ASSESSMENT OF LIBERATION WITH OPTICAL MICROSCOPY: A FAST, LOW COST PROCEDURE

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ABSTRACT

During the last decade of the millennium, important progress has been made in the area of liberation, its measurement and the simulation of the liberation process during comminution. With the development of an accurate procedure for stereological correction, it is now possible to measure complete liberation spectra in mineral particle populations, using sophisticated image analysis techniques applied to high-contrast images generated in a Scanning Electron Microscope. These systems are relatively expensive. Unfortunately, optical microscopes are unsuitable for generating high-contrast images from particles mounted in epoxy, when common silicates are present. An alternative approach is to use liberation prediction techniques to assess the liberation spectra of progeny from an unbroken sample of texture. Prediction techniques are however complicated by mathematical problems that are almost insurmountable. In this paper the prediction problem is approached from a different perspective, one that exploits the memory and computing power that is available in today's common desktop computers. The approach presented in this paper allows the prediction of the liberation of multiple phases using a relatively simple system based on optical images. Such system can be easily implemented, at a relatively low cost, in any mineralogy laboratory. Predicted liberation using the system is presented for an iron ore.

INTRODUCTION

The assessment of the liberation properties of a given phase in an ore is intimately related to the texture in which the phase is present in the mineral matrix. Quantitative liberation information ultimately provides the recovery of phase that is possible for a given fines of grind. Variations in texture throughout an ore body are common, and therefore the amount of recovery of a phase that is obtained in a concentrating plant is a function of the spatial origin of the feed particles in the ore body.

When liberation is a problem that affects plant performance, it is very desirable to know as much as possible about how the particles from the mine to the plant are going to behave prior to processing. Such ore liberation monitoring system has tremendous potential in optimizing mine/plant performance. Many mining operations already have a system or procedure in place that is essentially an indirect measurement of liberation. In the sulfides industry, batch laboratory flotation tests can be performed on samples of ore from the mine in order to predict the performance of the flotation plant. In the taconitic iron ore industry, a rather complicated procedure based on Davis tube separations in a size by size basis is used routinely. Although useful, these methods have many shortcomings. Batch flotation results can vary widely under slightly different conditions. Davis tube separations cannot account for the presence of hematite, and tends to significantly overestimate the amount of liberated magnetite because even low-grade particles will report to the magnetics.

The alternative is to grind and size the samples from the mine and use traditional liberation measurement techniques. This is done regularly in the coal industry, and the liberation of ash forming minerals and sulfides from the organics is accurately measured by dense liquid fractionation. In cases like the Taconite and sulfide industries, dense liquid fractionation is not feasible. This leaves image analysis techniques as the only alternative. Unfortunately, the existing image analysis techniques for measurement of liberation from particle cross-sections require careful sample preparation in a size by size basis. The polished samples are imaged in a SEM, and several high-contrast images are required from each sample to generate the linear and/or areal liberation spectra for the phase of interest. These results are then converted to volumetric grade distributions by stereological correction. It is possible to conceive that the entire procedure be carried out in 24 hours for six size intervals in a fine tuned laboratory that is geared for production measurement. Capital costs in setting up such a lab are significantly high, as well as the costs involved in maintaining the lab running, especially when considering the labor intensive environment that results from sample preparation, imaging and processing for several samples in a daily basis.

The use of optical imaging has several advantages over electron microscopy. Lower capital cost, quicker image acquisition and less preparation required are the main factors. Also, most mining companies are already equipped with good optical microscopes for mineralogy assessment. However, optical images cannot produce the required contrast between the epoxy mounting media and the common silicates present in most ores.

The solution to the problems lies in the area of liberation prediction. Under this scenario, a large fragment of ore, many times larger than the largest liberated progeny particle of any phase, is examined by image analysis. As the texture is measured from the unbroken sample, the liberation at any progeny size from that sample can be predicted. Because the images contain only ore, enough contrast is required only between the gangue minerals and the minerals of interest. Optical imaging can therefore be used with advantage in many cases. Also, only one sample of unbroken ore is necessary to predict the liberation spectrum at any progeny size, and consequently the amount of sample preparation is drastically reduced in comparison with standard broken ore particle analysis. These rather desirable features make the predictive system a valuable tool for the monitoring of even slight texture variations within the ore body.

The benefits of a predictive system are tangible across the board in the mining industry. For example, in the Taconite industry, the predictive system would completely replace the Davis tube procedure. In the sulfide industry, it would completely resolve liberation effects from other problems that affect flotation performance.

In this paper, results from preliminary work aimed at the development of a complete predictive system are presented.

THEORETICAL BACKGROUND

Liberation prediction is a rather complex matter. Meloy, Barberi and King have made relevant contributions in this area (Meloy, 1990; Barbery, 1991; King, 1994). Only the method due to King is useful here because the method is based on linear measurement. The method requires successive integrations and convolutions, as well as careful probability and statistics analysis. Essentially, King's model predicts the probability that a chord of length ℓ, when superimposed to the unbroken texture, have a linear grade g_ℓ. This is the number weighed, conditional on length, linear grade distribution, $p(g_\ell \mid \ell)$, a function only of texture, and can be viewed as a quantitative measure of texture. The equivalent length weighed distribution, $f(g_\ell \mid \ell)$ is exactly equal to $p(g_\ell \mid \ell)$, and this can be easily demonstrated. An important simplification of King's model is made in this work, and it is assumed that $p(g_\ell \mid \ell)$ can be measured directly from the unbroken ore by accounting for all possible intercepts of length ℓ that can be placed on the sample of texture. This assumption has implications from the sampling theory point of view. At this time, it is not known how important this assumption may be, but the experimental results obtained from the application of the method proposed here indicate that this is an accurate enough measure of $f(g_\ell \mid \ell)$ for practical applications. It is worth pointing out here that this procedure requires the measurement of linear grade from all possible lengths (smaller than the width of the image generated on the texture) from chords placed in every possible location on the sample of texture.

The measured $f(g_\ell \mid \ell)$ is used to calculate the linear grade distributions using:

$$f(g_\ell|D) = \int_0^\infty f(g_\ell|\ell)\, f(\ell|D)\, d\ell$$

where $f(g_\ell \mid D)$ is the conditional, on size, length weighed linear grade distribution. The corresponding volumetric grade distributions are then obtained by stereological correction, using tools such as StereoSoft™ (King and Schneider, 1998). $f(\ell \mid D)$ is the conditional, on size, length weighed chord length distribution. It is a function of particle shape, and the reader is referred to King and Schneider, 1994, for a detailed characterization of this function. The volumetric grade distributions can be calculated at any particle size D, thus rendering the complete liberation spectra that is predicted from breakage of the unbroken sample.

Figure 1

One important problem however is to generate images that are suitable for measurement of texture. If one takes in consideration low-grade porphyry ores for example, it becomes clear that the traditional image sampling procedures are not adequate. This is because many images will be placed partially or even entirely in areas where the phase of interest is not present, or present only sparsely. This rationale can also be expanded to banded ores such as coal, taconite and itabirite. Depending on the texture itself, images that encompass a large enough sample of texture may not have enough resolution to resolve the textural details. The method requires images with enough resolution and that cover a large enough area of the unbroken sample. Because this method relies in linear measurement, this property can be used with advantage, as strips of contiguous images can be generated across the texture. When these images are patched together, the resulting strip will cover the entire region of texture that is concerned with the direction of measurement, and with the resolution that is required for the textural details. Automated stage control and the implementation of image analysis software that is capable of assembling and processing these strips automatically are required here.

EXPERIMENTAL

An unbroken sample of Taconite (Eveleth Mines, Top Lower Cherty seam, section 2600, elevation 1330) was sectioned across the banding and polished. The resulting section was about 5 cm long by 2.5 cm wide.

The microscope used was a universal Zeiss microscope, equipped with a Kontron MCP box, with stage controller and autofocus. A Zeiss Plan 2.5/0.08 lens was selected for imaging. The images have a resolution of exactly 0.4 pixel/micron at this magnification, and it was determined that the stage should be moved 3200 motor steps in the x direction and 50 in the y direction to generate two contiguous images. The adjustment in the y direction is necessary because the images are not perfectly aligned with the movement in the x direction. This is due to the alignment of the video camera at the microscope-camera coupling. This miss-alignment is harmless, but it should not be exaggerated. The video camera is connected to the MCP (Microanalysis Control Processor) box, and the signal from the MCP box is acquired in a PC equipped with a frame grabber. This setup is probably standard for most optical image analysis systems. The MCP box is controlled via the PC's COM port. All that is required is to move the stage, focus, acquire and save. Most commercially available optical systems can perform these tasks. The exact amount of stage movement in each direction was determined by trial and error. This is constant for the lens, camera and microscope combination, and need to be determined only once. A set of 30 640x480 pixel contiguous gray level images were acquired at the same illumination. At the end of the run, a background image was acquired in a glass slide using the same illumination setup.

Each image was processed separately for background correction. This is carried out by subtracting the background image from each of the 30 contiguous images. This correction can be performed automatically by macro processing, using the Minerals and Metallurgical Image Analysis software, MMIA™ (King and Schneider, 1993). The resulting images were assembled in MMIA™ by making the image buffer width equal to 19,200 pixels by 480 pixels high. A MMIA™ macro is used to inset each image in the proper position. The resulting image is seamless, with constant contrast and brightness. This is shown in Figure 1, where the actual image has been rotated, and the actual height greatly exaggerated with respect to its width. The image is appropriate for texture measurement. After thresholding, to separate the magnetite from the chert background, $f(g_\ell \mid \ell)$ measurement is performed. This has been implemented as a standard binary measurement in MMIA™, and the distribution can be accumulated over several strips when more than one strip is available.

RESULTS

Processing of $f(g_\ell \mid \ell)$ has been implemented in StereoSoft™. The sizes at which liberation is to be predicted are input by the user, and the corresponding linear grade distributions, at the desired sizes, generated. Stereological correction is performed as if the linear grade distributions had been generated from standard measurement in particulate samples. The resulting predicted liberation spectra at several sizes is shown in Figure 2. StereoSoft™'s Iron Oxide linear kernel was selected for all sizes. The results show that the liberation of the magnetite for this texture is at about 45 microns, and that of chert at about 106 microns. Although direct confirmation is not available at this time, the liberation sizes are in agreement with the liberation sizes from particle measurement in a Cobber Concentrate sample originated from the Eveleth Mine (Schneider, 1995).

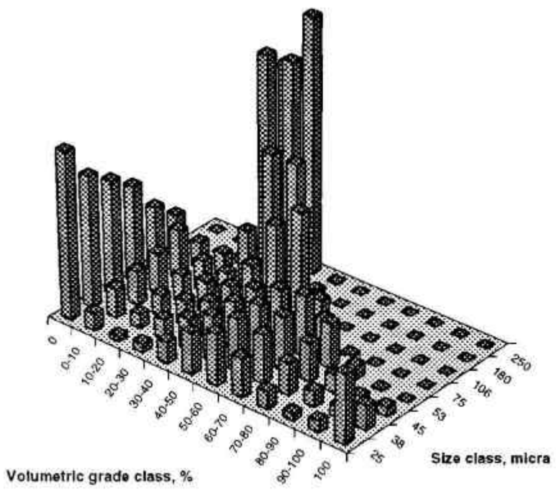

Figure 2: predicted liberation spectra from direct measurement on the image in Figure 1.

CONCLUSIONS

Further work is required to confirm the predicted liberation spectra, and this is currently under way. Also, the measurement of $f(g_\ell \mid \ell)$ requires further analysis from the point of view of sampling theory. Nevertheless, the procedure has been entirely implemented, and only careful experimentation is required to confirm the method.

The entire procedure, including image acquisition, image processing, measurement and stereological correction can be carried out in less than one hour time, and possibly faster with further automation. Cross sectioning and polishing of the unbroken sample is the more time consuming and labor intensive task. It is easily conceivable that this procedure be used routinely to monitor texture variations in any mined ore body, as long as the phases of interest can be discriminated in the optical images. It is also possible to use images generated in a SEM whenever this is not the case.

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