Minerals Engineering 52 (2013) 136–142

Contents lists available at SciVerse ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Automated characterisation of intergrowth textures in mineral particles. A case study

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ARTICLE INFO

Article history:
Available online 24 May 2013

Keywords:
Geometallurgy
Liberation analysis
Particle mineral texture characterisation
Digital image analysis

ABSTRACT

The characterisation of mineral texture has been a major concern for process mineralogists, as liberation characteristics of the ores are intimately related to the mineralogical texture. While a great effort has been done to automatically characterise texture in unbroken ores, the characterisation of textural attributes in mineral particles is usually descriptive. However, the quantitative characterisation of texture in mineral particles is essential to improve and predict the performance of minerallurgical processes (i.e. all the processes involved in the liberation and separation of the mineral of interest) and to achieve a more accurate geometallurgical model.

Driven by this necessity of achieving a more complete characterisation of textural attributes in mineral particles, a methodology has been recently developed to automatically characterise the type of intergrowth between mineral phases within particles by means of digital image analysis. In this methodology, a set of *minerallurgical indices* has been developed to quantify different mineralogical features and to identify the intergrowth pattern by discriminant analysis. The paper shows the application of the methodology to the textural characterisation of chalcopyrite in the rougher concentrate of the Kansanshi copper mine (Zambia). In this sample, the variety of intergrowth patterns of chalcopyrite with the other minerals has been used to illustrate the methodology. The results obtained show that the method identifies the intergrowth type and provides quantitative information to achieve a complete and detailed mineralogical characterisation. Therefore, the use of this methodology as a routinely tool in automated mineralogy would contribute to a better understanding of the ore behaviour during liberation and separation processes.

1. Introduction

Texture is a critical mineralogical feature for the characterisation of ore behaviour during mineral processing. The possibility of achieving liberation by comminution, thus the potential recovery, is intimately related to textural relationships between minerals. However, texture characterisation is usually subjective (Bonici et al., 2008) and traditionally more related to ore deposit exploration than to mineral processing performance. From this technical point of view three textural features appear as the most significant for mineral liberation characterisation: grain size, grain boundary irregularity and the pattern of intergrowth type (Petruk, 2000; Ramdohr, 1980; Gaudin, 1939).

The characterisation of grain size determines how much grinding is required to achieve liberation. On the other hand, the nature of boundaries between intergrown minerals indicates whether mineral grains will break at the boundaries or not (Petruk, 1995), and therefore, the ease or difficulty of liberating the mineral of interest. Based on textural attributes a variety of mathematical models have been developed for predicting mineral liberations (Gaudin, 1939; Wiegel and Li, 1967; King, 1982; Gay, 2004). However, the application of these models is not widely spread and liberation is commonly estimated from laboratory testwork. Liberation estimations obtained experimentally are then represented by liberation curves, using the concept of cumulative liberation yield developed by Miller et al. (1982). These curves are usually based on liberation computed as weight proportion of the mineral of interest (**MOI**) in particles. However, when the ore presents complex texture, mainly when locking exists, liberation computed as surface exposed to reactants seems to be more appropriate (Lastra, 2002). In these cases, textural characterisation, and especially the characterisation of the intergrowth pattern, is essential to determine the response of mineral particles to separation processes and the possibility of increasing liberation by a regrinding stage. As an example, Fig. 1 shows the significance of the intergrowth type on mineral processing. This figure shows four chalcopyrite bearing particles in which chalcopyrite (bright phase)

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http://dx.doi.org/10.1016/j.mineng.2013.05.001

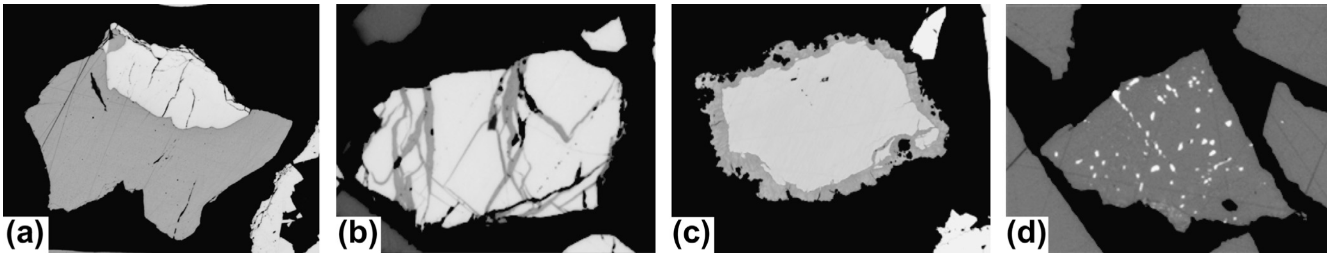

Fig. 1. Grey level images of ore particles under reflected light to illustrate the four intergrowth types described by Gaudin (1939) as the most relevant in flotation ((a): simple; (b): stockwork; (c): coated; and (d): emulsion).

will behave in a completely different way during flotation and regrinding.

Several authors have developed different methods for textural analysis of unbroken ores (Amstutz and Giger, 1972; Steiner, 1975; Miller et al., 1982; Leigh, 2008). However, the characterisation of intergrowth patterns in mineral particles is usually descriptive and based on direct observations. The procedure lacks automation, thus involving major limitations in the quantitative characterisation of this textural feature, and its integration in a geometallurgical model. With the aim of automatically characterising the intergrowth type that one specific phase presents within mineral particles, a new methodology has been developed (Pérez-Barnuevo et al., 2012).

The main objective of this paper is to assess the ability of this new methodology to achieve a complete characterisation of the intergrowth types within mineral particles. This method has been tested by its application to the characterisation of chalcopyrite in the rougher concentrate of the Kansanshi copper ore. The variety of intergrowth patterns that this mineral presents in this sample, especially when it is associated with secondary copper sulphides, makes this sample particularly interesting to test the method, even though the separation of chalcopyrite and secondary copper sulphides is not a requirement for successful flotation in the particular case of the Kansanshi flotation circuit.

It should be noted that results achieved in this work are intended to show the potential of the method for general cases. Therefore, results are presented and discussed in order to evaluate and illustrate the ability of the methodology to provide quantitative information about textural attributes and not to assess the specific behaviour of chalcopyrite in the Kansanshi flotation circuit.

2. Materials and methods

To perform the characterisation of chalcopyrite in the selected sample, digital images have been acquired and classified with a Mineral Liberation Analyzer (**MLA**) system. After classification, more than 500 unliberated chalcopyrite bearing particles are analysed with the *Textural Descriptors Methodology* (Pérez-Barnuevo et al., 2012). Through this methodology a set of indices is computed and used to identify the intergrowth type by discriminant analysis. Apart from their expected discriminant power, these indices have been developed to characterise the minerallurgical behaviour of particles, so from now on they are referred to as minerallurgical indices.

2.1. Rougher concentrate (RoCo) description

The sample selected comes from the rougher concentrate of the sulphide ore flotation circuit in the Kansanshi copper–gold mine. This mine is located in the North Western Province of Zambia and benefits a mixed oxide/sulphide copper–gold vein deposit with very variable mineralization (Broughton et al., 2002).

Modal analysis performed with the Mineral Liberation Analyzer (**MLA**) determined that this sample is composed of chalcopyrite [**Ccp**] (54.2%), pyrite [**Py**] (25.1%), secondary copper sulphides [**SsCu**] (chalcocite, covellite, bornite and digenite, 11.1%), gangue [**Gg**] (quartz, calcite, albite and dolomite 4.6%), copper oxides [**CuOx**] (malachite and chrysocolla, 3.0%), hematite [**Hem**] (1.7%) and other minor components [**Other**] (0.3%). Approximately 66% of the chalcopyrite is apparently liberated (i.e. in particles which appear completely composed by chalcopyrite in the 2D image, while composite chalcopyrite particles (i.e. unliberated chalcopyrite) usually present complex intergrowths (Fig. 2). In some of these particles, chalcopyrite is coated with a rim of secondary copper sulphides (Fig. 2a). In other cases, secondary copper sulphides occur as a network of fine veins cutting chalcopyrite (Fig. 2b), and sometimes chalcopyrite is coated and veined by secondary copper sulphides at the same time (Fig. 2c). Chalcopyrite in simple intergrowths is also present (Fig. 2d).

The first evidence of textural complexity in chalcopyrite is easily recognized analyzing Fig. 3. In this figure, chalcopyrite liberation based on cumulative liberation yield has been computed. The upper curve represents the distribution of chalcopyrite by particle composition (liberation based on area proportion), while

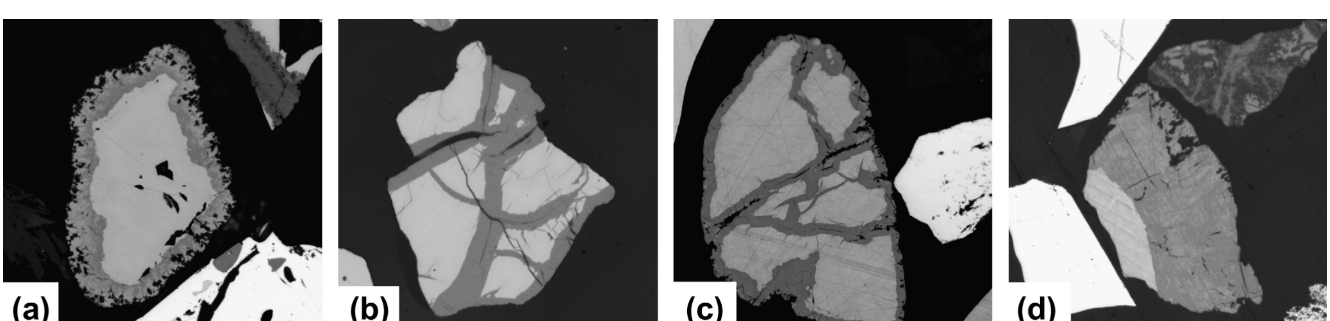

Fig. 2. Frequent intergrowth types between chalcopyrite (bright phase) and secondary copper sulphides (dark phase) in mineral particles of the Kansanshi rougher concentrate.