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Characterising and quantifying microwave induced damage in coarse sphalerite ore particles

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ABSTRACT

Microwave induced cracks have the potential to enhance metal recovery from coarse sphalerite particles in heap leaching operations by creating new crack surface areas for lixiviant. The characteristics and quantity of microwave induced cracks and how these cracks subsequently affect heap leaching recovery has not yet been investigated. This study characterised and quantified microwave induced crack damage by applying X-ray computed tomography (XCT) and Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) analysis. Sphalerite ore particles representing small (−5 + 4.75) mm, medium (−16 + 9.5) mm, and large (−25 + 19) mm HPGR and cone crushed products were microwave treated at specific microwave heating energies of between 1 and 3 kW h/t. Image segmentation, thresholding and spatial registration techniques were used to study crack patterns in the XCT 3D images. The results showed the presence of microwave induced cracks within the cone and HPGR microwave treated particles. The cracks consist of both interphase trans-granular and grain boundary cracks. Both XCT and QEMSCAN analysis results showed that microwave treatment resulted in a significant increase of over 500% in crack volume for both modes of prior comminution at all particle sizes.

1. Introduction

Heap leaching has been shown to be an economically viable energy efficient hydrometallurgical processing option route for extracting metals from complex low grade ores such as copper, zinc, nickel and gold (Pradhan et al., 2008). In heap leaching, the ore is typically crushed to a size fraction suitable for controlled irrigation and percolation of lixiviant and deposited in heaps. The heaps are irrigated with the lixiviant that reacts with the minerals present in the ore particles. The resultant pregnant leach solution is collected for further processing to extract the valuable metals. The kinetics of heap leaching reactions are a complex function of particle size distribution, ore mineralogy, surface properties, crack size distribution and ore permeability (Ghorbani et al., 2011b; Petersen and Dixon, 2007). One major drawback of heap leaching is the low recovery as compared to recovery by milling and flotation. This is because heap leaching is generally characterized by the extraction of valuable metals from poorly liberated, relatively coarse particles. Although mineral exposure has been shown to increase with decreasing particle size (Hsih et al., 1995; King, 1979; Miller et al., 2003). Heap leaching of too finely crushed ore may result in solution percolation and air flow problems in the heap. Thus heap leaching typically involves the recovery of metals from relatively coarse particles, often greater than 1 mm (Ghorbani et al., 2011a; Pradhan et al., 2008). Valuable mineral grain exposure and accessibility to lixiviant in these coarse particles are important factors that limit the extent of metal recovery in heap leaching.

The accessibility of mineral grains to leach solutions via cracks and pores within particles determines the performance of heap leaching sub-processes. This is because leaching primarily occurs at the subsurface regions that are available through surface cracks and pores (Ghorbani et al., 2011a; Petersen and Dixon, 2007; Pradhan et al., 2008). In heap leaching valuable mineral grains are usually embedded within larger ore particles and thus accessible only by diffusion through a network of connected cracks (Ghorbani et al., 2013a; Miller et al., 2003). Thus there has been recent interest in identifying ore crushing methods that favour improved mineral exposure. Recent studies have shown that high pressure grinding rolls (HPGR) products have more cracks when compared with products of the same size class from rod/ball mills (Daniel, 2007; Tavares, 2005). Daniel (2007) qualitatively compared MLA back scattered images of HPGR crushed particles against those from conventional ball mills. The results showed that HPGR promotes micro-cracking. Vizcarra et al. (2010) carried out

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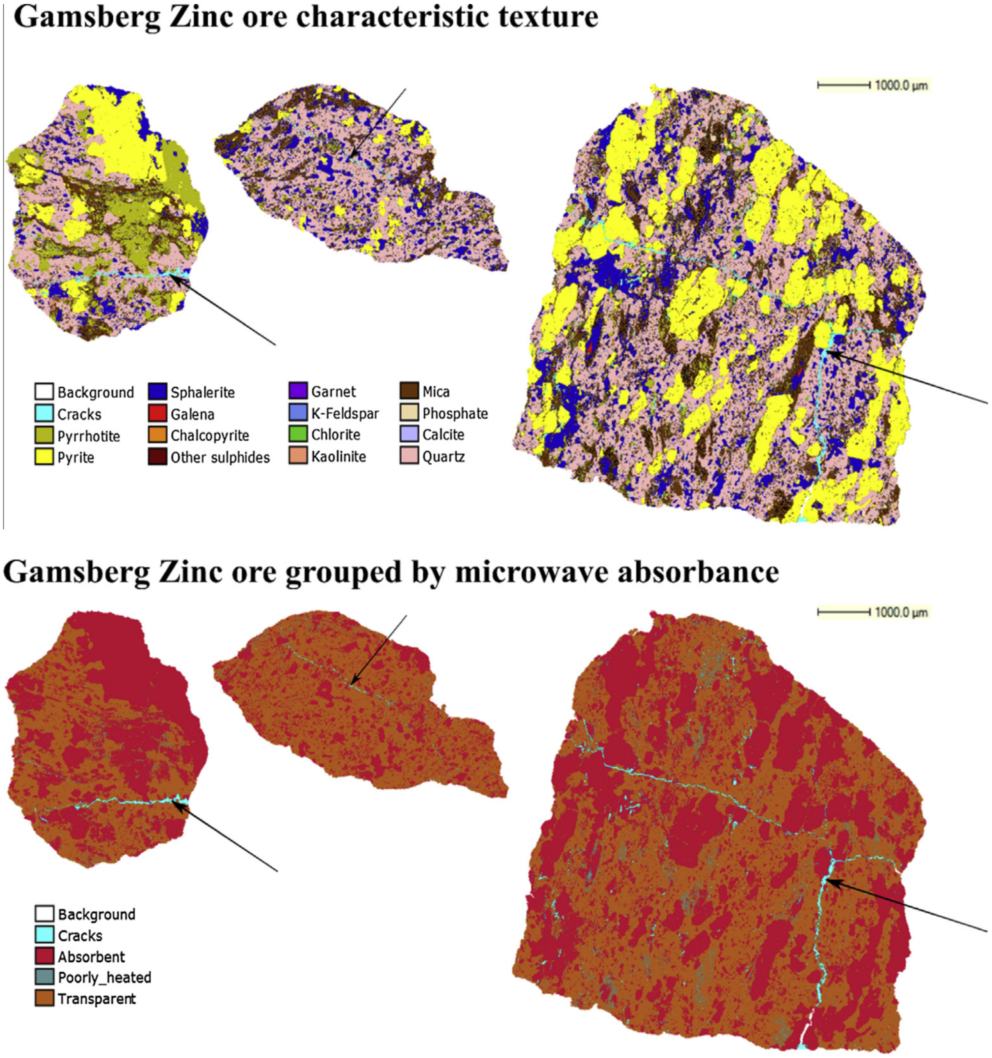

Fig. 1. Gamsberg Zinc Ore characteristic texture measured using QEMSCAN with arrows showing cracks.

studies to determine the effect of comminution mechanism on particle properties such as liberation. The results of the studies showed that liberation properties were independent of comminution route and degree of size reduction (Vizcarra et al., 2010). This suggests that the properties of the ore, and not the mode of comminution, determine the amount of cracks induced in the ore during size reduction (Powell and Morrison, 2007). Ghorbani et al. (2011b) investigated the effect of mode of comminution on crack formation on cone and HPGR crushed particles. Using a combination of 3D X-ray computed tomography (XCT) and 2D Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) techniques the study showed that HPGR produced particles with a higher density of cracks and micro-cracks compared to cone crushed products of the same size. Subsequent column leach tests of the mill products showed greater metal recovery in HPGR crushed particles than cone crushed particles due to the presence of micro-cracks (Ghorbani et al., 2012, 2013b).

Table 1
Bulk modal mineralogy of sphalerite ore (Ghorbani et al., 2011a,b) and the susceptibility of the mineral to microwave heating according to observations made by Chen et al. (1984).

Phase	Mineral	Abundance (wt.%)
Absorbent	Sphalerite (high Fe; ($(Zn_{0.78},Mn_{0.07}Fe_{0.15})S$)	16
	Pyrite	33.8
	Pyrrhotite	1.2
	Galena	0.2
	Chalcopyrite	<0.1
	Fe oxides/hydroxides	1.9
	Other sulphides (mostly Molybdenite, Pentlandite, Arsenopyrite)	3.2
Transparent	Garnet	0.3
	K-Feldspar	0.4
	Chlorite	1.7
	Kaolinite	2.8
	Mica	7.9
	Phosphate	2
	Calcite	<0.1
	Quartz	25.5
	Others	3.1

The application of high power microwave energy to secondary crusher products has been shown to induce micro-fractures and cracks in the ore (Bradshaw et al., 2007). This suggests that heap leaching metal recovery from coarse particles could be improved through the application of microwave treatment during ore preparation. Since the extent and kinetics of heap leaching processes depend on the accessibility of grains to lixiviant, microwave treatment has the potential to improve both the extent and kinetics of

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