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A study of the impact of blast induced conditioning on leaching performance

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ABSTRACT

Recent investigations have alluded to possible improvements of ore extraction efficiency by leaching due to blast induced fragment conditioning. This paper presents results from a series of controlled blasting tests supported by blast modelling and statistical analysis to study the effect of conditioning on copper extraction in laboratory leaching tests. A leachable synthetic material was developed and selected from 19 different preparations. It was possible to control copper grade distributions and provide homogeneous and isotropic characteristics to this material.

Combined statistical analysis of four individual controlled blasting tests exhibited no statistical difference in copper extraction between unblasted material and material subjected to a low degree of conditioning. In contrast, the percent copper extraction increased by 0.84% in the intermediate conditioning zones, which translates to an overall improvement in copper extraction efficiency of 39.7%. Leaching tests proved that increasing the blast conditioning does not necessarily improve percent copper extraction. The majority of fractures were generated along grains boundaries and not across the matrix. Therefore, conditioning may not be able to expose a significant amount of copper particles consistently to significantly impact extraction efficiency. In practical terms, the contribution of blast induced conditioning to leaching performance is in the increased probability of exposing mineral species to leaching paths.

1. Introduction

Fragment conditioning by blasting can be defined as the alteration of physical properties of the rock after blasting due to the extent of pre-existent cracks and the creation of new fractures. This phenomenon can be associated with two processes that take place at two different scales: macrofracturing and microfracturing. The former is generated at a scale of centimetres or greater whereas the latter is produced at scales of microns and millimetres.

This categorisation is far from being absolute and irrefutable as it depends on the size of the grains in the matrix and the scale of the phenomenon of interest.

In principle, fragment conditioning is expected to be present at all stages of mineral processing, providing a reduction in energy consumption during breakage as well as a potential increase in the permeability and liberation of minerals. Currently, microscopy and X-ray tomography are the most commonly used techniques to provide a direct measurement of crack density, extent and orientation of fractures. Nonetheless, the volume of data available for analysis is limited. Other techniques have been developed and applied to measure fracturing indirectly; these are based on the variation of mechanical and elastic properties of fragments and suffer from the same restriction as the microscopy techniques because they also have a limited application in terms of sampling volumes.

With regards to the classification of fractures in rock, three types have been identified in literature: intergranular, transgranular and intragranular (Åkesson et al., 2004; Muñoz et al., 2007). Intergranular fractures form along grain boundaries, transgranular fractures can cross multiple mineral grains and intragranular fractures are generated inside the grains.

Many studies have established that there is a direct relationship between stress induced by blasting and the extent of microfracturing generated inside the fragments. The stress intensity and

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direction (Liu et al., 2006) are not the only aspects that affect fragment conditioning; loading rate has also been shown to play an important role, particularly on the length of fractures (Chertkov, 1987; Liu et al., 2006).

Authors such as Rossmanith et al. (1997), Rathore and Bhandari (2007) and Katsabanis et al. (2008) have demonstrated that fracturing can be partially controlled through the application of suitable blast design parameters such as type of explosive, energy distribution and timing.

Although much has been learned from this experimental work, no link has been established with advanced modelling techniques to enable evaluations at scales used in production environments.

In addition, despite several authors such as Kojovic et al. (1995) and Michaux and Djordjevic (2005) proving the positive impact of blast induced fracturing on comminution, there is a limited understanding about the influence of this phenomenon on the mechanisms that govern leaching performance.

2. Fragment conditioning and leaching

Leaching performance can be evaluated by measuring three main indicators, namely ore recovery, reagent consumption and leaching kinetics. These parameters are controlled by several chemical and physical factors. A key parameter to improving total percent ore extraction is mineral exposure which defines the amount of mineral that is in contact with the lixiviant solution. The main factor contributing to mineral exposure within coarse particles is fracturing (conditioning) that may be induced by processes such as blasting and comminution.

Leaching kinetics is affected by both chemical and physical properties. Chemical factors include solution pH, temperature, mineralogical species, and ore grade. Physical factors controlling the rate of the leaching process at heap/dump scale are the mineralogical structure, the irrigation technique, natural porosity, fragment size distribution, amount and type of clays, heap height, and saturation degree. Given similar sized particles, the kinetics at fragment scale would be enhanced mainly by induced conditioning.

Reagent consumption is controlled mainly by chemical aspects such as target mineralogical species and impurities as well as solvent type. If a greater degree of conditioning could improve only targeted mineral exposure without increasing gangue exposure, then it is possible that conditioning could also reduce overall reagent consumption.

Over the years, fragment size distribution has been defined as a key factor influencing leaching performance (Wen et al., 1996; Lwambiyi et al., 2009). Minimal work has been conducted to study the effect of fracturing inside fragments (conditioning) on leaching performance. One such study was conducted by Fribla (2006) who incorporated one stage of crushing after blasting samples with different powder factors. Fribla (2006) identified a close relationship between powder factor and the generation of micro-fractures for 20 × 20 × 20 cm cube samples (using 2 and 4 g PETN – Pentaerythritol tentranitrate). The blasted material was crushed and classified to 100% minus 3/8″ and located in leaching columns 10.6 cm in diameter and 20 cm high. As shown in Fig. 1, higher micro-fracturing levels correlated positively with higher percent copper recovery (with 27 days leaching time). Despite the relationship between blast intensity and leachability that was observed, their approach was unable to differentiate the effect of increased fracture density from the increased proportion of fines.

3. Research methodology

To study the impact of blast induced conditioning in leaching performance it is necessary to eliminate the influence of overall fragment size distribution and other comminution stages. A methodology that allows an estimation of the extent of conditioning and an approach to scale up the phenomenon to production scales is also required. This section describes the research methodology adopted which involved three stages of experimental work, modelling and statistical analysis:

- Stage 1, a leachable synthetic material was developed. A number of preparations using different grouts and additives were cast and tested to verify whether they matched physical requirements for controlled blasting tests. The use of a synthetic material was a necessary step to enable greater control over strength homogeneity, blast induced stress propagation and boundary conditions.
- Stage 2 comprised the blast of a preliminary sample (P0) using PETN and was designed as an exploratory test to define final experimental procedures. This test also allowed the definition of operational and logistical matters associated with the casting and blasting of the samples such as curing time, mixer operation, fragment confinement and sampling. This stage also helped verify the synthetic material suitability, stress intensity of the small charge and effect of boundary conditions. Preliminary modelling was also conducted in this stage and a methodology to define conditioning zones was introduced.
- Stage 3 comprised two controlled repeatability tests with emulsion charges (E1 and E2). This stage was used to validate the experimental procedures and study the potential links between fragment conditioning and copper extraction efficiency. Stage 3 also comprised a validation phase (tests P1 and P2) where two different spatial configurations were tested to establish the effect of different boundary conditions on the extent of conditioning. In all these analyses, numerical modelling was used to define the conditioning zones and support the grouping of samples for detailed statistical analysis.

During stages 2 and 3, samples consisting of 10 fragments of at least 50 g in total were collected. Percent copper extraction was measured for each fragment with the average value for each sample being used in the statistical analysis to quantify variations before and after blasting. X-ray tomography was conducted to identify the type of fracturing observed and to support the leaching performance analysis.

An advanced blast modelling tool (i.e. The Hybrid Stress Blasting Model (HSBM)) was available to the authors to support this research process. As described by Furtney et al. (2009), the code uses a combination of a continuum numerical technique and discrete element modelling (DEM) to model the complete blasting process. The near-borehole area is represented using FLAC (an explicit Lagragian finite difference code), while DEM is used to represent the rock mass. The DEM representation uses a lattice-scheme where the rock matrix is created as a collection of randomly distributed points connected by springs. The theoretical distance between different springs depends on the resolution used for modelling. The key inputs of the model are: detonation parameters (i.e. explosive density, velocity of detonation, decoupling, etc.), material properties (i.e. density, unconfined compressive strength, tensile strength, Young's modulus, etc.) and stress/strength attenuation. Further information on the configuration and application of the code can be found in Onederra et al. (2013).

4. Development of synthetic material

At the early stages in this research it was obvious that it would be very difficult to obtain natural rock samples that would have homogenous and isotropic properties and could be shaped to suit