ARTICLE IN PRESS

Minerals Engineering xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Minerals Engineering

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

Relating mineralogical and textural characteristics to flotation behaviour

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ARTICLE INFO

Article history:
Received 23 December 2014
Revised 5 February 2015
Accepted 6 February 2015
Available online xxxx

Keywords:
Copper sulphides
Copper deportment
Grain size distribution
Copper recovery

ABSTRACT

Having knowledge of the ore mineralogy and texture can provide valuable information for effective design of a concentrator flowsheet. Specifically, these characteristics help in setting the appropriate grind size to achieve liberation and minimise overgrinding, and assist in identifying suitable flotation parameters to achieve optimum separation. This paper aims to obtain an understanding of the flotation behaviour of an ore by examining its mineralogical and textural features, particularly grain size distribution. Four samples with varying copper recoveries were obtained from different locations in a copper porphyry deposit. The samples were crushed to −4 mm and measured using a Mineral Liberation Analyser to determine the mineralogical characteristics of each. The mineralogical characteristics that were found to vary included: copper deportment and grain size and copper mineral association. This information was used to interpret batch flotation behaviour particularly copper recovery.

1. Introduction

It has been recognised that mineralogy of an ore significantly influences process variables such as recovery and throughput (Lorenzen and Barnard, 2011; Yingling, 1990). Mineralogical characterisation has become a fundamental analysis in understanding an ore deposit and has been found important in interpreting metallurgical response, in flowsheet design, and in process selection, control and optimisation (in Lotter, 2010). Mineralogical characterisation of ore includes identifying the mineral composition and analysis of the ore texture. There is a large body of literature that demonstrates the importance of process mineralogy in mineral processing. Much of the work that has been done gives emphasis to the type and amount of minerals present and relating it to processing behaviour (Alves and Hagni, 2008; Becker et al., 2008; Liang and Wang, 2008; Lotter, 2010; Rule and Schouwstra, 2011; Uliana et al., 2011). Some have looked at the texture of the ore (Bonnici et al., 2008; Chetty et al., 2012; Donskoi et al., 2008; McClung and Viljoen, 2011; Meadows et al., 2012; Rozendaal and Horn, 2012; Thompson et al., 2011; Zhou and Gu, 2008). In these examples texture is classified qualitatively based on abundance of mineral, metal/mineral deportment, shape of mineral, mode of occurrence of the mineral of interest (i.e. disseminated, in quartz veins, within fault zones) or the association of the mineral of interest (i.e. copper sulphide with mafic mineral association). According to Petruk (2000) "*all texture characteristics of the ore influence mineral processing, but it is the mineral grain size and bonding between grains that are the main characteristics influencing mineral breakage and mineral liberation*". Mineral grain size, in particular grain size distribution of both sulphides and gangue minerals and mineral association are expected to have the greatest influence on processing behaviour (Evans, 2010; Sutherland, 2007; Wills and Napier-Munn, 2006; King, 2001) but are not typically included in the descriptions of texture. Examples include the work of Becker et al. (2008), Bradshaw et al. (2011), and Hagni (2011) that provided qualitative estimate of mineral grain size at the micro-scale and used this information to explain processing behaviour. In the works of Hunt et al. (2008) and MacDonald et al. (2011), grain size distribution as measured by the Mineral Liberation Analyser (MLA) was used to link ore characterisation with mineral processing; however the implications for flowsheet design were not discussed.

The existence of automated imaging systems such as the MLA (Fandrich et al., 2007) and QEMSCAN (Sutherland and Gottlieb, 1991) allows reliable estimation of grain size. Even with modern technology, the interpretation of measurements particularly related to grain size is still a challenge, mainly due to stereological bias and the ill-defined nature of mineral grains (Sutherland, 2007).

This paper uses measurements of intact texture to interpret the flotation behaviour, in particular copper recovery, of different ore classes from a copper porphyry deposit. Texture will focus primarily on the grain size distribution and mineral association of the copper sulphides. Despite the challenge in interpretation of measurements, this paper aims to give emphasis on the importance of having knowledge of the textural features of coarse

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http://dx.doi.org/10.1016/j.mineng.2015.02.005
0892-6875/

materials to achieve liberation and separation (Evans, 2010; King, 2001) to provide useful information for effective and economical design of flowsheet. Measurements were done on four drill core samples selected from different locations of the deposit. This paper does not intend to make general conclusions but demonstrate how the potential flotation behaviour of the ore deposit, given the textural feature observed from the four samples, can be inferred. The approach described can be used to provide a framework for further research on the correlation between textural features and copper recovery in a porphyry deposit.

2. Experimental

2.1. Sample selection

Four drill core samples, at least 10 kg each, were obtained from different locations of a copper porphyry deposit, and were used to represent the feed to the concentrator. The drill cores were selected based on the geometallurgical characterisation performed on a copper porphyry deposit using the integrated geometallurgy method (Keeney, 2010). The method involves principal component analysis (PCA) to group the deposit according to geological and mineralogical characteristics. Each group is called a class and has a distinct set of characteristics. A model to predict the process performance, in particular the copper recovery, is then created for each class using the identified characteristics of the class as input parameters. This research used the logged geological and mineralogical characteristics from the exploration database of the deposit to do the PCA and create the classes together with predictive models of copper recovery. Each class created has a distinct set of geological and mineralogical characteristics that influence copper recovery. The dominant characteristics distinct to each class include alteration type, metal (copper, gold, magnesium, molybdenum, sulphur) and mineral (pyrite) grades. Two drill core segments (Samples A and B) with different predicted copper recoveries were identified and selected from one class and the other two drill core segments (Samples C and D), also with different copper recoveries, were identified and selected from another class.

2.2. Sample preparation and measurement

The drill core samples were treated as individual ore samples, and were measured and analysed individually. The drill cores were crushed to −4 mm and divided into representative sub-samples using a rotary sample divider. Three sub-samples underwent further size reduction to an 80% passing size of 150 μm using a stainless steel laboratory batch rod mill. Standard batch flotation tests were performed on these sub-samples at pH 11, using 300 g/t of potassium amyl xanthate as collector and methyl isobutyl carbinol as frother, and 10 min flotation time. The pH was modified using lime and the frother was added as required. A standard laboratory rougher batch flotation procedure was used for all samples. The flotation products were assayed for copper by inductively coupled plasma (ICP). Another sub-sample was sized using a standard sieve series and each size fraction was analysed using the X-ray back-scattered electrons (XBSE) method in the Mineral Liberation Analyser (MLA) to determine at which particle size the copper sulphides start to liberate using the approach described by Wightman and Evans (2014). Analysis of the liberation spectrum for copper sulphides indicated that copper minerals begin to liberate for particle sizes less than 710 μm. For particle sizes coarser than 710 μm it is expected that intact textural features will be observed and these size fractions were selected to determine mineral grain size and association characteristics. Mineral grain size was calculated based on equivalent circle diameter and the size distribution was taken from measurements in the −4 mm/+2.8 mm, −2.8 mm/+2 mm, −2 mm/+1.4 mm, −1.4 mm/+1 mm particle size fractions. No stereological corrections were made to the data outputs from the MLA measurements.

3. Results and discussion

The copper and total copper sulphide (i.e. chalcopyrite + bornite + chalcocite + digenite + enargite) head grade and copper recovery and grade for the four ore samples are listed in Table 1. The copper deportment in each of the samples is shown in Fig. 1.

Samples A and C, and Samples B and D have similar copper deportment and relative flotation behaviour, in particular copper recovery. Samples A and C contain more copper sulphides with chalcopyrite as the predominant copper mineral and resulted to higher copper recoveries. Samples B and D have bornite as the predominant copper mineral and also contain digenite–chalcocite which are not present in the other two samples.

3.1. Mineral abundance and grain size distribution

Grain size distributions of the copper sulphides in the ore samples are illustrated in Fig. 2. The number of particles and grains measured to generate the grain size distributions is shown in Table 2. A statistical technique of curve comparison was applied (Napier-Munn, 2012) to compare the plots and determine whether the plots are different or not. The results show that the plot of Sample A is different from the plot of Sample B, and the plot of Sample C is also different from Sample D, both at 99% significance. The following information can be extracted from the plots:

- All ore samples exhibit a wide range of grain sizes for the copper sulphide minerals as indicated by the shape of the curve.
- A shift to the right indicates that Samples A and C, which have similar copper deportment and contain more copper sulphides as shown in Table 1, exhibit coarser grain size distributions than Samples B and D.

One of the trends observed from the data was the apparent relationship between the abundance and grain size distribution of the copper sulphides. Samples A and C, having more abundant copper sulphides tend to exhibit coarser grain size distributions of the copper sulphides. The grain size distributions of chalcopyrite and bornite in Samples C and D shown in Fig. 3 are also compared. Chalcopyrite is more abundant in Sample C than in Sample D, while bornite is more abundant in Sample D than in Sample C. It can be seen from Fig. 3 that chalcopyrite in Sample C has coarser grain size distribution than in Sample D. Likewise there is a shift to the right in the plot of bornite in Sample D indicating a coarser grain size distribution of bornite in Sample D.

Table 1
Head grade and copper recovery of the ore samples.

Sample ID	Head grade		Flotation concentrate	
	[1]Cu (wt%)	[2]Cu–sulphides (wt%)	Cu recovery (wt%)	Cu grade (wt%)
A	0.49 ± 0.01	0.74 ± 0.07	89 ± 1	2.63 ± 0.08
B	0.53 ± 0.01	0.60 ± 0.08	80 ± 4	4.36 ± 0.94
C	0.44 ± 0.01	0.93 ± 0.12	90 ± 1	3.84 ± 0.54
D	0.66 ± 0.03	0.71 ± 0.16	85 ± 3	3.92 ± 0.63

± Confidence intervals based on 90% confidence level.
[1] Cu head grade of the entire sample, and flotation feed, concentrate and tails – measured by ICP.
[2] Cu–sulphides head grade of the −4 mm/+1 mm particle size fractions – measured from MLA.