Minerals Engineering 46–47 (2013) 68–75

Contents lists available at SciVerse ScienceDirect

Minerals Engineering

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

Image based modeling of rock fragmentation

Nenad Djordjevic *

JKMRC, SMI, University of Queensland, 40 Isles Road, Indooroopilly, Qld 4068, Australia

ARTICLE INFO

Article history:
Received 15 November 2012
Accepted 7 March 2013
Available online 2 May 2013

Keywords:
Image
Rock fragmentation
Modeling
Ore
Liberation
Fracture

ABSTRACT

In the mineral extraction industry, comminution modeling is not only interested in maximum rock strength, but also, or much more, in the energy required to induce rock fracture and, most significantly, into the effect of energy application on the produced rock fragments size distribution. An additional aspect of rock breakage, specific to the mineral extraction industry, is the modeling of liberation of particular mineral grains from the host rock matrix. These aspects of rock behavior make comminution modeling a unique field of rock mechanics.

From a traditional engineering point of view (mining and civil), rock samples are considered to be homogenous. Although the mechanical properties of individual minerals can vary significantly, the properties of the minerals and of the mineral boundaries interact randomly enough to assume that in the size of rock samples mechanical properties can be considered homogenous. However, from a comminution point of view, heterogeneity caused by a difference in the properties of minerals are crucial and therefore rock material, even in the scale of a few centimeters, should be considered as heterogeneous. The comminution response of such rock will be influenced by the textural parameters of the rock as well as mechanical properties of constitutive mineral grains.

Image based numerical modeling is a useful tool for investigation of the pattern and dynamics of the rock breakage process. Its usefulness rests on the fact that a difficult step of building a faithful model of rock texture and composition, as a pre-requisite for modeling of rock breakage, is removed. Numerical modeling based on the use of classified digital image of the rock surface, could be particularly effective in the mineral extraction industry, where one of the key objectives is liberation of specific minerals, by providing inside view of mechanisms that are responsible for liberation of valuable minerals embedded into specific ore matrix.

1. Introduction

One way to investigate the effect of different textural classes is to perform numerical modeling of the effect of certain textural types on rock fragmentation and mineral liberation. Textural classes can be the product of mathematical modeling or can be a digital image of a typical rock texture of a certain rock type. Regardless of how a particular ore texture is generated it is of interest to investigate the spatial and temporal pattern of the rock fragmentation.

Recent developments in computing power have created the opportunity for more rock specific modeling of rock fragmentation. This is based on the application of object-oriented finite element modeling of the rock deformation and breakage. In this context, the object represents a specific type of mineral or structural features. This modeling has been performed using the OOF (Object Oriented Finite) element code, (Langer et al., 2001). The proposed approach is particularly attractive, due to the nature of its input, which is a digital image of the rock surface.

The objective is to establish a cause-effect relationship between the presence of certain mineral grains and their pattern of distribution on the propensity for liberation of another mineral type, i.e., a mineral which is of economic interest. One of the most significant objectives is to establish the maximum size of the rock fragments required for the full or partial liberation of the mineral of interest. Obviously, critical fragment size is dependent on the textural features of the rock, mechanical properties of individual minerals, and the nature of the stress field to which a rock sample is exposed.

2. Modeling methodology

Before we continue, we should remind ourselves what rock texture is. According to Encyclopedia Britannica, the texture of a rock is the size, shape, and arrangement of the grains (for sedimentary rocks) or crystals (for igneous and metamorphic rocks). Therefore, the definition of texture is essentially geometric and pictorial, in nature. The classical definitions of texture do not include information about the mechanical/physical properties of grains or crystals. However, from the point of view of rock comminution in the

---

* Tel.: +61 7 3365 5888; fax: +61 7 3365 5999.
E-mail address: n.djordjevic@uq.edu.au

0892-6875/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.mineng.2013.03.002

context of the recovery of particular minerals, the mechanical properties of minerals are of great importance. Another parameter which is not explicitly considered in traditional definitions of texture is the presence and nature of voids (pores and microcracks).

The modeling methodology of rock mass behavior is strongly influenced by the nature of the rock mass. In the case of rocks as natural geologic materials, physical and mechanical properties need to be determined rather than selected through a manufacturing process. In the case of man-made materials, the common purpose of routine mechanical testing is not to gain new knowledge, but to provide quality control and verification.

Rock mass in situ is characterized by unknown structural properties, the unknown state of stress and unknown details of the mechanical properties. From a practical point of view, all these properties are not just unknown in detail but they are frequently practically unknowable. To a lesser extent, the same is applicable for the modeling rock matrix (in the scale of rock samples). This lack of precise information indicates that the approach to rock modeling should be different from one used for the modeling behavior of known materials (man-made), whose properties are generally known.

3. Determinations of the mechanical properties of the minerals

Input parameters for OOF modeling are mechanical parameters of the minerals identified in the image. Among them are Young's module of elasticity, Poisson's ratio, and compressive and tensile strength. These parameters are determined either from the available published information or they are measured through nano-(micro) indentation testing. In terms of the published information, they tend to be restricted to the modulus of elasticity and Poisson's ratio. The strength properties of minerals are rarely available.

Strength properties as well as elastic properties are determined through instrumented, computer controlled, nano-indentation testing. Indentation or hardness testing has been used for a long time for material characterization. Traditional hardness testing consists of the application of a single static force for a specified time. Depending on the shape and tip material of the indenter, the dimensions of the impression created will be in order of millimeters. The output of the traditional hardness tester is typically a single indentation hardness value that is a measure of the relative penetration depth.

In contrast to traditional hardness testing, instrumented indentation testing allows the application of a specified force or displacement history. Force and displacement are measured continuously over a complete loading cycle. For the purpose of instrumented nano-indentation we used the UMIS nano-indentation instrument from the CSIRO. UMIS measures elastic, plastic, strain hardness, creep, fracture and other mechanical properties of a material surface. The UMIS offers in situ observation of the indentation process, and specimen positioning to within 0.1 μm.

Testing has been performed using a Berkowich diamond tip indenter, with constant force (5–10 tests per mineral sample). In the case of homogenous minerals, testing produced an indent of highly reproducible size and shape, Figs. 1 and 2. From the unloading part of the load-deformation curve, the instrument calculates the elastic modulus of the indented surface.

Elastic modulus is calculated with the assumption that Poisson ratio is equal to the mean value published in the literature for a particular mineral. This assumption introduces error. However, the magnitude of the error in most cases is not high. Due to the high elastic modulus of the diamond tip used for indentation, and the nature of the testing method, the calculated values of the elastic modulus of the minerals are within the range of ±3% of the value if the exact value of the Poisson ratio of the mineral is known. For instance, an error of 20% in the assumed value of the Poisson ratio of the mineral results in an error of 3% in the calculated value of the elastic modulus, Fig. 3.

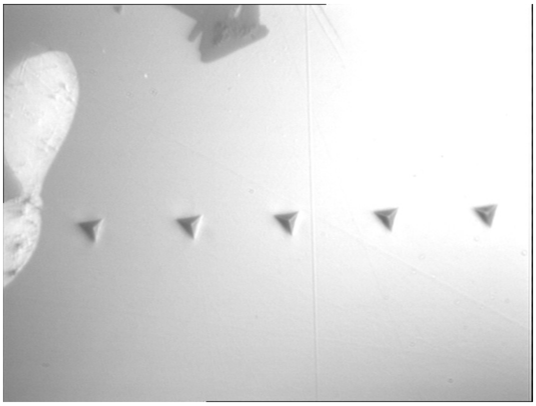

Fig. 1. Nano-indentation testing of sphalerite (Rosebury).

Fig. 2. Nano-indentation testing of sphalerite (Broken Hill).

Elastic properties of the same mineral vary from mine to mine, and probably within the same mine, depending on the specific history of mineralization. This is illustrated in the case of sphalerite, in which Young's modulus varies substantially between Rosebury and Broken Hill mines (Australia). Therefore, using the properties of Rosebury sphalerite to model behavior of Broken Hill ore may produce incorrect results, (see Fig. 4) Fig. 9.

However, within the same mineralization the mechanical properties of a particular mineral, tend to vary in a relatively narrow

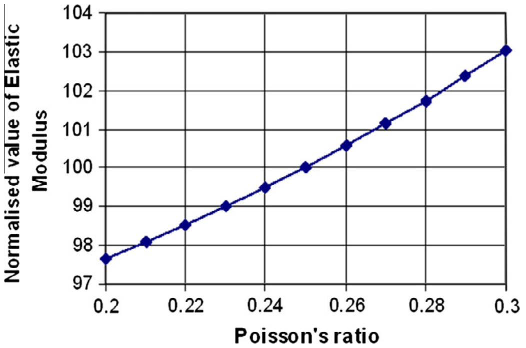

Fig. 3. Normalised (non-dimensional), value of the elastic modulus as a function of the assumed Poisson's ratio, using for normalization value of elastic modules that correspond to the Poisson ratio of 0.25.