bond's Work Index (BWI) model is to select the size of a grinding mill for a given duty. A variety of correction factors (CF) have been developed to adapt the Bond formula to situations not included in the original calibration set and to account for relative efficiency differences in certain comminution equipment. Most relevant are the CF1 factor for coarse feed and the CF2 factor for fine grinding that attempt to allow for sizes ranges beyond the bulk of the original calibration data set [8]. The equation that Bond developed is as follows:

$$W = \frac{W_i\sqrt{100}}{\sqrt{P}} - \frac{W_i\sqrt{100}}{\sqrt{F}} \tag{1}$$

And its simpler form is denoted as follows:

$$W = 10. W_i(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}) \tag{2}$$

where W is predicted mill energy consumption (kWh/ton), W_i is the work index (kWh/ton), 100 comes from 100 μm which is the product size in the definition of Work Index while P and F are representing 80% passing sizes in micrometres of the feed and the product respectively.

The Work Index equation is depicted as follows:

$$W_i = \frac{4.45}{P_i^{0.23} G^{0.82} \left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}\right)} \tag{3}$$

where P_i is the aperture of the limiting screen in micrometres (μm). G is the net mass of screen undersize produced per mill revolution (g).

2. Materials and Methods

2.1. Materials

A calcium-rich blast furnace ironmaking slag was made available by ArcelorMittal South Africa, Vanderbijlpark Works. The sample was received in lumps of rocks and underwent crushing and grinding stages. A pilot scale of a jaw crusher and a grinding mill were used for comminution of ironmaking slag. Furthermore, a laboratory scale shaking table and Falcon gravity concentrator for gravity separation of quartz in high silica ironmaking slag. In addition, a filter press connected to air compressor were also used for solid-liquid separation after the gravity separation experiments were done. Furthermore, samples were analysed by using X-ray Flourescence (XRF).

2.2. Methods

1 kg of the sample material was weighed out and screened for 15 min with a top size screen of 2000 μm and a closing screen of 75 μm with a pan. Thereafter, the screened material was milled for 15 min. This was designated as the first grind cycle material. The first grind cycle material was screened for 15 min and each size fraction was weighed and recorded. This procedure was repeated for three (3) more cycles. The end result was four (4) grind cycles and four (4) screened measurements.

3. Results and Discussion

Bond's Work Index and power draw calculations for ironmaking slag.

Table 1 shows results of work indices calculated for the slag with assumed work indices of 24.9 kWh/t and 13.8 kWh/t values. The reason is due to these extremes being the typical values for blast furnace ironmaking slag grindability. The highest calculated work index value is 6.882 kWh/t resulting from the fourth grind cycle with the least number of mill revolutions per minute. While tumbling mills have been designed to a high degree of mechanical efficiency and durability, energy expenditure is highly inefficient because the ore is frequently broken as a result of regular, unpredictable impacts that break both liberated and unliberated particles. Since the main purpose of grinding in mineral processing is the correct degree of release, this procedure is often used to increase the surface area of the precious minerals, although they may already be essentially released from the gangue. Power draw is related directly to mill length, and, empirically to the diameter to the power 2.34. Power draw is directly related to mill speed (in rpm. or, fraction of critical speed) over the normal operating range. Rod mills commonly operate with a volume charge of 35–40%, which during operation becomes a charge of 40–50%, with the bulk density slightly lower than that of the stacked rods.

Table 1. Bond's Work Index and breakage power calculations for ironmaking slag.

Grind Cycle	F_{80}	P_{80}	W at W_i = 24.9	W at W_i = 13.8	P_{Draw} at W_i = 24.9	P_{Draw} at W_i = 13.8
1	2000	900	0.8050	0.9345	2.9453	2.7895
2	2000	1400	1.087	0.6020	3.2675	1.8094
3	2000	1000	2.306	1.2780	6.9264	3.8384
4	2000	400	6.882	3.8140	20.6554	11.4472

The effect of particle size on removal of quartz from ironmaking slag by Falcon concentrator.

Figure 1 is the representation of XRF analyses for quartz separation by means of falcon concentration. The graph shows the mass in percentage of quartz which was recovered in both the overflow and underflow at different particle sizes. More quartz is found is overflow compared to the underflow. It's only at the particle size of −212 + 150 μm where more quartz reported at the underflow than in the overflow. At −106 + 75 μm particle size, most quartz was found in the overflow than in any of the particle sizes. −212 + 150 μm particle size recorded the lowest quartz recovery than any of the particle size. In the underflow stream, more quartz was found in the −106 + 75 particle size than in any of the particle size. Least quartz recovery was at −150 + 106 particle size in the underflow stream.

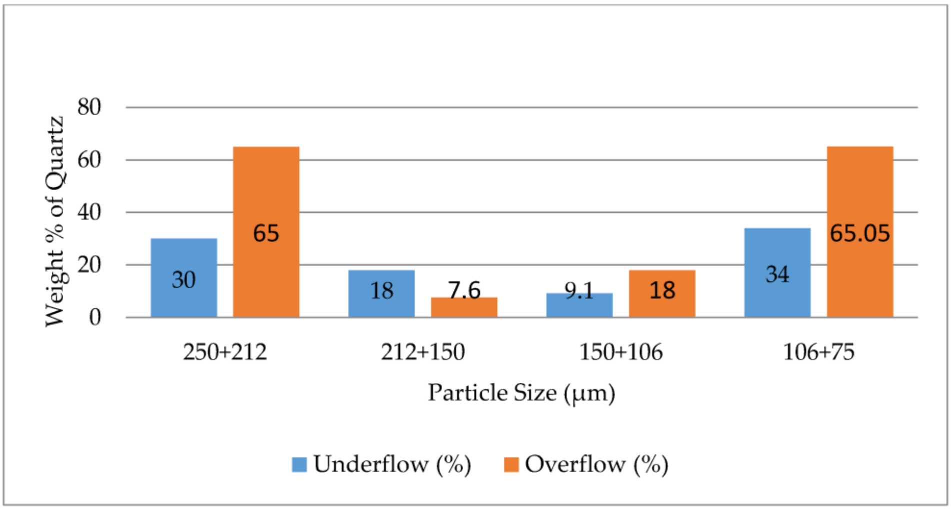

Figure 1. Weight percentage of quartz in underflow and overflow streams of Falcon concentrator.

The effect of particle size on separation of quartz from ironmaking slag by shaking table.

In Figure 2, it can be seen that most of silica was removed in the tailings. This is because silica have a specific gravity of 2.65 kg/m^3 and it is normally expected to report in the middlings and concentrate (heavy particles). From the result it shows that the particle size and the flow rate does not affect thesilica removed in the particles.

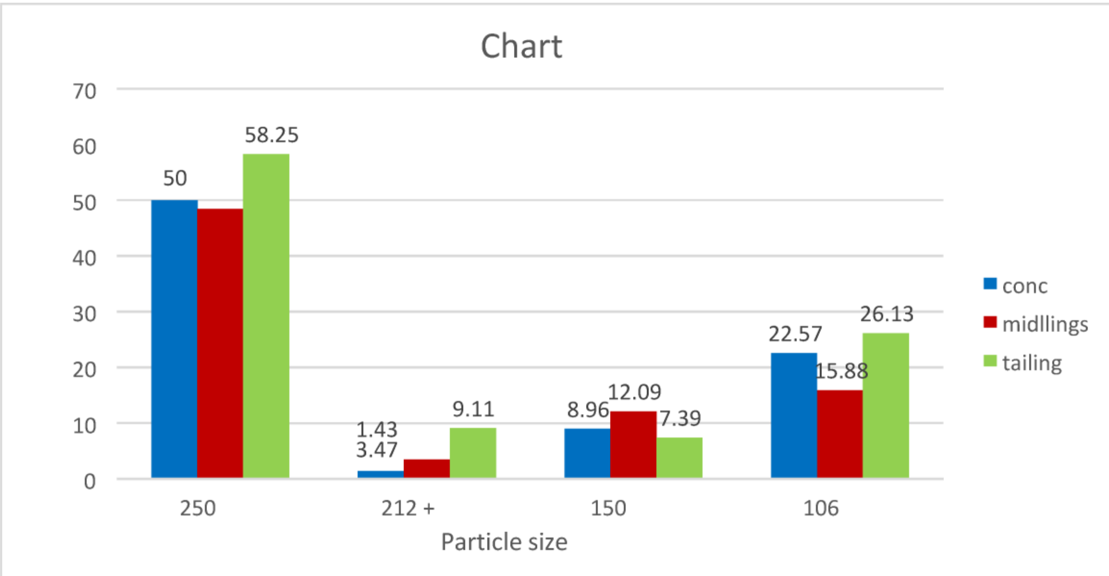

Figure 2. Shaking Table results on the separation of quartz from ironmaking slag.

4. Conclusions

Breakage power decreased significantly after numerous grinding cycles. This is influenced by equilibrium state reached by material sample in effectively separating coarse from fines. In contrast, from the shaking table results it can be concluded that a reduction in particles size decreases the mass collected at the concentrate (heavy particles) and the middling and the mass collected at the tailings (light particles). This is because the fine particles take time to settle on the table, as a result they report to the light particles (tailings) stream. The shaking table could not handle very fine particles (−106 + 75). During falcon concentration, it was observed that therefore, −106 + 75 µm particle size, most quartz was found in the overflow than in any of the particle sizes. Furthermore, it can be deduced that the particle size of −106 + 75 μm is efficient for physically separating quartz from iron making blast furnace slag.

Author Contributions: Conceptualization, K.M. and H.R.; methodology, M.M.; writing—original draft preparation, I.K.; writing—review and editing, M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Thuthuka PhD-Track Grant supported by National Research Foundation of South Africa, grant number 138165.

Acknowledgments: The authors would like to express their gratitude to National Research Foundation of South Africa for funding this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Matsukawa, K.; Shibata, T.; Kunitomo, K.; Ohno, K. A study on the utilization of iron and steel slag in civil engineering. *Int. J. Geomate* **2017**, *12*, 109–115.
2. Ahmadi, R.; Shahsavari, A. Investigation of quartz flotation from decarburized vanadium bearing steel slag using shaking table and centrifugal concentrator. *J. Clean. Prod.* **2017**, *161*, 1085–1094.
3. Liu, J.; Li, Y.; Xu, Z.; Wei, D. *Gravity Separation of a Low-Grade Iron Slag by Shaking Table*; 2019.
4. Carrasco, C.; Quiroz, R.; Fuentes, P.; Henningsen, P. Comparison of grinding characteristics in high-pressure grinding roller (HPGR) and cone crusher (CC). *Miner. Eng.* **2016**, *86*, 105–114.
5. Gupta, V.K.; Yan, D.S. *Mineral Processing Design and Operations: An Introduction*; Elsevier: Amsterdam, The Netherlands, 2016.
6. Chen, C.; Shi, F.; Xu, Z.; Wei, D. Performance of a multi-gravity separator for recovery of ultra-fine heavy minerals from coal fly ash. *Miner. Eng.* **2020**, *156*, 106539.
7. Zhao, Y.; Huang, H.; Lu, H.; Liu, Z.; Lin, C. A review of microalgal biomass harvesting using flocculation. *Bioresour. Technol.* **2019**, *280*, 386–396.
8. Wills, B. A.; Atkinson, K. *An Introduction to Mineral Processing*; Pergamon Press: Oxford, UK, 1993.