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The effects of electrical comminution on the mineral liberation and surface chemistry of a porphyry copper ore

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ABSTRACT

The surface chemistry and mineral liberation changes of a porphyry copper ore after high voltage pulse (HVP) electrical comminution have been investigated using X-ray photoelectron spectroscopy (XPS) and mineral liberation analysis (MLA). Previous studies suggest that electrical comminution has the potential to improve downstream flotation recoveries, due to increased mineral liberation. However, until now the effects on the surface chemistry have not been investigated in detail.

The mineral liberation results showed that chalcopyrite was more liberated in the electrical comminution product than in mechanical comminution, noticeably in the coarser size fractions. The surface chemistry of pure chalcopyrite was investigated, using XPS, and high resolution scans of iron and sulphur showed that both comminution methods led to iron oxidising preferentially leaving behind a passivating film of copper sulphides. However, the HVP product oxidisation was more severe with more iron oxide being produced and further oxidation of the remaining copper sulphides into copper sulphate. An attrition grinding stage may be useful in removing the oxidised layer from the surface of the particles prior to flotation separation. This paper presents a new application of the HVP technology in hybrid procedures using electrical comminution and mechanical grinding to prepare the flotation feed, rather than using excessive pulse energy to fully disintegrate ore to the flotation size. Better liberation and flotation performance were achieved through the hybrid procedures than the comparative mechanical comminution.

1. Introduction

Electrical comminution has emerged as an alternative to current mechanical comminution techniques, as it presents a way that can achieve preferential intergranular breakage. This leads to greater mineral liberation in coarser products which has the potential to improve downstream separation recoveries and performance. To date research on high voltage pulse treatment, using the SELFRAG device, has focused on the development and simulation of SELFRAG within comminution circuits, where the device is used to replace a comminution device or it is added as a pre-treatment stage (Cho et al., 2006; Wang et al., 2011, 2012a,b; Shi et al., 2013). Research has focussed primarily on the impact and benefits within the comminution circuit, not the full mineral recovery process, meaning that there is limited literature on the effects of electrical comminution on particle texture and surface chemistry.

During electrical comminution the high electrical field causes electrical polarisation of valuable mineral grains which leads to electrical charges concentrating at the interfaces of the mineral grains. Thin micro plasma streamers are attracted to these areas of high electrical field concentrations whilst they move through the particle to bridge the two electrodes. Once bridged the solids along the plasma streamer are heated rapidly, resulting in a large increase in the internal pressure. Since this process occurs so rapidly the pressure increase causes an explosion within the ore particle which in turn generates shock waves which reflect and refract within the ores inhomogeneties or inclusions selectively fragmenting the particle (Andres et al., 2001; Bluhm et al., 2000). During electrical comminution the extreme heat of the plasma channel results in the surfaces of the mineral grains being exposed to highly oxidative conditions and therefore the surface chemistry is expected to have changed. This is evident in the work done by van der Wielen (2013) where pyrite was seen to decompose along the plasma channel.

The surface chemistry of the valuable mineral is a critical factor in determining separation performances by flotation and leaching. The formation of a passivating polysulphide film during chalcopyrite oxidation (Parker et al., 1981; Buckley and Woods, 1984) prevents flotation reagents from adhering to the surface and the valuable minerals can therefore not be recovered. The passivating

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layer also inhibits the diffusion and dissolution of the valuable minerals during leaching, resulting in a decrease in the overall copper recovery.

Flotation studies were performed by Andres et al. in 2001 using a laboratory high voltage device to electrically comminute ore. The results showed improved concentrate grades; although the recoveries did not necessarily improve. It was concluded that the electrically disintegrated ore was more liberated leading to less impurities being recovered into the concentrate; however the particles were not always liberated sufficiently to improve the recovery. Their study did not, however, investigate the surface chemistry changes that occur as a result of electrical comminution and the fact that the reductions in recovery could be due to oxidised valuable mineral surfaces.

Thus there is a need to determine the effects of electrical comminution oxidation on the surface chemistry of valuable minerals and to determine if these changes inhibit the recovery performances. This knowledge will aid in the design of electrical mineral processing circuits which take full advantage of the benefits that electrical comminution has to offer.

2. Method

2.1. Feed materials

A porphyry copper ore was selected for this study as chalcopyrite is the main copper-bearing mineral and flotation tests could be performed. The feed size to the SELFRAG and mechanical jaw crushers was −53 + 9.50 mm for all the test work. The modal mineralogy of the ore can be seen in Table 1. The chalcopyrite average grain size was determined from the MLA particle images and mineral grain size distributions to be 120 μm.

Chalcopyrite ($CuFeS_2$) samples, obtained from Geodiscoveries, were used for the surface analysis, using X-ray photoelectron spectroscopy, as it eliminates any noise due to silicate impurities, resulting in a better understanding of surface chemistry changes. Prior to comminution the feed particles were painted red to identify existing exposed surfaces. This allowed newly generated surfaces to be identified for XPS analysis. Trace inclusions of quartz and pyrite were avoided in the XPS measurements.

2.2. Comminution methods

2.2.1. High voltage SELFRAG treatment

Half the porphyry copper ore was treated in ±620 g batches of −53 + 9.50 mm particles with a SELFRAG Lab machine, manufactured by SELFRAG AG in Switzerland. The facility has been described previously by Shi et al. (2012). The particles are placed in a process vessel, with a mesh size of 4 mm, which is filled with distilled water. The process vessel is then placed onto the lifting table within the process vessel chamber. The chosen operating conditions – voltage (180 kV), frequency (4 Hz), number (80) of pulses and electrode gap (40 mm) are set using the control panel. The lifting table lifts the process vessel until the electrode reaches the set gap. The HV pulse generator is charged by the HV power supply until the set voltage is reached and the energy is then discharged through the electrode. The bottom of the process vessel acts as a ground electrode which forces the high voltage pulses to pass through the sample in the vessel in order to reach the ground electrode. The high voltage pulse causes the rocks to fragment with the undersize particles falling through the mesh aperture. The lifting table is then lowered so that the process vessel can be retrieved. For safety reasons the doors are locked by the device while the lifting table is in motion and whilst treatment is underway. The SELFRAG product was then sized using a 3.35 mm screen and oversized particles were re-treated until all the product was at −3.35 mm.

The pure chalcopyrite sample was treated in the SELFRAG Lab using the single-particle/single-pulse treatment method (Shi et al., 2013). In this technique the height of the particle is measured so that the optimal electrode gap can be determined to ensure the voltage passes through the particle with less energy losses into the process water. Although the single-particle/single-pulse test ensures all the particles are treated, it is a time-consuming test and only small amount of ore can be treated hourly therefore batch processing was used to treat the porphyry copper flotation ore.

Table 1
Modal mineralogy of the porphyry copper ore.

Mineral	Mass percentage (%)
Chalcopyrite	3.5
Pyrite	2.8
Silicates	90.1
Magnetite	2.25
Other	1.35

2.2.2. Mechanical comminution

The remaining porphyry copper ore was mechanically comminuted with a jaw crusher to produce a −3.35 mm product. The aim was to produce the same overall particle size distributions for both the electrical and mechanical comminution products, shown in Fig. 1. To achieve this the samples were mechanically and electrically comminuted at specific energy levels of 1.5 kWh/t and 21.8 kWh/t respectively. The large energy consumption for electrical comminution is attributed to the inefficient batch treatment process in this laboratory-scale equipment. The electrically comminuted samples from these batch tests were used as feed in the subsequent batch flotation tests.

2.3. Mineral liberation analysis (MLA)

The MLA employs various analysis methods to determine the mineralogy, grain sizes, mineral liberation and associations and elemental deportment. It uses backscattered electron images, to define different phase boundaries within the particle, together with energy dispersive X-ray analysis (EDX) which provides elemental composition data used to identify the mineral. Accurate and detailed particle images and quantitative data outputs can then be produced (Burrows and Gu, 2006).

The MLA system at the Julius Kruttschnitt Mineral Research Centre (JKMRC) is based on a FEI Quanta 600 Mk 1 SEM fitted with

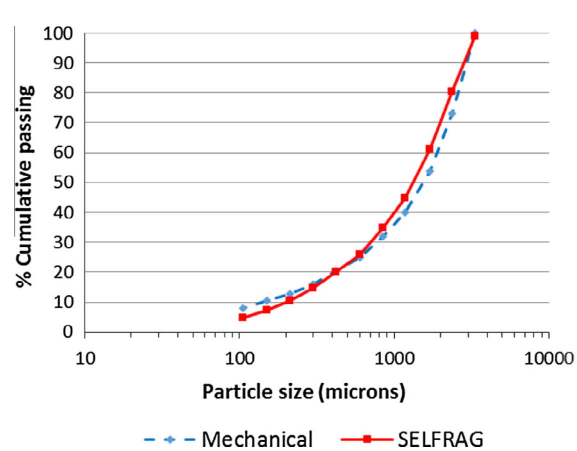

Fig. 1. Particle size distribution curves of the electrically (21.8 kWh/t) and mechanically (1.5 kWh/t) comminuted products at a feed of −56 + 12 mm.

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