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Further study of grain boundary fracture in the breakage of single multiphase particles using X-ray microtomography procedures

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ABSTRACT

The present work aims to verify the 3D quantitative analysis of grain boundary fracture in the breakage of single multiphase particles using X-ray microtomography. The breakage of single multiphase copper ore particles (6 mm cubic particles) by slow compression was examined. From XMT reconstructed images using the Marching Cube method, interfacial areas between copper mineral grains and host rock were determined for both parent particles and progeny particles. In this way, the specific interfacial area ratio was calculated as a metric for grain boundary fracture. Preferential grain boundary fracture only occurs at low energy dissipation rates and the current results confirm initial results for 3 mm cubes published previously by Garcia et al. (2009).

1. Introduction

The ever-increasing demand for metals, declining ore grades, increasing complex nature of ores, and rising costs for improved processing describe the mineral industry's current and future status. In such a scenario, there is even greater demand on comminution systems to achieve effective mineral liberation. Improved liberation is realized if preferential breakage of multiphase particles occurs along the mineral grain boundaries. However, for most comminution processes, it is assumed that random fracture occurs.

Direct observation of intergranular fracture (fracture along the grain boundary) during multiphase particle breakage is difficult to measure. The best method of analysis is based on the measurement of the interfacial area before and after comminution. For complete grain boundary fracture and complete liberation of all grains, the interfacial area is reduced to zero. If grain boundary fracture does not occur, but rather random fracture, the interfacial area is conserved and the ratio is unity. In this regard, the ratio of the specific interfacial area in the progeny particles to the specific interfacial area of the parent particles is used to describe the extent of grain boundary fracture. For random fracture, interfacial area is not reduced and the ratio is unity. The interfacial area criterion is an important metric to assess the significance of preferential breakage for different breakage conditions (Garcia et al., 2009). The importance of single particle crushing experiments with respect to energy consumption was stated by Rumpf (1977) "How much energy can, in fact, be saved can only be determined by systematic tests with single particles".

Particles are stressed either individually (single particle events) or in beds (multiple particle events) in large-scale mills that operate at high throughputs such as occurs in crushers, HPGR's, and grinding mills. Comminution is an energy-intensive operation and the efficiency of commonly used machines is very low. Particles are often loaded using insufficient energy to cause breakage, being fractured only after repeated low-energy stressing. For instance, when a bed of particles is compressed in a piston-die test device, the breakage of the particles can be correlated with the specific energy of compression (Fuerstenau and Gutsche, 1994). Thus, particle breakage is frequently studied for the purpose of improving the efficiency of comminution operations.

It has been established that X-ray microtomography (XMT) can be used for the 3D determination of the internal damage of ore particles which vary in size from 40 mm down to a few hundred microns. Recently, particle damage has been reported in HPGR crushing of copper ores using high resolution X-ray microtomography (HRXMT) (Kodali et al., 2011; Lin et al., 2012).

Further, the HRXMT procedure has been developed for 3D liberation analysis (Miller and Lin, 2004). A high degree of exposure/liberation would be achieved if preferential breakage of multiphase particles occurred along the mineral grain boundaries. Under what conditions does fracture occur at a mineral grain boundary? Initial

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Fig. 1. Cubic copper sulfide ore specimens (6 × 6 × 6 mm) from the United States.

Table 1
Comparison of previous work (Garcia et al., 2009) and present work.

	Current research	Previous research (Garcia et al., 2009)
Dispersed mineral phase	Chalcopyrite and pyrite	Chalcocite
Source	United States	Chile
Particle size	6 mm cubes	3 mm cubes
Grade (volume%)	5.09–12.58	Less than 1 (obtained from XMT image)
Displacement rate (mm/s)	4.7E−06 to 9.4E−04	5.0E−06 to 9.0E−04

Table 2
Time and strain rate for a 0.17 mm reduction in the height of the 6 mm cubic samples.

Time (h)	Strain rate (mm/s)
0.05	9.4E−04
0.5	9.4E−05
1	4.7E−05
3	1.6E−05
5	9.4E−06
7	6.7E−06
10	4.7E−06

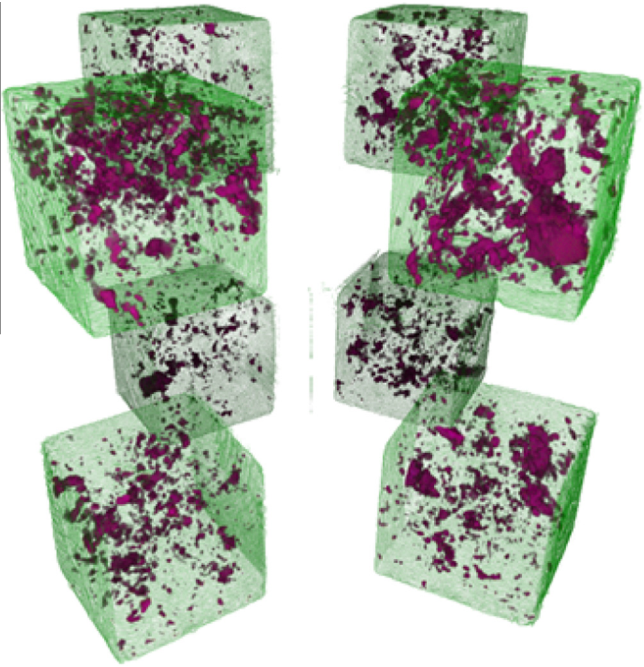

Fig. 3. 3D XMT images of the eight, 6 mm cubes of copper sulfide ore.

research suggests that a crack propagates and follows grain boundaries when slow compression is the method of breakage. These preliminary findings need to be confirmed and understanding of this phenomenon is required if more efficient comminution processes are to be developed for improved liberation.

Recently, conditions for grain boundary fracture under slow compression have been established by XMT (Garcia et al., 2009). The authors reported a procedure for detailed 3D analysis to quantify the extent of grain boundary fracture for different breakage conditions under compression loading using XMT. From these results, a relationship between the extent of grain boundary fracture and the specific energy dissipation rate was established. The present work is an extension of the previous work (Garcia et al., 2009) for confirmation and for examination of the effect of particle size on grain boundary fracture.

2. Materials and methods

Garcia et al. (2009) reported slow compression tests on 3 mm cubic samples of a copper sulfide ore from Chile. In this current study, 6 mm cubic samples of a copper sulfide ore from the United States were examined. See photo in Fig. 1. Comparison of the current sample with that of the earlier work (Garcia et al., 2009) is presented in Table 1. As shown in Table 1, the primary differences between the samples are ore type and particle size. Of course, the size of the grains will vary from sample to sample, but apparently

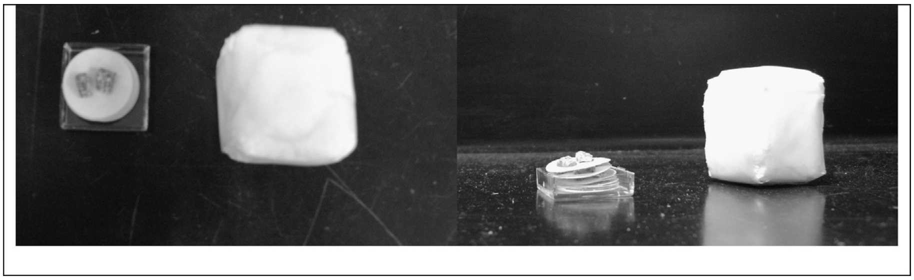

Fig. 2. Progeny particle size classes mounted on labeled filter papers and stacked in a cylindrical styrofoam container for CT scans.