Variations in Mill Feed Characteristics and Acoustic Emissions

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Abstract

Ore variability such as grade, competence, and hardness is becoming increasingly pronounced in the mineral processing industries. The present study investigates the noise characteristics associated with two different types of ores grind characteristics as a function of changing grind time using a non-contact acoustic sensor. Particularly, iron and quartz ores were used for the study in a laboratory-based Magotteaux ball grinding mill. The results suggest that the quartz ore grind characteristics are relatively different from iron ore with increasing grind time. An acoustic sensor offers a great opportunity and serves as a proxy tool to monitor and predict mill feed characteristics in real-time for mill stability and optimisation.

Keywords: Magotteaux ball mill, acoustic sensor, ore grind characteristics, ore variability, optimisation

1 Introduction

Grinding is one of the important process routes in mineral processing employed to reduce large ore materials into recommended size fractions suitable for further downstream enrichment processing. This requires the use of grinding mills such as Autogenous (AG), Semi-autogenous (SAG), and ball mills. Grinding mills usually account for about 30 % -50 % of the energy used in mineral processing (Vizcarra *et al*., 2010). It is therefore important that grinding mills are operated in an optimised mode. To optimise the process efficiency, knowledge of the ore variability and grinding characteristics are considered critical to address.

Ore materials that are fed into industrial mills may vary in mineralogical and chemical composition due to their geological formation, defining their physical properties such as competence, hardness, particle grain size and bond type (Bueno *et al.*, 2015). The physical features of the ore mechanically affect mill grind efficiency and optimisation. Knowledge of the ore physical characteristics influence decision making processes regarding comminution (crushing and milling). Many measurement techniques for describing the nature of an ore material physical properties include Bond Ball Mill Work Index (BBMWI), SAG Power Index (SPI) and JK Drop weight Test (JKDWT) (Starkey and Meadows, 2007; Young, 2019). However, these measurements are done offline or before the grinding operation, owing to the hostile environment of an operating mill. As a result, a sudden and unnoticeable change in the mill feed characteristics sometimes creates optimisation challenges. Monitoring the ore grind characteristics online can support appropriate measures to maximize mill performance.

Monitoring the mill acoustic emissions have been known over the years to give indications of the in-mill processes of grinding mills (Pax, 2001; Watson, 1985; Watson *et al*., 1985). The acoustic emissions resulting from complex interactions of the mill charge and mill liners are measured using an acoustic sensor, usually microphone (Pax 2012).

Several in-mill parameters have been monitored such as particles size, breakage rate, mill loading, liner wear rate, toe and shoulder position and ore type (Aldrich *et al*., 2000; Almond and Valderrama, 2004; Pax and Thornton, 2019; Spencer *et al*., 1999; Watson, 1985; Watson and Morrison, 1986; Watson *et al*., 1985).

This paper aims to employ acoustic sensing method to investigate the grind characteristics of different ore materials in a laboratory ball mill as a function of grind time. The study tends to address the following key questions;

1. Are there any significant acoustic frequency changes between different ore breakage characteristics?
2. Can acoustic frequency spectrum characteristics predict the grind behaviour of a given ore sample?
3. Do ore physical properties affect mill noise?
4. How does grind time variation affect grind characteristics and mill noise?

2 Experimental Methods

2.1 Sample Preparation

Two different mineral samples, namely iron ore and model quartz mineral samples obtained from SIMEC mining (SA) and Magotteaux Australia Pty. Ltd. respectively were used for the study. The elemental and mineralogical composition of the two ore samples were verified with XRD and XRF and presented in Table1.

Table 1 Elemental and Mineralogical Analysis

% wt.				% Mass
Element	**Iron**	**Quartz**	**Mineral**	**Iron**
Fe	45.23	0.69	Magnetite	37.95
Si	10.37	40.82	Hematite	5.39
Mg	8.10	-	Goethite	16.06
Ca	3.82	-	Pyroxene	5.24
Al	2.34	3.00	Quartz	6.81
P	0.10	0.01	Chlorite	6.52
Mn	0.39	0.03	Carbonates	14.00
K	-	0.56		
S	0.09	-		

The suitable feed particle size fractions (-3.35 + 0.106 mm) were prepared by subjecting the two ore samples through jaw and roll crushers. By using a riffle sample splitter, representative splits of four samples were obtained for each of the ore types. Based on the Tyler series, a set of screens (0.841mm, 0.5mm, 0.3mm, 0.212mm, 0.15mm and 0.106 mm) were used to obtain the feed size distribution analysis shown in Figure 1. The graph shows that the feed fractions prepared are statistically identical, depicting a strong basis for comparative analysis.

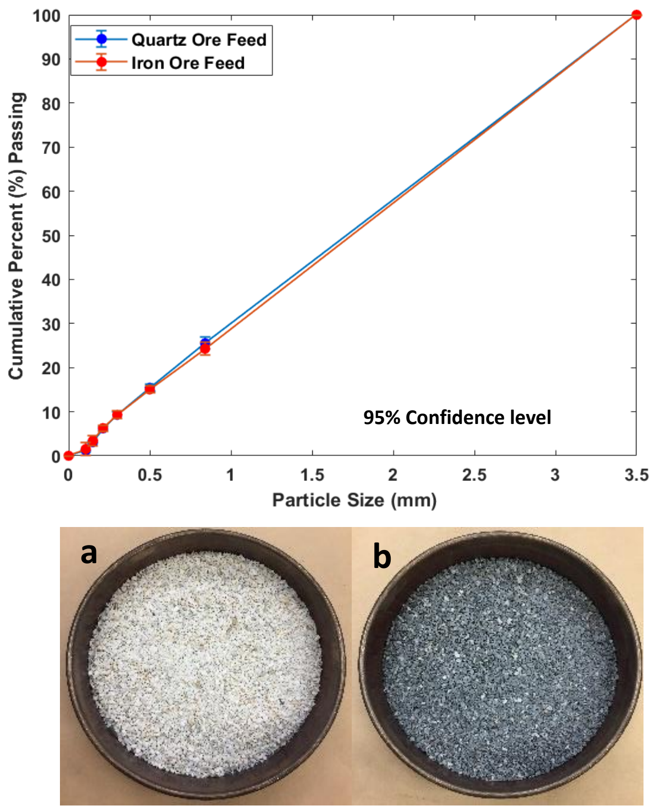


Figure 1 Feed size distribution analysis (a) Quartz and (b) Iron ore

2.2 Experimental Set-up and Grinding Studies

A laboratory-based Magotteaux ball mill was employed for the different ore grind characteristics. An audio recording system (acoustic sensor: PreSonus AudioBoxTM iOne) was employed to collect the mill acoustic emissions during grinding. The sensor is made up of one microphone with a low-noise, preamplifier and a +48V phantom power, connected by cables to a laptop computer. The microphone component was mounted on a supported system at a distance of ~ 10 cm from the toe angle of the mill shell to improve sensitivity. In this study, sampling frequency or rate at 44.1 kHz was selected (Huang *et al.*, 2014). A schematic representation of the Magotteaux ball mill and experimental set-up are shown in Figure 2.

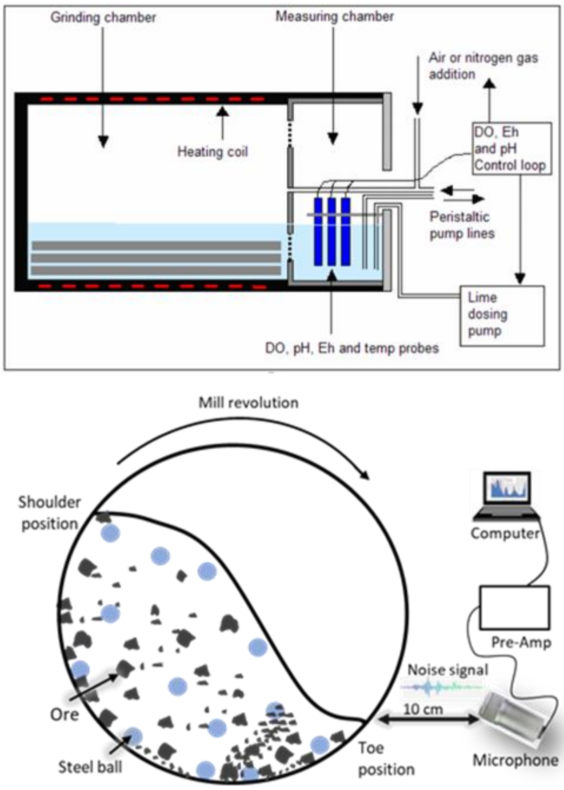


Figure 2 Schematic diagram of the Magotteaux Mill® and Experimental set-up

A charge of 1kg sample, 10 kg varying steel balls (26.5, 32, and 38 mm), and 650 ml volume of water (60.61 wt.% solids) were fed into the mill for each of the grinding studies. The mill was operated at 44.8 rpm, which translates to 58 % critical speed and cascading regime. The tests were conducted for 5, 10, 15 and 20 minutes for the two ores samples.

2.3 Acoustic Signal Data Acquisition and Pre-Processing

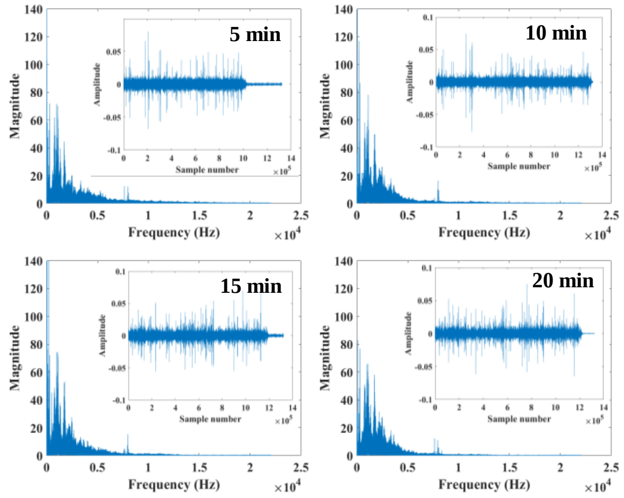
Acoustic emission resulting from the complex interaction of steel balls, ore sample, water and liner was visualised and monitored on audacity platform installed to a connecting computer. Acoustic signals are usually presented in the time domain. To extract useful signal features, acoustic signal analysis was performed using MATLAB™ software. The Fast Fourier Transform (FFT) was used to convert the time-domain acoustic signal to frequency-domain. Power spectral density (PSDE) analysis using Welch's method (improved periodogram) was also estimated. To obtain the effect of grind period on the milling and acquire identical sample data for comparison, the signal analysis was focused mostly on the last 30 seconds of each grinding time (close to the end of the milling).

3 Results and Discussions

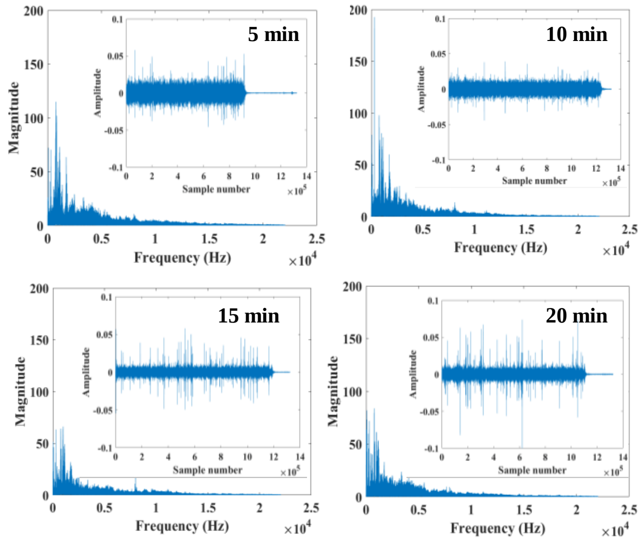
3.1 Time and Frequency Domain Analysis

The time and frequency signal domain of the iron and quartz ore grind characteristics for 5, 10, 15 and 20 minutes are presented in Figure 3. In the time domain, random signal spikes are produced in all the different grind periods. It is interesting to note that the signal spikes are more pronounced with increasing grind time for both iron and quartz ore grind characteristics, especially in the iron ore material. The spikes production could be the frequent collision between the steel balls and steels ball/mill liners. For the iron ore frequency spectrum graph, the spectrum bandwidth tends to have an appreciable magnitude which reduces considerably with increasing frequency. Relatively, lower frequencies present the maximum acoustic emission magnitude, which may inform possible interaction of the steel ball and steel/mill liner. This is because the collision of the steel ball and steel/mill liner produces extreme noise (Watson and Morrison, 1986). Magnitude levels vary at some specific frequency peaks as grind time increases, however, the variation remains nearly constant. On the other hand, frequency domain plots of quartz ore grind characteristics show a similar trend to that of the iron ore, in that the noise magnitude is relatively higher at lower frequencies and reduces significantly with increasing frequency along the spectrum. However, the magnitude of the signal tends to reduce gradually with increasing grind time, indicating the production of more fine particles which may contribute to coating steel balls and mill line and dampen the mill noise intensity.

Comparing the frequency plots of the iron and quartz grind characteristics, the quartz ore shows relatively higher mill noise intensity than the iron ore, especially at grind times of 5 and 10 minutes.



(a) Iron ore



(b) Quartz ore

Figure 3 Time and Frequency domain plots for (a) iron ore (b) quartz ore grind characteristics

3.2 Power Spectral Density Estimate (PSDE)

To evaluate the power content within the emitted signals during grinding for different grind time, the PSDE based on Welch's technique was employed. The PSDE results are presented in Figure 4. Generally, for all the grind time the PSDE is comparatively high at lower bandwidth and decreases gradually with increasing frequency. Also, the results show similar trends for both the iron and quartz ore grind behaviour for varying grind time. In comparison, the PSDE of the quartz ore grind characteristics is more or less superior along the whole frequency for all grind time. The differences tend to widen up with increasing grind time. This may indicate that the quartz and iron ore physical properties contribute to the different interaction of mill charge, hence different acoustic emission signals.

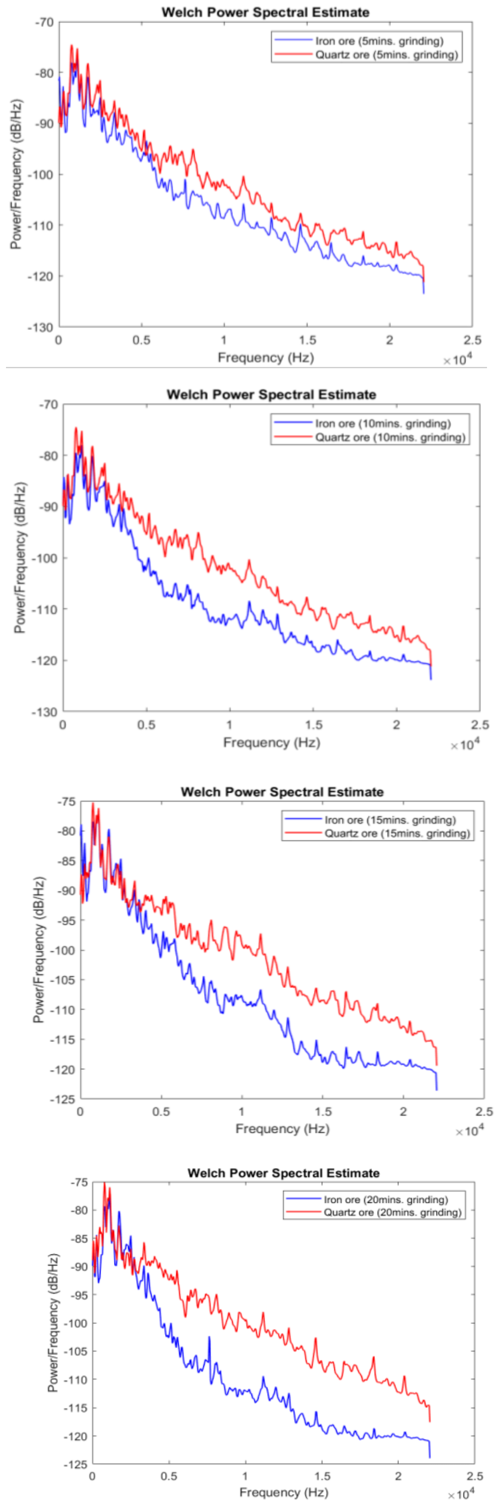


Figure 4 PSDE of Different Pulp Density Grind Characteristics

3.3 Mill Product Size Distribution Analysis (PSD)

The product size distributions are analysed to estimate the influence of grind time on both iron and quartz milling behaviour. As shown in Figure 5, the behaviour of the grind curves of the two ores happens to have an identical pattern with increasing grind time. Conversely, the iron ore breakage characteristics tend to produce more fine particles relative to the quartz ore for all the grind time. This clearly explains that the quartz ore material to some extent harder than the iron ore. Increase of the grind time subsequently increases the fine concentration in the mill. The fine particles could affect the viscosity by forming slurry coating around the steel ball and the mill liner. The resultant effect could reduce steel ball and steel ball interaction, hence reduction in mill noise intensity.

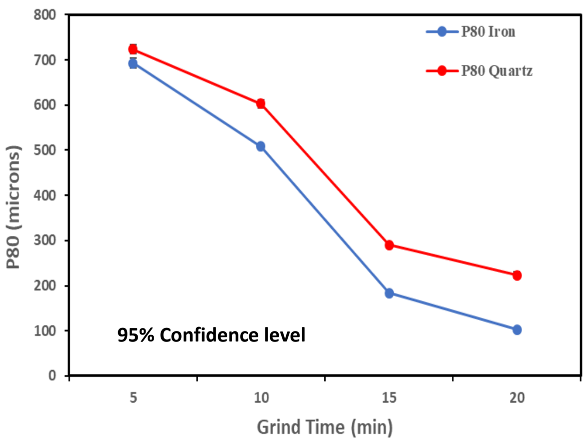


Figure 5 Product particle size distribution

4 Conclusions

The grinding behaviour of two different ores as a function of varying grinding time are studied using acoustic sensing technique. Extracting useful information in frequency spectrum using FTT (amplitude-frequency and PSDE), the study has demonstrated that through quantitative mill acoustic measurement, online prediction of mill feed characteristics can be visualised and clarified in a grinding mill. The main findings of the study are outlined;

- Different ore grind behaviour produces different acoustic frequency characteristics.
- Acoustic frequency spectrum (frequency domain and PSDE) could give indications of a given ore sample grind behaviour.
- Ore physical properties such as hardness may have an impact on the mill noise emission.
- The effect of increasing mill grind time was shown to produce more fine particle sizes which may influence the viscosity and flow of mill charge affecting the mill noise intensity.

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