Simulation of a ball mill operating with a low ball charge level and a balanced ball size distribution

Simulação de moinho de bolas operado com baixo enchimento e com distribuição balanceada de bolas

Douglas Batista Mazzinghy
Mining Engineer, Doctor
Federal University of Minas Gerais.
douglasmazzinghy@ufmg.br

José Guilherme de Abreu Valadares
Mining Engineer
Federal University of Minas Gerais.
jgulherme@eng-min.gard.ufmg.br

Roberto Galéry
Mining Engineer, Doctor, Professor
Federal University of Minas Gerais.
rgalery@demin.ufmg.br

Luiz Cláudio Monteiro Montenegro
Mining Engineer, Doctor, Professor
Federal University of Minas Gerais.
lcmm@demin.ufmg.br

Antônio Eduardo Clark Peres
Metallurgical Engineer, Ph.D., Professor,
Federal University of Minas Gerais.
aecperes@demet.ufmg.br

Resumo

A otimização de circuitos industriais de moagem tem sido realizada com sucesso, utilizando-se modelos matemáticos que relacionam dados industriais com parâmetros de quebra determinados através de testes de moagem em escala de laboratório. O material estudado é um minério de ouro moído através de um circuito fechado de moagem de bolas. A classificação foi realizada por hidrociclones. Várias campanhas de amostragens foram realizadas com o objetivo de fechar um balanço de massas e fornecer material para os testes em laboratório. Os parâmetros determinados nos testes em laboratório, foram utilizados para prever, por simulação, o comportamento do circuito operado com baixo enchimento de bolas e com distribuição balanceada de tamanhos de bolas.

Palavras-chave: Moagem, simulação, otimização, moinho de bolas.

Abstract

The optimization of industrial grinding circuits has been successfully performed using mathematical models that describe the industrial scale data from breakage parameters determined in laboratory grinding tests. The test material studied here is a gold ore ground in a closed ball mill circuit with hydrocyclone classification. Several sampling campaigns were carried out aiming to produce mass balances and provide material for laboratory tests. The parameters determined in the laboratory tests were used to predict, by simulation, the circuit behavior with a low ball charge level and a balanced ball size distribution.

***Keywords**: Grinding, simulation, optimization, ball mill.*

1. Introduction

The Cuiabá Expansion Project, property of AngloGold Ashanti and located in Sabará city, Minas Gerais State, Brazil, aimed to elevate the capacity of treatment of sulfide gold ore from 830,000 to 1,400,000 metric tons per year. The circuit is direct with an overflow ball mill, 5.2m of diameter and 7.8m of length, and classification is accomplished by a cluster of 6 cyclones of 500mm diameter. The geological model indicated high ore competency in deep mine levels. The mill was sized to meet this future demand. During the first years the grinding circuit will be operated with a less competent ore. The objective of this paper is to determine the mill's optimized condition for the first years by simulation.

2. Mathematical modeling

Population balance model

Equation 1 describes the population balance model for batch grinding:

$$\frac{dm_i(t)}{dt} = S_i m_i(t) + \sum_{j=1}^{i=1} b_{ij} . S_j . m_j(t) \text{ , } i=1,2,\ldots,n \tag{1}$$

$m_i(t)$ represents the fraction by mass of particles contained in interval size *i* after grinding time *t*; S_i represents the selection function of particles in the interval size *i* and b_{ij} represents the fragment distribution after the breakage event.

Breakage function

The cumulative breakage function B_{ij} can be modeled by Equation 2 (Austin et al., 1984):

$$B_{i,j} = \beta_0 \left(\frac{d_i}{d_{j+1}}\right)^{\beta_1} + (1 - \beta_0)\left(\frac{d_i}{d_{j+1}}\right)^{\beta_2} \quad , \; 0 \leq \beta_0 \leq 1 \tag{2}$$

The parameters $\beta_{0,}$ β_1, β_2 are characteristic by material.

Energy specific selection function

According to Herbst & Fuerstenau (1980), in practice it has been observed that the values of the selection function for each size, S_i, represent proportionality relationships with the power absorbed by the mill as shown in Equation 3:

$$S_i = S_i^E \left(\frac{P}{H}\right) \tag{3}$$

S_i^E is the energy specific selection function in t/kWh; *H* is the mill hold up and *P* is the net grinding power. These equations have been used to determine the energy demanded by grinding a certain given product size distribution, and can also be used in the scaling up of industrial grinding circuits, from laboratory scale tests.

The selection function S_i can be modeled using equation 4 (Austin et al., 1984):

$$S_i = \frac{\alpha_0 \, (d_i)^{\alpha_1}}{1 + \left(\frac{d_i}{d_{crit}}\right)^{\alpha_2}} \qquad \alpha_2 \geq 0 \tag{4}$$

The parameters $\alpha_{0,}$ α_1, α_2, d_{crit} are characteristic of material and grinding conditions.

3. Methodology

The study was conducted in the following sequence:

1) Produce a mass balance through data from industrial circuit sampling.
2) Determine the breakage function parameters through batch lab scale tests with narrow size fractions.
3) Determine the specific selection function parameters through ball mill with torque measurement.
4) Simulate the industrial grinding circuit through the information obtained in the previous items.

Moly-Cop Tools version 2.0 was used for steps 1, 3 and 4 and an application developed by the authors was used for item 2. *Moly-Cop Tools* uses the Plitt model (1976) modified for hydrocyclones simulations.

Table 1 shows the correspondent parameters used in the *Moly-Cop Tools*.

Selection Function		Breakage Function	
Moly-Cop	Austin's	Moly-Cop	Austin's
α_0	a	β_0	ϕ
α_1	α	β_1	γ
α_2	Λ	β_2	β
d_{crit}	μ		

Table 1
Correspondent breakage parameters.

Procedure to determine the breakage function

The batch mill used has a diameter and length equal 254mm and eight charge lifters equally spaced. It was operated with a ball charge equal to 20% (J=0.2), powder filling (voids between the balls) equal 50% (U= 0.5) and ran at 70% of the critical speed. The breakage parameters were determined by Austin *BII* method (Austin et al., 1984). Five narrow size fractions were tested using the methodology described in Alves et al., 2004.

Procedure to determine the energy specific selection function

The torque mill used has a 460mm diameter by 360mm length with four lifters. The test was carried out under the same operational conditions of the industrial grinding circuit. The power consumed in the torque mill was calculated using Equation 5 where P (W) is the power, T (Nm) is the measured torque and v (rps) is the speed.

$$P = 2\pi(T)\,(v) \tag{5}$$

Every procedure used in the grinding tests is described in detail in Mazzinghy (2009).

4. Results

Ball charge sampling

The ball charge of the industrial ball mill was sampled during one of the maintenance stops. The mass of balls required to consider the sample representative was too high and it was not possible to achieve the necessary mass. The sampling showed many balls with different shapes as shown in the Figure 1.

Figure 1
Balls collected from ball charge sampling.

Breakage function parameters

Table 2 shows the breakage function parameters obtained in the batch mill tests with five narrow size fractions.

β_0	β_1	β_2
0.62	0.58	3.67

Table 2
Breakage function parameters.

Energy specific selection function parameters

The energy specific selection function was determined in the torque mill operating under the same operational conditions except for the ball size distribution. The Bond equilibrium ball size distribution was used because the ball sampling campaign did not achieve the desired accuracy. The test was performed with a 77.9% solid concentration, 23.3% ball charge level and 75% of the critical speed.

Table 3 shows the parameters for the energy specific selection function determined in the torque mill tests.

Figure 2 shows the particle size distributions from the torque mill test.

The dots represent the experimental data and the lines represent the model prediction.

Table 3
Specific selection function parameters.

α_0	α_1	α_2	d_{crit}
0.0074	0.6875	2.50	7144

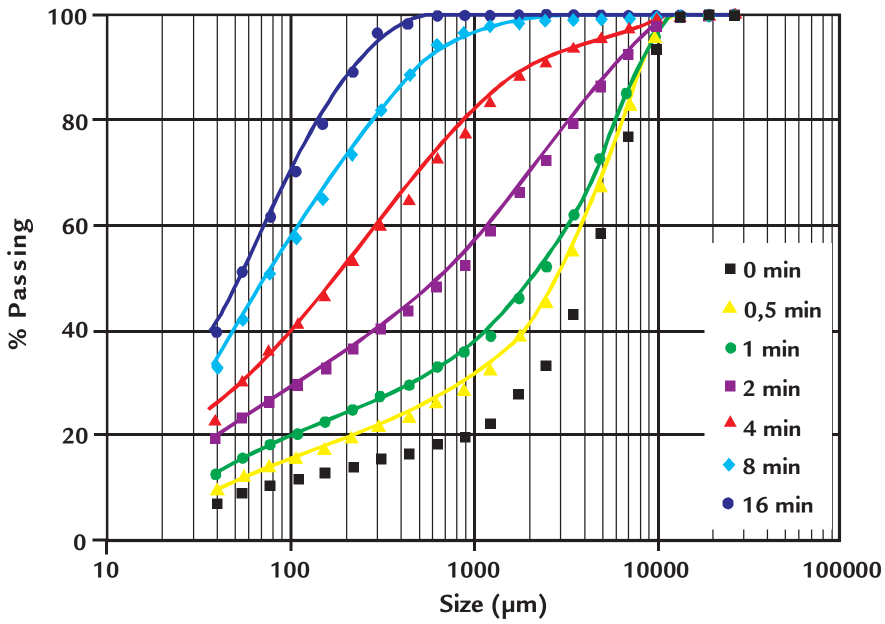

Figure 2
Particle size distributions from the torque mill test.

Simulations with Bond equilibrium ball size distribution

The energy specific selection function and the breakage function were used in the simulator to predict the behavior of the industrial circuit operated with 23.3% ball charge level and Bond equilibrium ball size distribution. The transport model consisted of three equally sized perfect mixers.

The results showed that the P_{80} of the industrial mill, estimated by the simulator, is equal to 49.1 μm. The solids feed rate to the grinding circuit could be increased, but the flotation circuit has a limited capacity. In order to optimize the grinding operation, the ball charge level was reduced until the flotation circuit target P_{80}=74μm was achieved. Simulations indicated that the target would be achieved at a 15% ball charge level using the Bond equilibrium ball size distribution.

Validation

A new laboratory test was conducted with torque mill considering a 15% ball charge level that was determined by simulation. Table 4 presents the energy specific selection function parameters obtained with 15% ball charge level.

A new simulation was performed with the new energy specific selection function parameters, presented in Table 4. The simulation indicated that the target P_{80} was achieved with 16.2% ball charge level, an acceptable deviation in relation to the previous value of 15% obtained by simulation.

Table 4
Energy specific selection function parameters obtained with 15% ball charge level.

α_0	α_1	α_2	d_{crit}
0.0051	0.7404	2.50	7585

5. Discussion

The simulations showed that it was possible to reduce the ball charge level if a Bond equilibrium ball size distribution was considered. This result is consistent with the data presented by Arentzen and Bhappu (2008), who investigated the optimization of Copperhill, Isabella and Sydvaranger grinding circuits operated with low ball charge levels.

It was not possible to confirm industrially the results obtained by simulation because the AngloGold Ashanti concentrator starts being fed with high competency ore requiring high ball charge levels to meet the grinding product specification of P_{80}=74μm.

6. Conclusions

The optimized grinding circuit condition has been provided by simulation using the breakage parameters obtained in the lab mill tests. The grinding circuit would be optimized considering a low ball charge level and a balanced balls size distribution. In this case it is recommendable to use the discrete elements modeling to check if the balls will be launched against the liners if the low ball charge levels are considered.

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