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Using mineralogical and particle shape analysis to investigate enhanced mineral liberation through phase boundary fracture

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ABSTRACT

In comminution, liberation has been recognised as a more important performance indicator than size reduction because the degree of liberation of valuable minerals dictates the theoretically achievable grade-recovery curve for downstream separation processes. The degree of liberation of a certain mineral within an ore, ground to a specific particle size distribution, will be dependent on the primary ore texture, the mineral grade and grain size distribution, and the degree and nature of phase boundary fracture, which can, allegedly, be linked to the breakage mechanisms employed within the comminution device. The occurrence of enhanced liberation through phase boundary fracture is desirable, and in recent years, studies have focused on whether or not certain comminution devices enhance this phenomenon. However, comparatively little attention has been paid to quantifying phase boundary fracture in typical mineral processing operations. In this study, a novel approach to quantify phase boundary fracture is proposed which is based on the conservation of grain shape. The approach is demonstrated through a mineralogical analysis of UG2 ore sampled from the discharge of a primary ball mill. Phase boundary fracture was found to be the mechanism responsible for producing 50% PGM liberation at a grind of 40% passing 75 μm, rather than a grind of 50% passing 3 μm which would be required under theoretical random breakage assumptions.

1. Introduction

1.1. Introduction and objectives

In mineral processing applications, the purpose of comminution is typically to liberate the valuable minerals in an ore so that they can be separated from the gangue minerals in subsequent separation processes such as flotation. However, the performance of a comminution circuit is typically modelled, designed or assessed based on product size distribution rather than liberation. Powell and Morrison [1] describe the incorporation of liberation as the "holy grail" of comminution modelling. King [2], as quoted by Powell and Morrison [1], stated that "… significant advances in comminution technology will only come from the exploitation of basic fundamental understanding of the fracture process".

The ability to measure phase boundary fracture is critical to the development of understanding of how liberation changes during size reduction. Some progress has been made towards quantifying phase boundary fracture in fundamental research studies, typically incorporating different grinding devices. It is however a challenging task, and there have been no industrial case studies that convincingly demonstrate the significant impact that phase boundary fracture can have on liberation in a typical comminution circuit. The first objective of this study is to present a new approach for quantifying the occurrence of phase boundary fracture based on the conservation of grain shape. The technique is used here to determine the extent to which the rounded chromite grains in UG2 ore are liberated by detachment. This is then compared to the traditional approach based on conservation of phase specific interfacial area (PSIA). The second objective of the study is to demonstrate the key role of phase boundary fracture in the liberation of finely grained platinum group minerals (PGMs) during UG2 ore processing.

1.2. Breakage mechanisms and liberation

For discussion of fracture mechanisms, two broad terms are commonly used to describe fracture: *random* and *non-random*, although these vary depending on the underlying assumptions and the application. When using the population balance model, the term random is used to describe breakage in which particles from a single size class will be broken into a predictable unimodal distribution of finer particles. Liberation and mineralogy are not taken into consideration, so whether phase boundary fracture occurs or not does not necessarily influence the applicability of this modelling approach to a given ore type. However, when liberation is of interest, the definition of random breakage is extended to include liberation effects, and Barbery [3] describes this as random uniform isotropic fragmentation (RUIF). Key assumptions are

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that interfacial area is conserved during breakage and that grade does not vary with particle size. Any breakage in which these criteria are not satisfied is then classified as non-random fracture. This is discussed in more detail in Section 3.1.

King and Schneider [4] described several mechanisms of non-random fracture, including selective breakage, differential breakage, preferential breakage, phase boundary breakage, liberation by detachment and boundary region fracture. However, it is not typical to differentiate between all of these mechanisms; the first three mechanisms can be referred to as preferential breakage, and the latter three as phase boundary breakage. A phase boundary is defined as the interface between two different minerals within a multi-component ore. A schematic illustrating these fracture mechanisms, along with definitions related to how energy is imparted to a particle is provided in Table 1 [5–14].

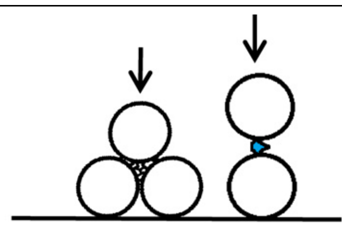
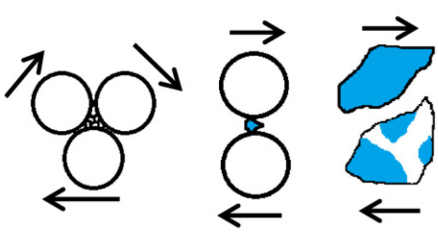
In the late 1980s and early 1990s, various authors attempted to develop approaches for modelling and simulation of random and non-random fracture, and the subsequent liberation response [3,7,15,16]. However the majority of the work was theoretical, and mostly involved predicting the liberation response under random breakage assumptions, and then showing whether or not this matched experimental data. In recent years, the topic has received much less attention, which is surprising as there has been an increase in the use of Automated Scanning Electron Microscopy with Energy Dispersive X-ray Spectrometry (Auto-SEM-EDS). This technology is widely used for analysis of liberation, providing valuable insight into mineral processing operations, but the liberation data produced is seldom being linked back to fracture mechanisms. Of the more recent work that has been done in the field, most studies have focused on whether or not grinding devices utilising compression breakage give enhanced liberation relative to traditional tumbling mills [17–22]. The conclusions of these studies, based on comparison of liberation, are not always in agreement. From a statistical analysis of Auto-SEM-EDS liberation data, Vizcarra [22] suggested that most of the differences reported in literature may not be statistically significant at a high confidence level. Qualitative research has also been carried out into phase boundary fracture during electric pulse breakage (SELF-RAG) and microwave pre-treatment [23–27].

The occurrence of phase boundary fracture and the implications for liberation will vary from ore to ore, so findings relating to phase boundary fracture will not usually be generalizable between studies considering different ore types and different grinding devices. The main approach that has been used to quantify phase boundary fracture to date has been the measurement of PSIA before and after breakage [7,13,18,19,21,27]. A decrease in PSIA during breakage indicates the occurrence of phase boundary fracture. With 3-D data from micro X-CT, this technique has great potential for research in this area [19,21]. However, when based on 2-D data from the more widely used Auto-SEM-EDS devices; it relies on a number of assumptions, stereological correction procedures and correction factors which result in an indirect measurement. After developing and demonstrating this technique, King [7] observed that other, more direct measurements of phase boundary fracture would be required to supplement this approach.

1.3. UG2 ore mineralogy and processing

The UG2 ore is a multi-component platinum group element (PGE) ore from the Bushveld Complex in South Africa, contributing an

Table 1
Definitions of breakage mechanisms - circles represent grinding media, shaded and not-shaded represent different mineral phases. A mineral grain is defined as a 3-dimensional entity consisting of only one mineral phase: particles consisting of one, two, or more grains are defined as liberated, binary and composite particles respectively.

Grinding Action	Other factors affecting outcome	Grinding outcome
 Compression	**Contact energy** (Repeated, low energy contacts vs single high energy contacts)	 Inter-granular fracture Phase boundary fracture Grain-boundary fracture
 Impact	**Ore characteristics** (Strength of independent mineral components and grain boundaries)	 Preferential fracture Selective breakage
 Shear		 Massive fracture Random fracture  Abrasion Attrition Chipping