TEXTURAL DESCRIPTORS FOR MULTIPHASIC ORE PARTICLES

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ABSTRACT

The monitoring of mineral processing circuit based on particle liberation analysis using quantitative image analysis has become a routine technique within the last decades. But liberation indices are computed as weight proportions, which is not convenient when complex texture ores are treated by flotation. In these cases, liberation has to be computed as phase surface available to reactants, and the type of intergrowth between phases has to be characterized so as to determine the possibility of liberation. To achieve this characterization some indices have been developed in terms of 2D phase contact and mineral surfaces exposed. These indices, as well as indices suggested by other authors and additional measures, have been explored on simple synthetic textures ranging from single to multiple inclusions and single to multiple veins. The ability of these parameters to discriminate the various textures is analyzed.

KEYWORDS: Mineral liberation, mineral intergrowth characterization, image analysis.

INTRODUCTION

Ores are complex assemblages of mineral phases, some being economically valuable and others being considered as uneconomic or gangue material. The main objective of mineral processing is to separate the valuable fraction from the gangue material by making use of contrasted properties such as density, magnetic susceptibility, hydrophobicity, etc.

The most efficient separation techniques operate on monomineralic particles obtained after crushing and grinding, but obviously this ideal situation can hardly be achieved and most often multiphasic or so-called unliberated particles are present in the process. Hence, a complete characterization of unliberated particles is essential for mineral processing control, and consequently, to increase mineral recovery.

Mineral Particles Characterization

To completely characterize mineral particles quantitative data about composition, liberation and texture should be measured.

Mineral liberation can be expressed in different ways, being weight proportion the most frequently used. However, when it deals with flotation, liberation must also be expressed in terms of exposed surface proportion. This feature, as well as the possibility of liberation by physical or chemical means is intimately related to mineralogical texture

The main textural features that must be quantified are size, grade of contact between phases and type of intergrowth. While the two firsts are usually measured, automatic characterization of mineral intergrowth has not been resolved yet.

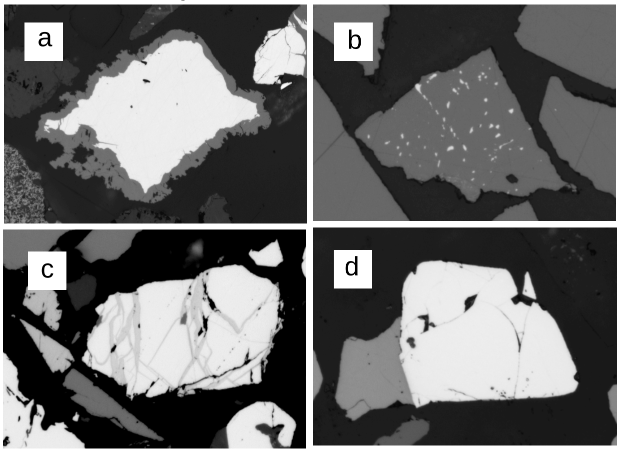

Figure 1: Real ore particles to illustrate typical intergrowths described by Gaudin as the most relevant in flotation (a: coated; b: emulsion; c: stockwork; d: simple).

Based on the classification established by Gaudin[1], Fig.1 shows the four kinds of intergrowth considered as the most relevant from the point of view of particles behavior during flotation.

With the aim of automatically identifying these four intergrowths and completely characterizing particles texture, some indices and textural descriptors have been developed. Moreover, indices proposed by other authors for the quantification of mineral intergrowth are explored.

MATERIALS AND METHODS

The definition of textural descriptors is made on the basis of the quantification of 2D phase surface exposure and phase-to-phase contact. Additional measures such as areas and perimeters are also performed. The automatic quantification of these features is made on digital images provided by scanning electron microscopy or optical microscopy. In both cases, mineral particles are mounted on polished samples, whose surfaces are scanned and a number of pictures, large enough to guaranty the sample representativeness, are taken for a later analysis.

Linear Intercepts Method

The methodology used to extract the mentioned parameters is the linear intercepts method, which is applied on every single particle of a classified image. By means of this method, a set of parallel lines (linear intercepts) is superimposed on the particle; for every linear intercept the total length across each phase is measured, and the number of transitions between phases, and between phases and background are counted. This procedure is carried out in different directions, rotating the set of lines at regular angular intervals, thus data for characterizing the internal structure of the particle are acquired.

First attempts of texture characterization have been done on a series of simple textures in synthetic biphasic particles that represent in a simple way some of the intergrowths described by Gaudin [1]. The proportion of each phase is fixed and the internal structure varies from single (coated intergrowth) to multiple inclusions randomly distributed (emulsion-like intergrowth), as shown in figure 2.

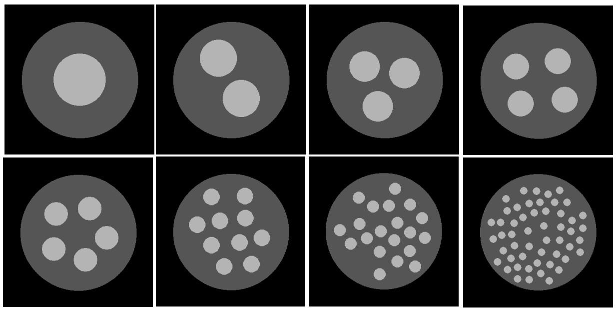

Figure 2: Synthetic particles: from one inclusion (coated intergrowth) to multiple inclusions (emulsion-like intergrowth).

TEXTURAL DESCRIPTORS

Based on the measurements achieved trough linear intercepts, some descriptors have been developed for the quantification of liberation and 2D phase contact.

Liberation Indices

Areal and boundary ratios (1) are essential for the characterization of mineral particles' floatability, as they indicate volumetric and surface composition respectively. In addition, the average (2) and apparent (3) linear liberation are calculated and the shape of the linear liberation grades and apparent linear liberation distributions are analyzed for each particle, as these liberation distributions are considered a function of texture ([2],[3],[4]).

$$A_A(\alpha)=\frac{\sum_i\sum_j P_{i,j}(\alpha)}{\sum_i\sum_j P_{i,j}(\varphi)};\quad B_B(\alpha)=\frac{\sum_j N_j^{\theta}(\alpha,o)}{\sum_j N_j^{\theta}(\varphi,o)} \tag{1}$$

$$\overline{L_L}(\alpha)=\frac{1}{N(I^{\theta})}\sum_{\theta} L_{Li}^{\theta}(\alpha) \tag{2}$$

$$L_{LA}(\alpha)=\frac{\left(\sum_i\sum_j P_{i,j}(\alpha)\right)_{Liberated}}{\sum_i\sum_j P_{i,j}(\varphi)} \tag{3}$$

Phase Contact Indices

In order to quantify how phases are distributed inside the particle, some ratios derived from the measurements of αβ contact (4), and α and β exposures (5) are calculated. Along with these ratios, those proposed by Amstutz & Giger [5] and Jeulin [6] are also calculated, (6) and (7) respectively. One additional index (8) related to texture geometry is calculated like the number of αβ contacts divided by the number of non-liberated linear intercepts.

$$I_{C1}(\alpha\beta) = \frac{\sum_j N_j^\theta(\alpha,\beta)}{\sum_j N_j^\theta(\varphi,o)} \quad (4)$$

$$I_{C2}(\alpha) = \frac{\sum_j N_j^\theta(\alpha\beta)}{\sum_j N_j^\theta(\alpha,o)} \; ; \; I_{C2}(\beta) = \frac{\sum_j N_j^\theta(\alpha\beta)}{\sum_j N_j^\theta(\beta,o)} \quad (5)$$

$$Ii(\alpha\beta) = \frac{\sum_j N_j^\theta(\alpha,\beta)}{\sum_j N_j^\theta(\varphi,\bullet)} \quad (6)$$

$$I_C(\alpha\beta) = \frac{\sum_j N_j^\theta(\alpha,\beta)\times\sum_j N_j^\theta(\varphi,\bullet)}{\sum_j N_j^\theta(\alpha,\bullet)\times\sum_j N_j^\theta(\beta,\bullet)} \quad (7)$$

$$N_{\alpha\beta} = \frac{\sum_j N_j^\theta(\alpha\beta)}{N(I^\theta)_{NonLiberated}} \quad (8)$$

RESULTS

The analysis of the values obtained for textural descriptors applied to synthetic particles (Table 1) reveals the metallurgical significance of some of them. Boundary ratio, as well as phase contact indices such as I_{C2} and I_C indicate the locking grade of one phase, and so, the possibility of particle recovering by flotation. On the other hand, I_{C1} and I_i give an idea of the complexity of contact surfaces between phases: the higher the value of these indices, the most contact between phases exists. Moreover, it has been observed that I_i is always lower than 0.5 for particles type "coated". $N_{\alpha\beta}$, in spite of not having metallurgical significance, is important for the identification of intergrowth type because indicates the differences in the geometry of the contact between phases. As shown in table 1, a particle with one inclusion has $N_{\alpha\beta}$ of approximately two, while higher values indicate more complex geometries (more than one inclusion or stockwork).

In addition to these textural descriptors, the distribution of phases through linear intercept grades has been analyzed (figure 3). This part of the work is still in progress and only preliminary results are presented.

Linear Liberation Distribution

The shape of linear liberation distribution has been analyzed in order to quantify the differences between distributions for the various particles. Curves shown in figure 3 represent the distribution of phases in linear liberation grades for three different particles of the series shown on figure 2: with 1, 20 and 50 inclusions.

As figure 4 reveals, phases in particles with more than one inclusion have a general trend different from the one exhibited by phases in particle with one single inclusion. Hence, the quantification of these differences could provide new data for intergrowth identification.

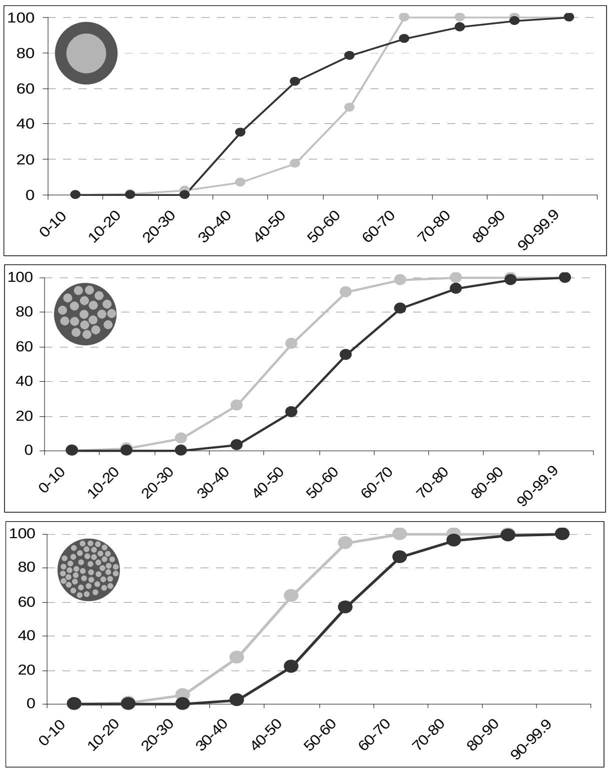

Figure 3: Phase area percentage (ordinates) per linear intercept grade (abscissas). Only non-liberated linear intercepts are considered.

Table 1: Textural Indices values for synthetic particles of figure 2

No Inclusions	A_A		B_B		$\overline{L}_L$		L_{LA}		I_{C1}	I_{C2}		$I_{i(Amstutz)}$	$I_{C(Jeulin)}$	$N_{\alpha\beta}$
	α	β	α	β	α	β	α	β		α	β			
1	40.3	59.7	0.0	100.0	52.6	47.4	0.0	5.1	0.63	∞	0.63	0.39	1.0	2.2
2	40.6	59.4	0.0	100.0	48.9	51.1	0.0	10.7	0.90	∞	0.90	0.47	1.0	2.7
3	41.1	58.9	0.0	100.0	45.8	54.2	0.0	16.4	1.11	∞	1.11	0.53	1.0	3.1
4	40.9	59.1	0.0	100.0	45.2	54.8	0.0	22.4	1.27	∞	1.27	0.56	1.0	3.5
5	41.1	58.9	0.0	100.0	44.1	55.9	0.0	29.2	1.43	∞	1.43	0.59	1.0	3.7
10	41.2	58.8	0.0	100.0	43.0	57.0	0.0	36.5	2.02	∞	2.02	0.67	1.0	5.1
20	40.6	59.4	0.0	100.0	42.1	57.9	0.0	44.8	2.87	∞	2.87	0.74	1.0	7.1
50	42.4	57.6	0.0	100.0	42.3	57.7	0.0	55.1	4.60	∞	4.60	0.82	1.0	10.7

CONCLUSIONS

In this paper, preliminary results for the characterization of particle textures have been presented. The analysis of these results shows that the proposed textural indices, based on the quantification of 2D phase contact, take values which differ enough to discriminate synthetic textures in biphasic particles. Hence, the first step to the quantification of the most relevant intergrowth from the point of view of flotation has been established.

Taking into account the results obtained, the next step of this work will involve the application of these textural indices on real mineral particles. Thus, a complete mineralogical characterization could be achieved, and the prediction of the behavior of mineral particles during flotation could be established in a more reliable way.

NOTATION

α, β: mineral phases

φ: any mineral phase

•: any phase including background (resin)

o: background (resin)

$P_{ij}(\alpha)$: pixels corresponding to phase α.

$P_{ij}(\varphi)$: pixels corresponding to phase φ (particle area)

$L^{\theta}_{Li}(\alpha)$: linear fraction of α along the i^{th} linear intercept (linear liberation).

$N_j^{\theta}(\alpha\beta)$: total number of transitions of the type αβ along the jth intercept in the direction θ.

$N_j^{\theta}(\alpha,o)$: total number of transitions of the type α-background (idem for $N_j^{\theta}(\beta,o)$.

$N_j^{\theta}(\varphi, \bullet)$: total number of transitions of the type any phase-any phase and any phase-resin (idem for $N_j^{\theta}(\alpha, \bullet)$ and $N_j^{\theta}(\beta, \bullet)$).

$N(I^{\theta})$: number of linear intercepts.

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