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The effect of particle breakage mechanisms during regrinding on the subsequent cleaner flotation

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ABSTRACT

Stirred mills have been widely used for regrinding, and are acknowledged to be more energy efficient than tumbling mills. These two types of mills present different particle breakage mechanisms during grinding. In this study, the effect of regrinding by both mills on surface properties and subsequent mineral flotation was studied, using chalcocite as the mineral example. A rod mill and a stirred mill with the same stainless steel media were used to regrind rougher flotation concentrates. Different chalcocite flotation recovery was achieved in the cleaner stage after regrinding in tumbling and stirred mills. The factors contributing to the different recovery included particle size, the amount of created fresh surfaces, surface oxidation and the redistribution of collector carried from rougher flotation. All the factors were examined. It was determined that the predominating factor was the different distribution of collector resulting from different particle breakage mechanisms in the stirred and tumbling mills, in line with ToF-SIMS analysis. In the tumbling mill, the impact particle breakage mechanism predominates, causing the collector to remain on the surface of newly produced particles. In the stirred mill, the attrition breakage removes collector from the surface, and decreases particle floatability. Furthermore, the type of grinding media in the stirred mill also influences the subsequent flotation, again due to the change of particle breakage mechanisms. The results of this study demonstrate that the selection of regrinding mills and grinding media should not only depend on the required energy efficiency, but also on the properties of the surfaces produced for subsequent flotation.

1. Introduction

Regrinding rougher flotation concentrates is a common practice to improve the recovery and grade of valuable minerals as a result of the need to process low grade and complex ores. For example, in Newcrest's Telfer gold mine, the regrinding of copper rougher concentrates significantly improves copper and gold recovery, especially when processing the West Dome ores containing copper sulphides (e.g., chalcocite and bornite etc.) with a small grain size (Seaman et al., 2012). The small grain size means finer grinding is needed to provide sufficient mineral liberation. In many mineral processing plants treating low grade ores, mineral liberation can only be achieved at a regrind size of less than 10 μm (Johnson, 2006).

Grinding is the single largest energy-consuming process in mineral processing plants, and the selection of energy efficient mills is critically important for fine grinding. The stirred mills, recently introduced to mineral processing, have proved to be more energy efficient than tumbling mills in terms of fine grinding, and have been extensively used in many mineral processing plants at the regrinding stage (Gao et al., 2002; Jankovic, 2003; Pease et al., 2006). In contrast to tumbling mills, where motion is imparted to the charge via the rotating mill shell, stirred mills impart the motion to the charge by the movement of an internal stirrer, providing different particle breakage mechanisms. In tumbling mills, impact breakage from the free-fall motion of grinding media is the main breakage mechanism with some attrition existing at the bottom of the mill (Wills and Napier-Munn, 2006). In stirred mills, the movement of the stirrer through the ball bed and the sliding/rolling motion of the charge provides a solely attrition based breakage environment (Wills and Napier-Munn, 2006). Recent studies suggest that impact breakage mechanisms may also exist in stirred mills, and the proportion of impact and attrition varies from case to case (Kwade and Schwedes, 2002; Yue and Klein,

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2005; Roufail and Klein, 2010). The different breakage mechanisms have been proved to influence the particle size distribution (Kelly and Spottiswood, 1982; Gao and Forssberg, 1995; Hogg, 1999), particle shape (Andreatidis, 1995; Roufail and Klein, 2010) and mineral liberation (Andreatidis, 1995; Roufail and Klein, 2010). Furthermore, these parameters may play a role in the subsequent flotation.

The grinding chemistry, including the use of different types of grinding media and pulp chemistry (pH, Eh and dissolved oxygen), have a significant effect on the subsequent flotation behaviour (Johnson, 2002; Peng et al., 2003a,b; Bradshaw et al., 2006; Ekmekci et al., 2006; Bruckard et al., 2011; Chen et al., 2012a,b), and different grinding mills used may affect the subsequent flotation not only through changes in particle size and shape, but also through the change of mineral surface properties. As demonstrated by Chen et al. (2013), there are two types of surfaces after regrinding: the remaining surfaces carried over from the regrind feed, and the fresh surfaces generated during regrinding. In terms of regrinding rougher flotation concentrates, the surfaces carried from rough flotation concentrates are generally covered by collector resulting in a certain degree of residual floatability. The distribution of collector on the new surfaces is influenced by the particle breakage mechanisms. As shown in Fig. 1, if an impact or compression breakage is applied, surface collector may be evenly distributed on the new particle surfaces. If the attrition breakage is applied, the collector may be removed from the surfaces and distributed onto fine and ultra-fine particles. Ye et al. (2010a) found that the floatability of coarse particles decreased, to a greater extent, after regrinding by a stirred mill rather than a tumbling mill. This could be due to the greater contribution of the mechanism to size reduction provided by the stirred mill. However, this phenomenon was only observed for the regrinding of relatively coarse particles i.e. from P_{80} of 80–60 μm. Ye et al. (2010a) proposed that breakage mechanisms were not influential for regrinding of finer products.

Besides the surfaces carried over from regrind feed, a large amount of fresh surfaces may also be produced during regrinding. Chen et al. (2013) reported that the large amount of fresh surfaces after regrinding strongly depressed pyrite flotation in the cleaner stage. However, it is important to note that sulphide minerals can be easily oxidized during regrinding, and oxidation species formed on the surfaces can markedly change the mineral floatability (Smart, 1991; Gonçalves et al., 2003; Bicak and Ekmekci, 2012; Chen et al., 2014). Some species are hydrophobic, such as metal-deficient sulphide and polysulphide, improving the particle floatability, while some species are hydrophilic, such as metal hydroxide and sulphate species, decreasing the particle floatability. Therefore, the different types of grinding mills may affect mineral flotation through different oxidizing conditions on and above the effects due to breakage mechanisms.

In this study, the effect of particle breakage mechanisms on chalcocite flotation was investigated. Two types of grinding mills, a tumbling mill and a stirred mill, were used to produce ground chalcocite via different breakage mechanisms. The same type of grinding media, stainless steel, was used in the two mills in order to eliminate the potential influence of the type of grinding media on flotation. Furthermore, as ceramic media is widely used in stirred mills commercially, it was also used in this study to compare results obtained with stainless steel media.

2. Experimental

2.1. Materials and reagents

Chalcocite single mineral, supplied by GEO Discoveries, was crushed through a jaw crusher and a roll crusher, and then screened to collect the – 3.35 + 0.71 mm particle size fraction. XRD analysis indicated that the chalcocite sample had a high purity with a minor amount (<2%) of iron sulphide impurity. The processed feed samples were sealed in polyethylene bags and then stored in a freezer at a temperature of −20 °C to avoid further surface oxidation.

Potassium amyl xanthate (PAX) and Interfroth 56 were used as a collector and frother, respectively. Collector and frother were of industry grade and were used as received. The pH was adjusted by the addition of a NaOH solution. De-ionized water was used in all experiments. All chemical solutions were made fresh daily.

2.2. Grinding and flotation

The crushed chalcocite (100 g) was combined with 150 ml of de-ionized water, and ground in a stainless steel rod mill (Length: 260 mm, Diameter: 205 mm) for 8.3 min using 4 stainless steel rods (3750 g) to achieve a P_{80} of 75 μm. A certain amount of 2.5% w/v sodium hydroxide solution was added in the feed before grinding to achieve pH 9.0 in the mill discharge.

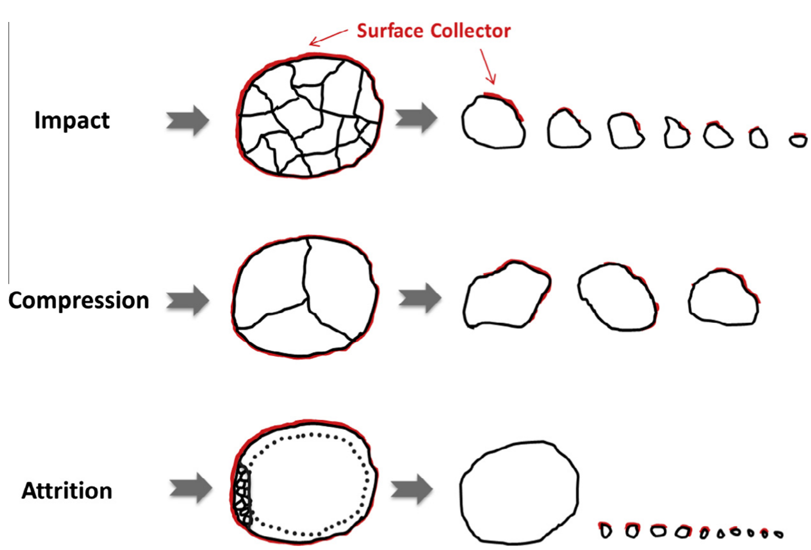

Fig. 1. The three different proposed particle breakage mechanisms, and the resultant distribution of surface collector on broken particles. (Revised based on Kelly and Spottiswood, 1982).