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Recovery of copper sulphides mineral grains at coarse rock fragments size

Nenad Djordjevic *

JKMRC/SMI, The University of Queensland, Brisbane, Australia, 40 Isles Road, Indooroopilly, Qld 4068, Australia

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ABSTRACT

Assuming the random distribution of sulphide mineral grains and random rock breakage, a relatively small percentage of sulphide grains will be exposed on the rock surface. Early liberation of sulphide grains needs to be considered in terms of the mechanical properties of such grains relative to the properties of the host rock matrix.

Clustering of sulphide mineral grains, will make early liberation possible. Depending on the nature of mineral associations, crushing of such rocks will result in different outcomes. Where clustering is manly of very soft copper minerals, with the host rock being moderately strong feldspars or quartzite's, the copper rich parts of rock are likely to fragment first, resulting in relatively small size being rich in copper minerals. However, in the case of moderately strong chalcopyrite, the difference in elastic properties between chalcopyrite and feldspar or quartz, will not be significant enough to cause a propensity for early liberation.

Where clustering of copper minerals occurs with grains of pyrite (or magnetite), the stronger part of the rock fragment will be one rich in valuable minerals. During crushing of such rock, the sulphides rich zones will fragment in a different way than gangue. Stress concentration within pyrite (or magnetite) will result in failure of the relatively soft surrounding matrix, thus promoting liberation of chalcopyrite or chalcocite grains. Therefore, textural information about the associations of sulphide minerals (copper sulphides vs. pyrite/magnetite/garnet) will be of critical significance in the evaluation of the propensity for coarse liberation of copper sulphide minerals. An absence of close spatial associations will significantly reduce the possibility of early liberation of copper sulphides.

During blasting ore is exposed to sufficiently intense, high-strain rate loading to be able to induce micro-fracturing originating from individual sulphides mineral grains as well as their clusters. Due to the high rate of loading, a substantial amount of energy can be dissipated with embryonic rock fragment, before macro-failure of rock, which will relieve rock of blast induced stress. Created micro-cracks will play a significant role in subsequent comminution, where rock fragments with enhanced density of micro-cracks will be crushed more easily. Extensive micro-cracking is also likely to play a significant role during heap or dump leaching, stimulating infiltration/diffusion of leaching fluids into the interiors of rock fragments.

1. Introduction

The most important objective of the rock size reduction process is to release all targeted valuable mineral from the host rock at as coarse rock fragment size as possible. Achieving this would bring about huge savings in the overall cost of mineral production. Considering that the density of metal rich grains, such as sulphides of copper, are generally much higher than the density of gangue, in many mines, metal rich sulphides grains represent only 1–2% of the volume of the mined and processed ore. Therefore, for typical porphyry copper ore, close to 99% of the treated ore volume is a costly by-product of the production of copper concentrate.

At present, liberation of such minerals is achieved primarily through crushing and grinding of ore to a fragment size comparable to minerals grain size (80% passing size 100–300 μm). Rejection of part of the waste material at a coarser fragment size will greatly improve the efficiency of mineral recovery (Bearman, 2013). When final mineral recovery is achieved through processes such as leaching, the more modest objective would be to achieve a high exposure of valuable minerals at as coarse as a rock fragment size as possible. In the context of this paper, the term liberation is used

* Tel.: +61 7 3365 5888; fax: +61 7 3365 5999.
E-mail address: n.djordjevic@uq.edu.au

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in a broader sense, to include not just full liberation of minerals, but also their substantial exposure on the surface of rock fragments.

Considering that the cost of rock size reduction is the principal operational cost of mining/mineral processing, a reduction of the communication cost could have a very significant impact on the overall economics of mineral recovery from a particular deposit. In some cases, this impact may result in some marginal or sub-economic ore bodies, currently considered as resources, becoming reclassified into reserves, with subsequent ramifications to the value of deposits and mining companies.

2. Modelling of liberation of randomly distributed grains

Where sulphide grains are randomly distributed within the volume of the rock, it is of interest to examine what percentage of sulphide grains will be exposed on the surface of rock fragments. By doing so a base case can be established, i.e., what can be expected if there is no early liberation of sulphide minerals.

Sulphides are present in the form of numerous grains, their total number is a function of grade and size. Even in a very marginal ore, the number of grains is likely to be in the hundreds, (for the rock fragment size in the range of 30–50 mm). Hsih and Wen (1994) and Hsih et al. (1995) developed a geometrical model to calculate the fraction of mineral grains that are exposed on particle surfaces during comminution of a two-phase ore.

In the case of random breakage, with large number of grains present within the rock, the fraction of sulphide grains that will end-up exposed on the rock surface is determine by the ratio of rock size vs. grain size. Assuming constant grain size, the fraction of available sulphide grains that are partially exposed on the rock surface will increase with a decrease in rock size, as expected.

Similarly, for constant size of rock, the fraction of available sulphide grains that will be exposed on the rock surface will increase with an increase of the grain size. So coarse grain mineralization will be more liberated than fine grain (i.e., greater percentage of available grains will have some exposure on the rock surface). For example, assuming that grains size is in the range 0.1–0.3 mm, for the rock size of 30 mm, application of the model shows that only about 2–7% of sulphides grains will be exposed on the rock surface. Therefore, assuming random breakage and random distribution of sulphide grains, a relatively small fraction of such grains can be relatively easily recovered from the rock. In such case, only further reduction of rock fragments size will ensure fuller liberation/surface exposure of valuable sulphide minerals.

In the case of copper ore, the typical grain size of copper minerals is often in the range of 0.1–0.3 mm. Difficulties in liberation are further highlighted by the modest grade of many major copper deposits (~0.5%Cu). Considering that for chalcopyrite the copper content is 35%, and copper grade is 0.5%, for uniform distribution of copper minerals, each grain of chalcopyrite will be surrounded by 200 grains of gangue minerals. It will be difficult to expect that the process of rock size reduction will be so efficient as to preferentially liberate such small mineral grains, homogeneously distributed within volume of rock fragment.

How to define coarse particle liberation; i.e., from which fragment size and above does liberation of valuable minerals becomes coarse particle liberation? It is possible to assume that the required final size of fragments coming from comminution is dictated by the requirements of the next step in the process of mineral recovery. In the case of sulphide minerals, this is often flotation. In such case, ore is ground to, at least 300 μm, depending on the size of sulphide grains. Thus, if valuable minerals can be liberated, fully or partially, while grinding ore to a size coarser than ~300 μm, then that specific coarser size would represent liberation at coarse fragment size.

Although the final fragment size of gangue particles could be coarser than 300 μm, the size of fragments containing valuable sulphide grains should remain the same, i.e., under 300 μm (i.e., at the top size that will maximise their subsequent recovery). For instance, if ore comminution to top size of 1 mm, would liberate (fully or partially), all valuable sulphide minerals grains by having them in the fragment size range up to ~0.3 mm; then that would constitute liberation at coarse fragment size. Obviously, it would be highly advantageous if such liberation of sulphide minerals can be achieved at a much coarser fragment size of gangue, for instance 5 or 10 mm, or even coarser.

At best such early liberation may result in the product of SAG milling or HPGR crushing, being composed of coarse, almost barren gangue fragments, and finely crushed sulphide rich fragments. This creates an opportunity for avoiding highly energy intensive ball milling or reducing such a need to a minimum. Strongly bimodal fragment size distribution coming from SAG mill or HPGR, can be separated into a dominant coarse gangue part and highly enriched fines (size less than ~0.3 mm). In the context of a modest grade of typical copper ores, it is worth noting that the amount of high grade fines does not need to be large to contain almost all valuable minerals present in ore (<5% of total ore mass).

Consideration of the propensity for earlier substantial liberation of sulphide minerals (while the rock fragments are still coarse), should start from an analysis of the mechanical properties of valuable minerals in the context of properties of host gangue minerals.

3. Elastic properties of minerals

The values of modulus of elasticity of minerals and solid rock are of critical significance in the evaluation of the propensity for early liberation, Fig. 1. Related parameters such as strength (in compression and tension) can be approximated based on knowledge of elastic constants. Vickers hardness is frequently available and can be used as proxy to elastic constants of minerals.

The most interesting aspect of the above figure is the difference between the elastic modulus of chalcopyrite and the group of typical gangue minerals such as feldspars, quartz and calcite. The difference is not very large. In contrast, the elastic constants of pyrite and magnetite are much higher than those of the most common gangue minerals. Other main copper sulphides such as chalcocite and bornite, due to their much higher copper content and lack of iron, have an even lower modulus of elasticity than chalcopyrite.

In the course of this work, strength properties as well as elastic properties are determined through instrumented, computer controlled, micro-indentation testing. In contrast to traditional hardness testing, instrumented indentation testing allows the

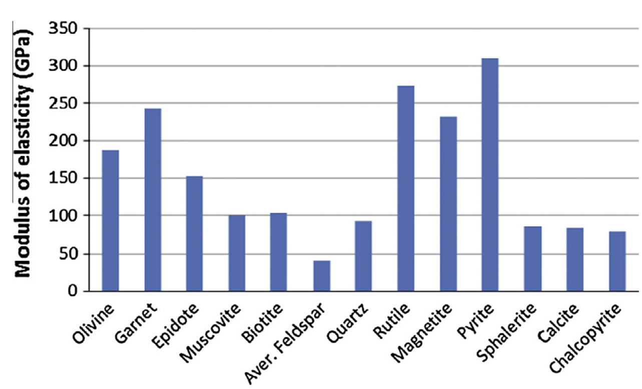

Fig. 1. Modulus of elasticity of some common minerals (after Mavko et al., 2009).