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Pre-concentration of copper ores by high voltage pulses. Part 1: Principle and major findings

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ABSTRACT

A novel ore pre-concentration technique using high voltage pulses is proposed in this study. The technique utilises metalliferous grain-induced selective breakage, under a controlled pulse energy loading, and size-based screening to separate the feed ore into body breakage and surface breakage products for splitting of ores by grade. Four copper ore samples were tested to demonstrate the viability of this technique. This study consists of two parts: Part 1 presents the principle, the validation and the major findings; Part 2 discusses the new opportunities and challenges for the mining and mineral industry to take up this technique.

1. Introduction

The mining and minerals industry is facing challenges of declining ore grades and increasing ore competence, and the associated increase in processing plant throughput rates, energy consumption and operational costs. Powell and Bye (2009) estimated that ore competence, in terms of kWh t^{-1} to treat, is increasing at about one per cent per annum and ore grade dropping at about one per cent per annum. Based on these figures, they calculated that to achieve the mining company targets of a 10–20% saving in absolute energy, specific energy usage (kWh t^{-1} of ore treated) needs to drop below 40% of the usage in 2000 by 2020 and 20% by 2050! Applying current technology will not achieve anything near this objective.

Coarse waste rejection before grinding has a potential to pre-concentrate valuable minerals. The upgraded ore can bring benefits of reduced milling throughput to achieve the required metal production, reduced energy consumption and improved comminution and recovery efficiency. This technique has a potential for the mining and minerals industry to make a step-change in reduction of the energy input per unit of final product (Bearman, 2013).

Implementation of coarse waste rejection is dependent on the geological setting and association of ore and host rock type in a deposit. In some processing plants, the Run-of-Mine (RoM) ore exhibits a size-related grade differentiation between the value hosting rock particles and barren material. Burns and Grimes (1986) reported pre-concentration of a copper ore by screening at the Bougainville copper plant operation. Based on detailed recovery-size-yield data collected from the Newcrest Telfer operation, Bowman and Bearman (2014) reported a potential application of coarse waste rejection through size-based separation for copper production.

It was found that rock strength may sometimes associate with metal grade. Modifications to the energy intensity delivered to various areas of the blast can also be implemented to induce the size-related grade differentiation for coarse waste rejection (Powell and Bye, 2009).

Despite the simplicity of a separation system using a conventional screen to achieve size-related grade splits, the success of coarse waste rejection is largely dependent on the accurate classification into a dedicated ore database. There is no doubt that ore variation will affect the waste rejection efficiency and the value loss, since the grade of the coarse waste component in the feed is not directly measured by an on-line grade measuring system before being rejected.

By contrast with the size-related waste rejection through screening, ore sorters use sensors to determine grade related physical properties. In essence, ore sorters have a better opportunity to minimise value loss during waste rejection. However, many of the currently used sensors measure particle surface properties, which are then used to infer the grade of each particle for a selection decision. It may be argued that the surface properties cannot completely represent metal grade, resulting in potential miss-classification of ore as waste or vice versa. In addition, the control and ejector system used by the sorters can be onerous in operation, as

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they are more complex than the simple mechanical ejector by screening.

In recent years, high voltage pulse technology has been explored for the potential application of ore pre-weakening (Wang et al., 2011; Shi et al., 2013; Shi et al., 2014a) and mineral liberation (Wang et al., 2012a). This paper proposes a third major application: ore pre-concentration by high voltage pulses. The technique utilises metalliferous grain-induced breakdown of particles under a controlled pulse energy input, and size-based screening to separate the feed ore into body breakage and surface breakage products for splitting of ore by grade.

2. Discovery of the grade-splitting function

High voltage pulse breakage is a comminution method that uses high voltage pulses to initiate electrical breakdown inside an ore particle, generating a strong tensile force to disintegrate the particle. The mechanisms of high voltage pulse fragmentation can be found in literature, eg. Andres et al. (2001a), Bluhm (2006). It was proposed as a possible alternative to conventional breakage methods for improving mineral liberation (Andres, 1977; Anon, 1986). It was also found that high voltage pulse can be used to pre-weaken ore particles before downstream mechanical comminution, making it possible to significantly reduce the total energy consumption of the comminution process (Wang et al., 2011; Shi et al., 2014a, b).

Although the selective fragmentation by high voltage pulse has been known to the mineral industry for a long time, the pre-concentration application remained un-discovered until a single-particle, single-pulse test procedure for high voltage pulse breakage characterisation was proposed (Shi et al., 2013). This method was developed to replace the traditional batch test procedure, in which there was no opportunity to track the behaviour of individual ore particles subjected to electrical pulses.

The concept of pre-concentration by high voltage pulse originated from the studies of the effect of metalliferous grains on the breakage behaviour of particles (Zuo et al., 2014a, b). In these studies, natural rock particles or synthetic particles were treated by high voltage pulse using the single-particle, single-pulse test procedure. It was found that the existence and the position of metalliferous grain had a pronounced influence on the breakage behaviour of particles subjected to high voltage pulse. The natural rock particles or synthetic particles with metalliferous grains inside always produced finer progeny particles than those without.

By way of example, two groups of synthetic samples (Syn-15 and Syn-24) made of construction grout (following Zuo et al., 2014a) were tested. The synthetic samples were made using high strength grout made of quartz sand in a narrow size fraction around 300 μm and cement powder. A single pyrite grain of 2.36–3.35 mm was embedded in the centre of Syn-15 particles immediately after the casting of paste, while Syn-24 particles were made from the grout only. The diameter and height of the synthetic particles were 38 mm and 30 mm respectively.

The two groups of synthetic samples were treated by high voltage pulse at the same machine settings. A total 30 particles for Syn-24 as the control-sample and 10 particles for Syn-15 as pyrite-bearing sample were tested to increase the statistical validity. The test result indicated that the existence of metalliferous grains dominated the breakage response of the synthetic sample to high voltage pulse. The synthetic particles with pyrite grain embedded in their centre (Syn-15) attracted electrical breakdown channel passing through the boundary of the pyrite grain, causing radial explosion from the particle centre. As a result all the Syn-15 particles were broken explosively by one high voltage pulse. By contrast, at the same pulse treatment conditions, only 43% of the synthetic particles made of pure grout (Syn-24) were broken by the first pulse under the controlled low specific energy loading.

Sample Syn-24 was found to be unsusceptible to high voltage pulse breakage compared to Syn-15, as the channel of electrical breakdown was more likely to grow along the particle surface. This resulted in only a few small fragments being stripped off the particle surface, or splitting the particle into a number of large fragments. Fig. 1 shows the product size distributions of the synthetic samples subjected to one high voltage pulse under the same machine settings. The comparison suggests that the product of Syn-15 (82.5% passing 26.5 mm) is much finer than the product of Syn-24 (16.2% passing 26.5 mm).

It is worth noting that the volume of pyrite grain took up less than 0.07% of the whole synthetic particle. The difference in breakage behaviour of the synthetic particles caused by such a tiny amount of metalliferous grain reflected the significant influence of selective fragmentation mechanism in high voltage pulse breakage.

The selective fragmentation mechanism of high voltage pulse is attributed to enhancement of the electrical field intensity on the boundary of minerals with different permittivities and conductivities, as a result of the electrical polarization of the composite mineral fragments and the presented plasma streamers during the discharge of high voltage pulse (Andres et al., 2001b). In high voltage pulse breakage, disintegration of the solid is achieved by the explosive expansion of the electrical breakdown channel, which grows preferentially along the maximal electrical field in solid. Such enhancement of electrical field had been confirmed by the simulations of electrical field for particles subjected to high voltage pulse (Andres et al., 2001a; Wang et al., 2012b).

The observed difference in breakage behaviour and the product size distribution caused by metalliferous grain-induced selective breakage has led to the discovery of the ore pre-concentration technique by electrical pulses. Fig. 2 illustrates the ore pre-concentration process, in which a single or two electrical pulses with a controlled energy are discharged to ore particles in a narrow size fraction. This causes selective breakage to the particles with high conductivity/permittivity minerals. Based on the difference in product size distributions, screening is used to separate the pulse treated product into two components. It is hypothesized that the two components have different metal grades. An experiment was conducted to prove the hypothesis and to confirm the finding of the electrical pulse pre-concentration technique.

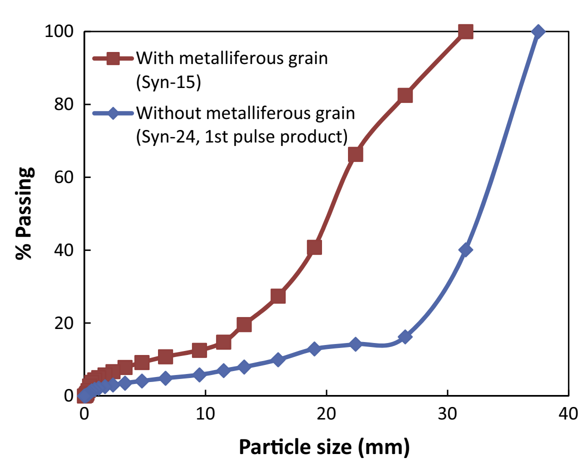

Fig. 1. Comparison of product size distributions between Syn-15 and Syn-24 samples subjected to one pulse discharge.