Minerals Engineering 122 (2018) 251–257

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Effect of frictional grinding on ore characteristics and selectivity of magnetic separation

Shaoyan Wang[a,*], Ke Guo[a], Shuokun Qi[a], Liming Lu[b,*]

[a] *School of Chemical Engineering, University of Science & Technology Liaoning, Anshan, Liaoning 114051, China*
[b] *CSIRO Mineral Resources, Pullenvale, QLD 4069, Australia*

ARTICLE INFO

Keywords:
Magnetite ore
Magnetic separation
Frictional grinding
Iron grade
Iron recovery

ABSTRACT

Frictional grinding was evaluated to improve the selectivity of two magnetite samples A and B in the magnetic separation process. Sample A containing 64.42% Fe was a magnetite concentrate upgraded from a low grade magnetite Ore, Sample B, containing 46.63% Fe, through an upgrading process involving 1-stage ball milling and 3-stage wet magnetic separation in a beneficiation plant. Frictional grinding was found extremely efficient in dispersing the grains in the agglomerates and on the surface, consequently improving the selectivity of the sample. A magnetite concentrate containing 66.22% Fe was produced from Sample A at an iron recovery of 96.86% by introducing a simple dry frictional grinding step prior to the magnetic separation process. The results have demonstrated that Sample A can be further upgraded even though it was processed through 3-stage magnetic separation. Given its beneficial effects, frictional grinding was further adopted in a multiple-stage flowsheet to upgrade both Samples A and B. A magnetite concentrate containing 68.75% Fe was produced from Sample A at an iron recovery of 97.23% through the multiple-stage wet frictional grinding-magnetic separation flowsheet. When the same flowsheet was applied to process Sample B, a concentrate of 69.97% Fe, higher than Sample A obtained by ball milling, was produced at an iron recovery of 86.44%.

1. Introduction

Magnetic separators exploit the difference in magnetic properties between materials to separate valuable minerals from gangue minerals (Svobodaa and Fujita, 2003; Ezhov and Shvaljov, 2015). With the advantages of large capacity, low operating cost and being environmentally friendly, magnetic separation technology has played an important role in upgrading low-grade iron ores (Xiong et al., 2015). However, the entrainment of nonmagnetic particles during magnetic separation, due to the agglomeration of magnetic and non-magnetic particles, is a serious concern, especially when magnetic separation is carried out under dry conditions (Wills and Finch, 2015b, Chapter 13). Hence, the capacity and efficiency of magnetic separators is greatly limited. To obtain a concentrate of a higher Fe grade, more grinding and/or subsequent floatation are usually adopted in traditional flowsheets (Ma, 2012; Xiong et al., 2015; Wills and Finch, 2015a, Chapter 7). As specific energy required for grinding increases exponentially with product fineness, energy efficiency is always a concern in fine grinding operations (Little et al., 2017). The grinding process is known to be responsible for approximately 50% of the operating costs in a beneficiation plant (Curry et al., 2014). To deal with the rising energy consumption, more efficient comminution technologies (Jankovic, 2003; Reichert et al., 2015) and other alternative technologies, have been developed and deployed. The flotation process, on the other hand, involves various chemical reagents which end with the tailings pond, leading to serious environmental concerns.

In this paper, a new flowsheet of frictional grind-magnetic separation was developed. Different from conventional grinding operation which is the last stage in the comminution process where the size of the mineral particles is reduced by a combination of impact and abrasion, either dry, or more commonly, in suspension in water (Wills and Finch, 2015a,b; Little et al., 2016; Moosakazemi et al., 2017), frictional grinding used in this paper refers to a process where ores are lightly ground to disperse the agglomerated particles thoroughly and therefore improve the selectivity of the subsequent magnetic separation.

2. Experimental

2.1. Materials and characterization

Two magnetite samples A and B sourced from Anshan, China, were tested. Sample A was a concentrate product upgraded from Sample B

* Corresponding authors.
E-mail addresses: wangshaoyan@ustl.edu.cn (S. Wang), Liming.Lu@csiro.au (L. Lu).

https://doi.org/10.1016/j.mineng.2018.04.015
Received 11 January 2018; Received in revised form 21 March 2018; Accepted 15 April 2018
0892-6875/

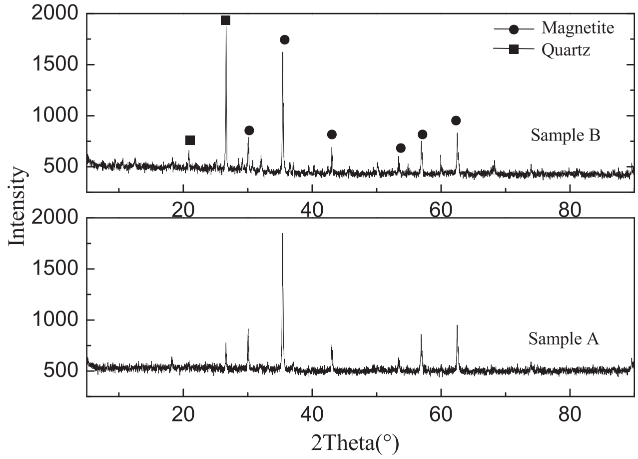

Fig. 1. XRD patterns of Samples A and B.

through an upgrading process involving 1-stage ball milling and 3-stage wet magnetic separation in a beneficiation plant. Therefore compared with Sample B (46.63% Fe), Sample A contained a much higher Fe grade of 64.42%.

The crystalline mineral phases of the ores were identified by powder XRD technique using Cu Kα radiation. Fig. 1 shows the XRD patterns of the two ores, suggesting that the major gangue mineral phase in the samples was quartz. The XRD observation was in good agreement with chemical analysis results. The SiO_2 contents of the samples were 9.10% and 28.25%, respectively, for Samples A and B.

The size distribution of the ores before and after frictional grinding was determined by mechanical sieving method and is shown in Fig. 2. Compared with Sample B with 84.7% material passing 74 µm, Sample A was considerably finer with 96.0% due to the milling effect during the beneficiation process.

The morphologies of the ores were examined in a scanning electron microscope (SEM) equipped with an X-MAX50 energy spectrum detector. Fig. 3 shows the back scattered electron (BSE) images of the samples, which further confirmed the XRD observations in Fig. 1. The samples were dominated with magnetite and quartz. As evidenced by the EDS spectra of selected particles, the brighter particles in the BSE images contained magnetite while the quartz particles are darker due to the lower atomic number of silicone. Overall, Sample A being a concentrated product of Sample B was finer and contained considerably more bright particles than Sample B. The fine particles in both samples tented to stick on the surfaces, edges and angles of the bigger ones or attract each other, forming agglomerates. Some of the agglomerates are believed to form in the comminution process where fresh surfaces, edges and angles are formed as a result of the breakage of ore particles. Van Der Waals force was reported to operate between the fine particles of −1 µm (Greenwood, et al., 2002). The agglomerates can also form in the magnetic separation process owing to the magnetic force. The gangue minerals entrained in the agglomerated particles were difficult to liberate. In other words, both ores can be readily upgraded if the composite particles are dispersed. Apart from the agglomerated particles, composite particles were also observed in Sample B and to a less extent in Sample A. Clearly the ball milling process has helped break up and reduce the amount of composite particles in Sample A.

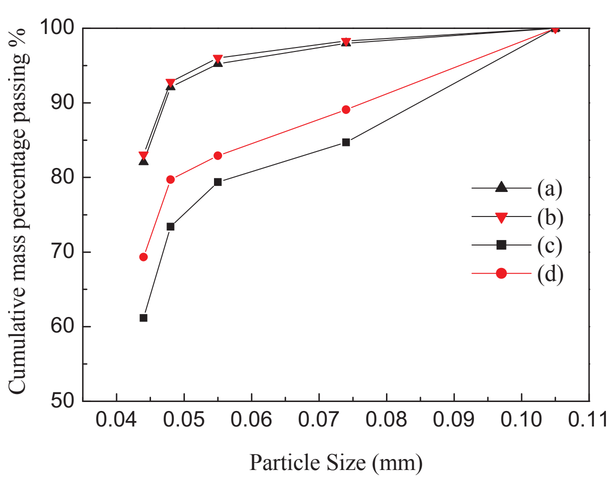

Fig. 2. Size distributions of Samples A and B before and after the dry frictional grinding. (a) Sample A; (b) Ground Sample A; (c) Sample B; (d) Ground Sample B.

2.2. Frictional grinding and magnetic separation

Frictional grinding was carried out using a mortar and pestle for 2 min, either under the dry condition or in a slurry. Preliminary tests have found no obvious effect of the grinding forces applied on pestle and the movement of pestle. Different grinding time of 0.5–5 min was trialed, 2 min grinding was found to be sufficient for the purpose of particle dispersion. The ground samples were then subjected to single- or multiple-stage magnetic separation.

The magnetic separation was conducted in an in-house built magnetite separator, which was composed of a nonmagnetic sorting chamber and a permanent magnet rod of a size of 38 × 10 × 10 mm. The sorting chamber consisted of a tailings receiver and a clapboard located above. The working distance between the clapboard and the tailings receiver was about 18 mm. With a contact area of 38 × 10 mm on the top surface of the clapboard, the magnet rod was capable of producing a non-uniform magnetic field with its intensities varying between 2100 and 3200 Gauss in the sorting chamber below the clapboard. Before magnetic separation, a dry sample of about 3 g or a slurry containing 5 g ore was loaded into the sorting chamber. During the magnetic separation procedure, while the magnet was moved to and fro on the clapboard above the sorting chamber, it attracted magnetic particles which clustered underneath the clapboard and moved with the magnet. The movement of the particles in the cluster allows the non-magnetic particles to be thrown away and drop into the tailings receiver, leading to better separation efficiency. At the end of 2 min separation, the magnet and clapboard with the magnetic particles attracted underneath were moved away from the tailings receiver. The magnetite concentrate was discharged from the clapboard and collected for further characterization when the magnet was moved away from the clapboard.

3. Results and discussion

3.1. Effect of frictional grinding on ore characteristics

The size distributions of Samples A and B before and after 10 min dry frictional grinding are compared in Fig. 2. As evidenced in Fig. 2, the frictional grinding had negligible effect on the sizing distribution of Sample A even after 10 min, however it made Sample B slightly finer. After dry frictional grinding, the cumulative percentage passing 74 µm was increased from 84.7% to 89.1% for Sample B. The size reduction observed on Sample B after frictional grinding is more likely due to the de-agglomeration of particle clusters during frictional grinding. However the size reduction caused by the dry frictional grinding was considerably less severe than that caused by the ball milling, particularly, in the size range of fine particles. Compared with 84.7% for Sample B prior to the ball milling stage, the cumulative percentage passing 74 µm was increased to 96.03% after one stage of ball milling for Sample A.

Fig. 4 shows the BSE images of the samples after the frictional grinding. Compared with the samples prior to fractional grinding (Fig. 3), less adhering fines and agglomerates were observed in the