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Calculating breakage parameters of a batch vertical stirred mill

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ABSTRACT

The paper discusses the outcome of a series of test work carried out in a screw type batch vertical stirred mill to evaluate the effect of experimental conditions on the product particle size distribution and generation of fines. A time-based population balance model has been utilized to develop mill selection and breakage function for different operating conditions. A systematic variation in both selection and breakage functions of the population balance model with changes in process conditions are fitted through regression models.

1. Introduction

Fine grinding is becoming increasingly common in mineral processing plants in order to liberate valuable minerals from fine-grained and low-grade ore bodies. Stirred milling technology are gaining wider acceptance in replacing ball mills for fine grinding ($<100\ \mu m$) as they consume less energy. Low speed vertical screw type stirred mills (such as the Metso Vertimill and Nippon Eirich Tower Mill) are an important class of the stirred mills used extensively in the minerals industry. Currently, more than 450 units of Vertimill have been installed worldwide with a total power of 300 MW (Allen, 2013). To understand mill breakage behaviour and the influence of process variables over particle breakage, it is essential to develop a process model for predicting particle size of the mill product, under different operating conditions for a given feed size distribution.

Epstein (1948) introduced the concept of population balance modelling in the comminution process through defining the selection and breakage functions. According to author, the selection function is the probability of a particle being selected for breakage, and the breakage function is the size distribution of the broken particles. This fundamental idea was used to develop time or energy-based population balance models or content based perfect mixing models. Austin et al. (1984) developed the kinetic or time based population balance model where the concept of rate-mass balance of each particle size was quoted. Instead of numbers of particles, the mass of the particles was considered in the model. Breakage and selection functions are the most important part of the population balance model to fit and simulate vertical stirred mill operation. An empirical function proposed by Austin et al. (1984) can be used to provide a simulated breakage function in the population balance model. The breakage function in a cumulative form ($B_{i,j}$) is shown as follows:

$$B_{i,j} = \Phi_j\left(\frac{x_{i-1}}{x_j}\right)^{\gamma} + (1-\Phi_j)\left(\frac{x_{i-1}}{x_j}\right)^{\beta}, 0 \leqslant \Phi_j \leqslant 1 \quad (1)$$

where Φ, γ and β are dimensionless and specify characteristics of the broken materials. According to Morrell et al. (1993), a breakage event in any mill grinding process is a function of the material being ground, the way the material is captured for breakage, the energy level and the direction of the force applied during the time of capture. Austin (1992) and Gao and Frossberg (1995) defined three modes of breakages in the grinding process, described as follows:

Abrasion is due to the application of local low-intensity surface breakage and results in a bimodal particle size distribution. Hence for each breakage event, a particle close to the parent particles is developed along with fine particles taken from the surface of the parent particles.

Cleavage results due to the slow application of relatively intense stresses (compression) producing fragments slightly smaller than the parent particles.

Fracture is a result of rapid application of intense stresses and generates a wide size distribution, producing small particles with respect to the parent particles.

Kelly and Spottiswood (1982) have depicted these three modes of breakage as shown in Fig. 1. The authors mentioned that these different breakage mechanisms never take place alone, instead they are associated with one another. Moreover, the type of mill, operating conditions and the materials being ground determine the ratios of these breakage modes in a breakage event.

The standard breakage function developed by Broadbent and Callcott, has been successfully used for ball mill modelling and simulation (Napier-Munn et al., 1996). This breakage function is extensively used, such as in the perfect mixing ball mill model in the JKSimMet mineral processing simulator (JKTech, 2012).

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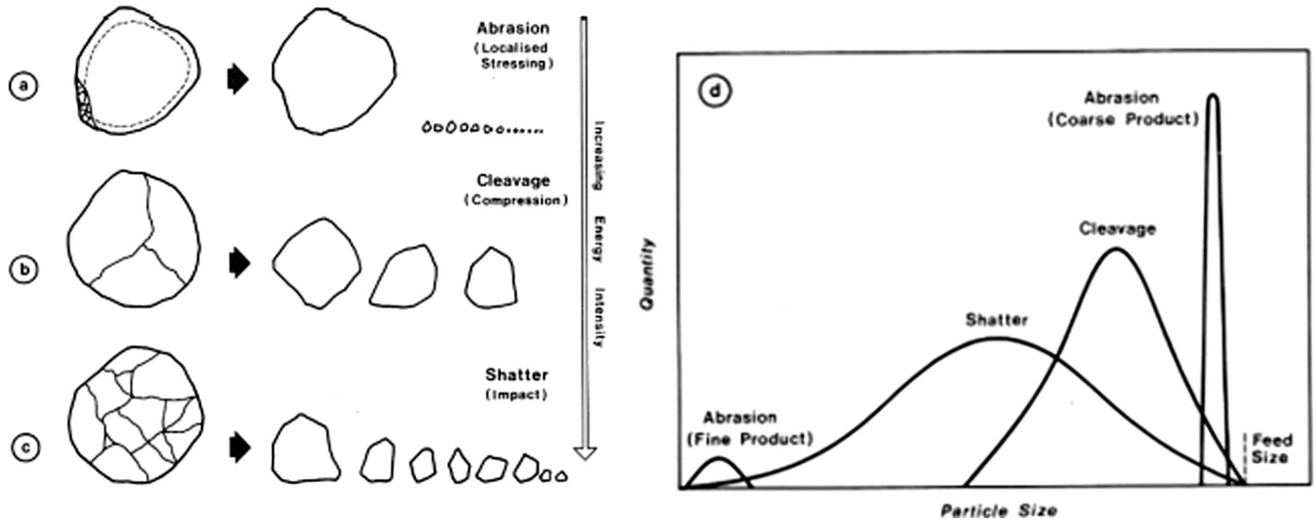

Fig. 1. Different breakage mechanism and associated particle size distribution (Kelly and Spottiswood, 1982).

The selection function shows the rate at which particles are selected for breakage. Particle selectivity for breakage depends on its size and changes with process conditions of the mill. Morrell (1989) referred to selection function as particle breakage events occurring per unit of time. According to Bueno (2013), the selection function is the mass transfer rate (1/h) from coarse to fine size fraction. Leung (1987) mentioned that the selection function depends on the breakage function used to develop it. Austin et al. (1984) specified that the selection function varies with mill type, its operating conditions and ore characteristics. The selection function having a unit of min^{-1} can be used in the population model to the following form as proposed by Austin et al. (1984):

$$S_i = A\left(\frac{x_i}{1000}\right)^{\alpha} * \frac{1}{1+\left(\frac{x_i}{\mu}\right)^{\Lambda}}, \Lambda \geqslant 0 \tag{2}$$

where A, α, μ and Λ are model parameters. A has the unit of min^{-1} and varies with mill conditions. α and Λ are dimensionless, and their value depend on the material properties. x_i is the particle size in μm and μ is particle size expressed in μm at which dS_i/dx is zero.

The general shape of the selection function is shown in Fig. 2 which depicts the particle selectivity for breakage reaching a maximum value at a certain particle size, i.e., x_m. This implies that the particles coarser than x_m are not broken efficiently in the mill. Therefore, x_m can be a useful indicator to prepare the feed for the mill; hence the mill efficiency can be improved. The selection function parameters in Eq. (2) are related to grinding operation as follows:

A = *f* (mill conditions, e.g., media size, solids concentration, mill speed, mill filling)
α = *f* (ore hardness, mineralogy, specific gravity, etc.)
μ = *f* (mill media size and mill speed)

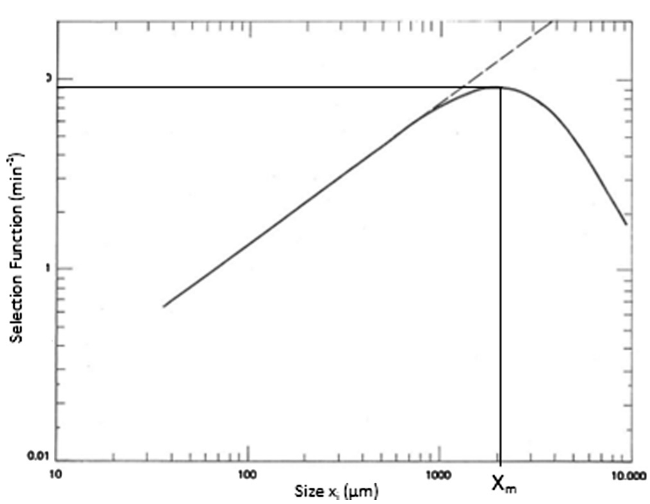

Fig. 2. Typical shape of the selection function (after Austin et al., 1984).

Menacho and Reyes (1989), Tuzun (1993), Jankovic (1999), Mazzinghy et al. (2012,2014,2015a,2015b), Mazzinghy and Russo (2014) have used the population balance technique to model vertical stirred mills. These authors have concentrated their work mostly on developing scale-up models for the vertical stirred mill. However, no attempt was taken previously to determine the types of breakage occur in the vertical stirred mill and how it gets affected through process conditions. In addition, it is also necessary to understand how process conditions influence the particle breakage rate in the vertical stirred mill and how it can be quantified through population balance modelling technique. Comprehensive test work was conducted in a batch vertical stirred mill with a screw stirrer by varying specific energy consumption, slurry density and tip speed. The paper discusses the effect of the process variables on the selectivity for breakage (selection function) and progeny of each breakage event (breakage function) for grinding Limestone.

2. Test methodology

2.1. The batch mill

The grinding test work was carried out in a 2.2 kW batch vertical stirred mill at the JKMRC pilot plant as shown in Fig. 3. A steel pot (380 mm diameter) forms the grinding vessel, with a cage lining inside he shell used to lock in the media against the shell, replicating the effect of a magnetic liner used for wear protection. A two-start steel screw (200 mm diameter and 200 mm height) was used as a stirrer. The mill shaft was attached to a non-contact rotating and reaction type torque transducer to measure the applied torque to stir the media. The torque meter was connected to a computer to record real time torque and mill speed data, using the manufacturer's custom data logging software. The mill speed was varied from 0 rpm to 350 rpm controlled by a potentiometer. The clearance between the screw and mill floor was maintained at 8 mm to reduce the possibility of media being locked between the digging shoe and mill floor. The grinding pot was placed on a heavy rigid metal frame with an interlocking system to ensure that the grinding pot remains in its place while running the mill. The mill design