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Numerical modelling of heterogeneous rock breakage behaviour based on texture images

Yicai Wang

JKMRC, The University of Queensland, Isles Rd, Indooroopilly 4068, Australia

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ABSTRACT

The main objective of this study is to understand rock breakage behaviours which may provide a means to improve fragmentation efficiency. In this study, numerical modelling technology and image analysis are used to investigate the behaviour of actual rocks in the breakage process. A texture-based finite element method (FEM) modelling technique has been developed to present a realistic modelling method for characterizing heterogeneous rock breakage behaviour according to its actual microstructure using integrated microscopic observation, image analysis and numerical modelling.

Understanding the role of texture and crack propagation can provide fundamental knowledge for predicting and improving energy-efficiency of comminution. A number of samples were analysed with the aim of providing key information on mineralogical and textural controls which primarily influence preferential liberation.

The results in this study demonstrated that mineral distributions and minerals with lower tensile strength play a very important role in the breakage process.

1. Introduction

It is essential to understand how fractures initiate and propagate under the different distributions of minerals in rock in order to provide a better understanding of the rock fracture processes occurring in various mining and mineral processing operations (Blair and Cook, 1998; Vasarhelyi and Bobet, 2000; Besuelle et al., 2000; Fang and Harrison, 2002; Man and van Mier, 2011; Morrel, 2008; Wong et al., 2000). For analysis of the breakage behaviour of mineral associations in rocks, the values of Young's modulus and Poisson's ratio of each mineral is critical (Schon, 1997; Mavko et al., 2009). Fractures generally initiate between two minerals with very different Young's modulus and Poisson's ratio. One of the most important factors affecting breakage behaviour during the failure process is the heterogeneity of the rock. Liu and other collaborators modelled rock heterogeneity using the software R-T^{2D} (Liu et al., 2004; Tang et al., 2004). In their study, the heterogeneity of rocks was characterized by the Weibull statistical model as a few characteristic parameters. Their sample is considered as a single uniform material and using the Weibull statistical model introduces the rock heterogeneity.

With the development of high performance computers and the technology of image processing, image segmentation has been widely applied in mining and metallurgy. Lepisto (Lepisto et al., 2006) and Holden (Holden et al., 2009) presented an automatic online crystal detection technique to identify individual crystals using ROI (regions of interest) detection which is based on a combination of colour, brightness, texture and segmentation using iterative, marker-based, watershed algorithm and edge detection.

Once classified mineral maps have been generated finite element meshes can be constructed, physical properties for specific mineral phases can be input, and complex, interactive stress displacement models can be run, facilitated by advances in computing power. Current applications of FEM modelling are based on the use of two-dimensional input images derived from core imaging, optical and SEM-based microscopy.

Yue and other scholars have published work (Yue et al., 2003) on a digital image processing based FEM for two dimensional particle segmentation. In their study, digital image techniques were used to determine the main homogeneous distribution of a geomaterial on a homogeneous matrix material, in order to form the in-homogeneity of a geo-material in the whole sample.

This study uses an edge detection method of image processing to establish the microstructures of inhomogeneous rock based on a texture image and then the material inhomogeneity is introduced into mechanical modelling.

In order to improve fragmentation efficiency in mineral processing an understanding of the effects of mineralogy, mechanical

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E-mail address: yi_cai_wang@yahoo.com.au

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properties and ore textures in the breakage process is very important.

Texture-based finite element method (FEM) modelling is a sophisticated tool for simulating stress and failure under loading in complex, heterogeneous solid state systems, typical of mineralized ores and rocks. Applications of texture-based FEM modelling SimRock have been developed within the AMIRA P843 GeM project (Wang, 2013) and applied to the prediction of bulk rock strength and to investigate controls on selective breakage.

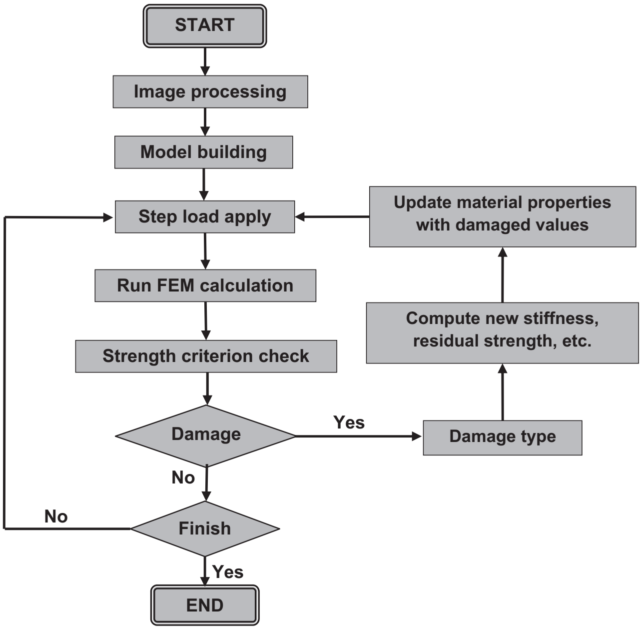

Fig. 1. Flow chart of the modelling process.

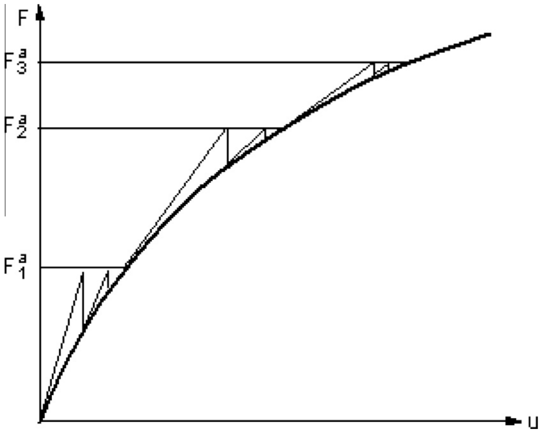

Fig. 2. Incremental Newton–Raphson procedure.

The major difference between the software SimRock and other approaches is that this model is built from a digital image, i.e. the distributions of mineral can be decided from the classified mineral map. Also SimRock can differentiate many different minerals in one sample, which cannot be achieved with other software.

The potential to simulate rock interactions and to gain a fundamental insight into the texture-based controls on failure was recognised by GeM sponsors as providing an important new tool for understanding and predicting controls on comminution and liberation.

This study was undertaken to investigate the energies required for several different aspects of rock breakage, and to obtain statistical data to identify patterns that can be used to further develop the breakage process.

2. Modelling procedure

Fig. 1 shows the flow chart of breakage modelling procedure in SimRock.

One of the most important factors affecting breakage behaviour during the failure process is the initiation and propagation of cracks. Generally, for heterogeneous rocks, higher order functions is used to simulate this process in FEM.

In the image process, the goal is to create a mesh of triangular elements each of which covers a homogeneous mineral property. In the current study, the Monte Carlo method was employed in the mineral segmentation process. Monte Carlo methods have become popular for obtaining solutions to global optimization problems. The optimization technique is simulated to detect the edge of different minerals.

2.1. Anisotropic elasticity

In the current version of **SimRock**, a triangle element is used and is treated in either plane strain or plane stress. The samples used in this paper are considered as plane stress.

In linear elasticity, the relation between stress and strain depends on the type of material under consideration. This relation is known as Hooke's law. For anisotropic materials Hooke's law can be written as Eq. (1)

The total strain component is expressed as:

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \tag{1}$$

The stress can be derived from Eq. (2):

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl} = C_{ijkl}\varepsilon_{ij} \tag{2}$$

where σ_{ij} is the stress tensor, ε_{ij} is the strain tensor, and C_{ij} is the elastic stiffness tensor and summation has been assumed over repeated indices $i, j, k, l = 1, 2, 3$.

Table 1
The mineral properties of sample A1.

Mineral	Colour	E (GPa)	Tensile Strength (MPa)	Compressive Strength (MPa)
Sphalerite	Purple	54	13.5	135
Galena	Pink	71	17.8	178
Chlorite	Light	75	18.8	188
Biotite	Dark	84	21	210
Quartz	Blue	100	25	250
Pyrite	Yellow	292	73	730