Powder Technology 279 (2015) 42–48

Contents lists available at ScienceDirect

Powder Technology

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

Application of basic process modeling in investigating the breakage behavior of UG2 ore in wet milling

Gwiranai Danha [*], Diane Hildebrandt, David Glasser, Clayton Bhondayi

University of South Africa, Department of Civil and Chemical Engineering, College of Science, Engineering and Technology, Private Bag X6, Florida, 1710 Johannesburg, South Africa

ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form 13 March 2015
Accepted 21 March 2015
Available online 3 April 2015

Keywords:
Wet milling
UG2 ore
Process modeling

ABSTRACT

We carried out wet milling batch tests in a laboratory scale ball mill on a minus 600 μm UG2 ore as feed. In this paper, we aim to investigate the nature of the UG2 ore using a simple method that relies only on the breakage kinetic data and knowledge of basic process modeling skills. Our results show that a two component model more accurately predicts the breakage behavior of the UG2 ore when compared to the homogeneous or true first order model. This paper takes the view that due to the effectiveness of the two component model in describing the milling behavior, it may be hypothesized that the ore might best be described as composing material of two different hardness; termed the 'soft' and 'hard' components. Our results also show that for all solid concentrations investigated, the rates of breakage of the 'soft' component are much higher than for the hard component. We also found that at 20% solid content the difference between the rates of breakage of the soft component (0.15 per second) and that of the hard component (0.0159 per second) is 0.1341 per second, while at 50% solids the difference is 0.111.

1. Introduction

The work reported in this paper is an ongoing research on platinum group metal (PGM) ore at the University of South Africa. In this test work, we used small ball sizes (10 mm), a low ball filling ($J = 8.2\%$) and low solid content (20–50% by mass). These experimental parameters were chosen for the purposes of achieving moderate breakage and developing fundamental ideas, and not intended to be used as ideal operating conditions for industrial mills. We are of the view that the current operational problems in the mining industry, especially here in South Africa can be resolved by going back to the basics in order to come up with fundamental solutions. Current practice employs 'real industrial operation parameters' in order to achieve high milling rates at the expense of prioritizing selective grinding, hence our motivation to investigate outside the 'real parameters'.

We carried out a series of wet milling batch tests in a laboratory-scale ball mill with a UG2 ore feed, in which the particles were below 600 μm in size. We obtained the feed material from Anglo Platinum Amandelbult Plant's primary cyclone underflow (feed to the secondary mill). The purpose of these experiments was to investigate whether the UG2 ore is homogeneous or heterogeneous in nature. If it is found to be heterogeneous, then one could in principle selectively grind one component only, thereby effectively reducing the feed to the subsequent processing units. The novelty of the work presented here lies in the simplicity of the method used to carry out the investigation, which requires only the breakage kinetic data and basic process modeling skills.

The outcome of this study might be of great benefit to scholars, mineral processors and designers of milling circuits, as it offers a new approach to how process modeling can be used to determine the nature of an ore.

2. Process modeling

One of the tools that are commonly applied to evaluate whether comminution is being carried out effectively is process modeling [6], which in theory makes it possible to predict accurately the product particle size distribution (PSD) after a certain grinding time and under specified grinding conditions [5]. Process models can be used, among other things, as benchmarks that can be used by operators to set mill residence times and process conditions in order to produce particles in the size range required by a designated downstream process. The problem associated with using a wrong model in estimating the amount of material remaining in a chosen particle size range (size class) is that one misses out on optimum grind time to be used to produce a desired fineness of grind, and hence risks either grinding too fine (wasting energy in the process) or grinding too coarse (reducing the efficiency of downstream processes such as flotation). Using a wrong model also leads to over- or under-design of equipment, and following operating procedures that are neither optimal nor economic.

---

[*] Corresponding author at: University of South Africa, Department of Civil and Chemical Engineering, College of Science, Engineering and Technology, Private Bag X6, Florida, 1710 Johannesburg, South Africa. Tel.: +27 116709288.
E-mail address: danhag@unisa.ac.za (G. Danha).

http://dx.doi.org/10.1016/j.powtec.2015.03.034
0032-5910/

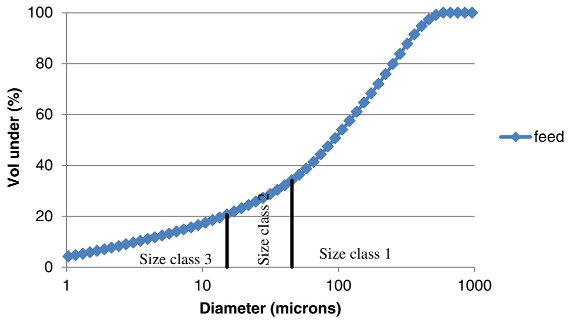

Fig. 1.1. The particle size distribution (PSD) of the feed material used for the experiments. The size ranges of the feed size class (class 1), the intermediate size class (size class 2) and the fines (size class 3) are shown in the figure.

First order models are often valid and frequently used in the analysis of the rate of breakage of single-component (homogeneous) material in a batch laboratory scale ball mill. However, batch tests do not always fit the first order model [10], and there are various hypotheses as to why this happens. Austin et al. [1] postulated that the non-linear breakage of material can be due to a general slowing down of all grinding rates as fines accumulate in the charge. He further discussed that non-linear breakage also occurs when the particles are too large to be properly nipped by the balls. In this case the material behaves as if some particles are relatively weak while others are stronger. For the latter effect, the first order breakage model can then be split into two parts, a fraction β of the weak material (with a specific rate of breakage S_a) and a fraction 1 − β of strong material (with a specific rate of breakage S_b).

Various models can be used to predict the PSD of multi-component or heterogeneous feeds, as summarized in Section 5. These models appear to be non-first order, but can be a simple combination of two first-order models. The models can be employed to predict the grinding of the overall mixture by fitting data obtained from simple batch tests, and it is the method we used in our investigation. The model parameter estimation is arrived at via a 'force fixing' technique, which involves minimizing the numerical estimation of the sum of squares of the deviation between model prediction and experimental data. This is done by searching in the parameter space until an acceptable fit with the experimental data is achieved.

3. Mineral processing circuits

At present, the extraction of PGMs from ores in South Africa follows the traditional route, which involves four stages: size reduction to liberate values, concentration to remove the gangue followed by smelting that chemically separates mineral components and refining that purifies to achieve a saleable product [4]. In this approach, the efficiency of the extraction process depends strongly on that of the first stage. The majority of PGMs produced in South Africa are obtained from the UG2 chromitite reef [8] of the Bushveld Igneous Complex. This is because the Merensky reef deposits have become depleted, while the Plat reef deposits are low in PGM values.

Because current mineral processing circuits are not as effective in liberating valuable minerals (values) from gangue in the UG2 ores as they could be, researchers [8,9] are continually investigating ways of improving their performance. The laboratory-scale study outlined in this paper adds value to the research on UG2 ore. If our results prove that the UG2 ore is heterogeneous, we can derive many advantages. We infer that it may then be possible to grind the desired component selectively and/or remove the component of no value. Selective grinding might reduce the amount of energy required by the mill, require a smaller mill size, and greatly improve overall mineral recoveries, as only material of value would be processed.

4. Particle size classification

In this experimental work we considered three particle size classes. These are the feed (size class 1); an intermediate (size class 2) or desired size class and the fines (size class 3), which are difficult to float resulting in the loss of values. The feed size class chosen was particle sizes above 45 μm in diameter; the intermediate was particle sizes between 15–45 μm; and the fines' particle sizes below 15 μm. Although any set of size classes and size specifications could be defined, we chose the set of sizes above to place size class 2 as the desired product within the ideal range for flotation [9] to remove the valuable material from the gangue.

5. Kinetic approach to grinding

In the analysis of various types of grinding mills, the concept of treating grinding as a rate process (like chemical reactor design) is well accepted [13]. A batch grinding process is commonly characterized by two main functions, selection (S_i), which gives the rates of breakage of each size class i; and breakage (b_{ij}), which describes the size distribution of the primary product particles [3] broken from size class j and reporting to size class i. An expression of the rate for a grinding system is given by a size-mass balance equation:

$$dm_i(t)/dt = -S_i m_i(t) + \sum\nolimits_{j=1}^{i-1} b_{ij} S_j m_j(t), \tag{1.1}$$

where:

i and j	are the size classes;
$m_i(t)$	is the mass fraction of the particles in size class i, after a grind time t,
S_i	is the specific rate of breakage of size class i
b_{ij}	is the mass fraction of broken products from size class j, which appear in size class i on primary breakage; and
t	is the grinding time.

Eq. (1.1) makes it possible to predict the product PSD at various grinding times [11] if the parameters b_{ij} and S_i are known for all size classes. For breakage of the feed (size class 1) material, integration of Eq. (1.1) yields:

$$m_1(t) = m_1(0)\exp^{-S_1 t} \tag{1.2}$$

or

$$\ln[m_1(t)/m_1(0)] = -S_1 t. \tag{1.3}$$

If the grinding process follows a first-order model, then a plot of $\ln[m_1(t)/m_1(0)]$ versus t should give a straight line, the gradient of which is the selection function or first-order rate of breakage (S_1) [12]. In many cases, breakage of material in a batch laboratory ball mill will show a reasonable approximation to what Eq. (1.2) leads one to expect [1].

Considering a composite binary mixture of a soft and a hard material [2,7], with φ the fraction of soft material 'A' and $(1 - \varphi)$ the fraction of hard material 'B', the left-hand side of Eq. (1.1) can be modified such that the total rate of breakage of size class i (as shown by Eq. (1.4))

Table 1.1
Size class specification.

Size class	Cut-off points (microns)	Composition (%)
1	+45	67
2	−45 + 15	13
3	−15	20