Multi-Compartment Rod/Ball Mill Evaluation on Bauxite Operation

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ABSTRACT

In mineral processing operations, the grinding circuit is a key step in the process to achieve the particle size and liberation required for the subsequent stage of the productive chain. Especially for bauxite processing, wet grinding can be complex due to the changes in the grindability when exposed to conditions commonly used: high temperatures and alkaline medium, for example. To better understand the operation of the multi-compartment rod/ball mill of a bauxite operation in Brazil, a complete study was conducted to evaluate the impact of feeding the circuit with different ore blends and maintaining product specifications. Each ore blend represented different ratios of two types of bauxite with different mineralogical properties and size distributions. The traditional part of the project consisted of sampling the grinding circuit, data collection from the plant historian system, completion of the Bond Work Index test and particle size distribution, and calculations using the Bond theory and power model. The challenge was the condition of the feed material, which for some blends was not competent enough for standard Bond tests, therefore the methodology was adapted to compensate. This paper presents the details of the study, including methodology and results obtained for each of the ore blends. Based on the results, it was possible to analyse and predict the behaviour of the grinding circuit due to changes in different conditions, as well as to identify the restrictions on the circuit for each scenario. The results are presented for different scenarios which vary in F_{80}, Work Index and P_{80} in the ball and rod compartments to show the corresponding feed rate variation in the mill.

INTRODUCTION

The effects of different bauxite blends in the grinding feed of a plant in Brazil were evaluated to assess the performance of the compartmented rod/ball mill. Suitable blends to feed the mill while maintaining product specifications were identified. Each ore blend represented different ratios of two types of bauxite with different mineralogical properties and size distributions.

Traditionally, the sizing of mills for the minerals industry is based on the Bond Work Index (BWI) [1]. The standard Bond test is performed in a mill with predefined characteristics and in a dry process, with subsequent application of correction factors proposed by Bond and Rowland for equipment sizing [2]. Bauxite grinding typically has specific process conditions, such as high temperature and an alkaline medium which significantly alter bauxite grindability.

Safonov et al. [3] developed a study to evaluate the effects of process parameters on grindability and BWI considering two types of bauxite as a function of composition: gibbsite and diaspore. The tests were conducted in Bond and Hardgrove mills and adapted to investigate the following scenarios: dry, wet and alkaline wet at different temperatures. The results showed that, for bauxite rich in gibbsite, the BWI decreased by 45 to 49 % for wet conditions at room temperature when compared to the dry test. The reduction was even greater when considering the increase in temperature and alkaline medium. For bauxite rich in diaspore, the same tendency was also observed, but with different rates of reduction. Thus, the bauxite grindability index can be corrected from the dry test to a new condition considering an empirical correction factor (Equation 1), which depends on the characteristics of the medium and the type of bauxite [4].

$$\boldsymbol{Bond\ WI_{corrected} = \frac{Bond\ WI_{standard}}{k}} \tag{1}$$

The bauxite mine has an open circuit compartmented rod/ball mill, with an alkaline wet medium and at room temperature. The study consisted of sampling the grinding circuit, data collection from the plant historian system, a BWI test and particle size distribution, and Bond theory and power model calculations. From the results, it was possible to analyse the grinding behaviour in different conditions, in addition to understanding the limitations of the circuit.

METHODOLOGY

STEP 1: Sampling and Data Collection

Currently, mill feed (Blend A) is composed of two types of bauxite with different mineralogical properties and size distributions. The grinding circuit was sampled, and feed rate (tph) and power draw (kW) data was collected for the calculations [5]. Once samples were collected, the mill was ground out and stopped to perform internal measurements (length, diameter and rod/ball charges). The operating conditions of the mill at the time of sampling are shown in **Table 1**.

Table 1 Operating conditions of the mill when sampling

Parameters	Values	Parameters	Values
Feed rate, tph (wet basis)	260	Average power draw, kW	1144.6
Feed moisture, %	11	Installed power, kW	1500
Mill speed, rpm / % critical speed	13 / 55	Power utilization, %	76.7
Rod charge, %	27.2	F_{80}, μm	56,195
Ball charge, %	27.8	P_{80}, μm	280

STEP 2: Laboratory Tests

Both types of bauxite were sent to a laboratory for the composition of new blends, size distribution analysis and BWI (rod/ball) tests. The ball BWI tests for Blends 2 and 3 were conducted with a reduced number of revolutions on the first cycle in order to keep the original conditions of the samples and avoid the possible effects that scalping could generate. The sample collected (Blend A) in the mill feed was sized and BWI tested (rod/ball), representing the base case. The size distribution curves for each blend (feed) are shown in **Figure 1** while the F_{80} and BWI (rod/ball) test results are shown in **Table 2**. The slurry sample collected from the mill discharge had a P_{80} of 280 μm (downstream target is 300 μm).

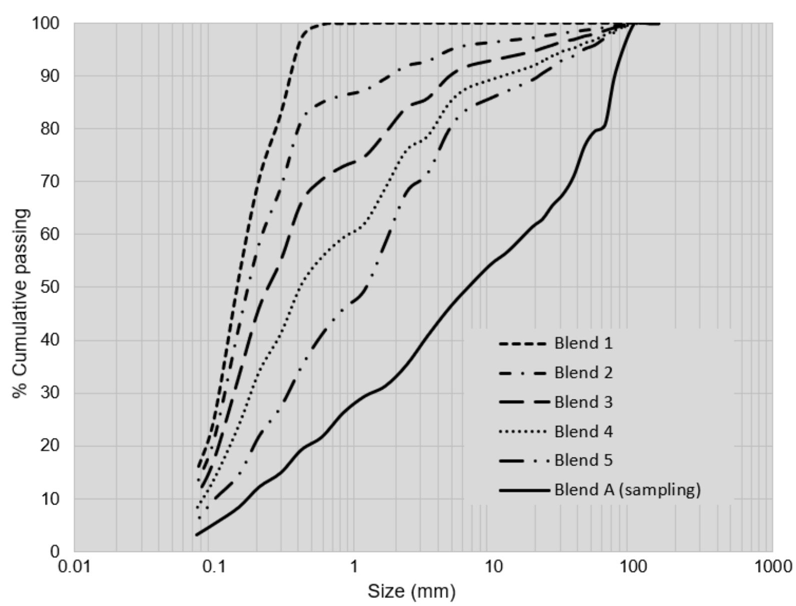

Figure 1 Size distribution curves of each blend (feed)

Table 2 F80 and BWI values

Samples	F_{80}, µm	Rod WI (kWh/t)	Ball WI (kWh/t)
Blend 1	280	*	*
Blend 2	405	*	4.6
Blend 3	1800	*	8.1
Blend 4	3700	*	9.2
Blend 5	4900	18.0	11.0
Blend A (Survey)	56000	16.8	11.0

* Inconclusive test results due to excessive fines in the sample.

STEP 3: Calculations – Bond Theory and Power Model

The correction factor (K) was used to adjust the grindability of bauxite in an alkaline medium using the BWI test results (dry process). The base case K-factor was calculated and assumed constant for all blends. The calculated value was similar to reference studies, providing reasonable verification.

Rod grinding is suitable for feed with an F_{80} between 4 and 20 mm (on average), being more efficient for coarse material. Rod mills generate small amounts of fines, as fine particles typically accumulate in the space between rods without enduring comminution [2]. Effective grinding of this material occurs in the ball mill compartment, generating finer fragmentation.

The Bond Rod Mill Work Index (BRMWI) test was only possible for Blend 5 (Table 2) due to excessive fines in the other blends. The calculated power required for the remaining blends only considered grinding the coarse fraction in the rod compartment.

The Bond formula and power model were used to verify the effects of operational variables, hardness and size distribution of the ore in the mill. Mill power calculations were performed based on conditions at the time of sampling, in addition to considering other scenarios. The Bond formula and the correction factors described by Rowland (2002) were used for power calculations (Equation 2).

$$P = T.10\,Wi\left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right) \times EF_1 \times EF_2 \times \ldots \times EF_8 \qquad (2)$$

Where,

T : Feed rate, tph
Wi : Bond Work Index for rod and ball compartments
F_{80} : 80 % passing size of the circuit feed, µm
P_{80} : 80 % passing size of product, µm
$EF_{1\text{-}8}$: Correction factors

To estimate power draw in the rod and ball compartments, Equations 3 and 4 were used [6] [7].

$$P_{(Rod)}(kW) = 1.752 \text{ x } D^{0.34} \ x \ (6.3 - 5.4 \text{ x } V_R).C_F \tag{3}$$

$$P_{(Ball)}(kW) = \left(4.879 \ x \ D^{0.3} \ x \ (3.2 - 3 \ x \ V_B) \ x \ C_F \ x \ \left(1 - \frac{0{,}1}{2^{9-10xC_F}}\right) + S_S\right) x \ 1.16 \tag{4}$$

Where,

D : Internal diameter, m
C_F : Fraction of critical speed C_s, %
V_R : Rod charge, %
V_B : Ball charge, %

RESULTS AND DISCUSSION

The calculated power of the mill (1153.7 kW) for the base case as a function of dimensions, mill speed and grinding media charge (Equations 3 and 4) is consistent with the average power consumed during sampling (1144.6 kW). The operational WI calculated with measured and calculated power was 8.9 and 9.0 kWh/t, respectively. The power consumption calculated for the rod and ball compartments were 401 and 753 kW, respectively. These values indicate a power consumption ratio of 34.8 % for the rod compartment and 65.2 % for the ball compartment.

The Bond formula (Equation 2) was used to calculate the required power for both compartments (rod and ball) for each scenario. Requirements include: power to maximize the feed rate of the mill while achieving a P_{80} of 300 µm, available power (401 kW for rod and 753 kW for ball) and reaching an optimal transfer size between the compartments. The results are presented in **Figure 2** and **Table 3**.

As the mill feed becomes finer, the greater the feed rate for the same power consumed, considering a P_{80} of 300 µm (**Figure 2** and **Table 3**). In the ball compartment, such behaviour is also influenced by the decrease in WI as the blend becomes finer.

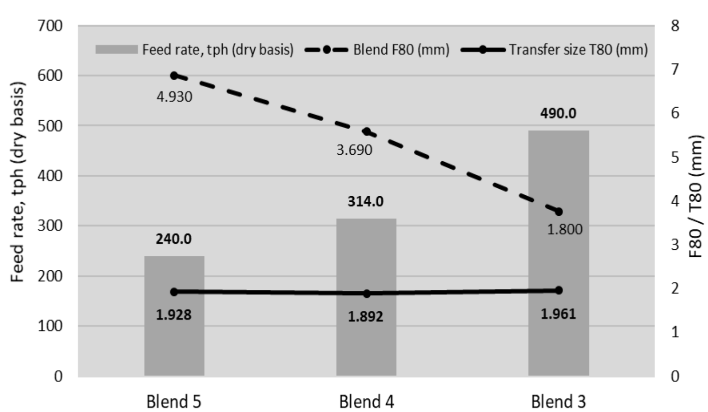

Figure 2 Results of the evaluation of the samples when feeding the mill

Table 3 Results

Rod Compartment						
	Blend A	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
Rod WI (kwh/t) - sample	16.9	*	*	*	*	18.0
Rod WI (kwh/t) - used	16.9	18.0	18.0	18.0	18.0	18.0
K Factor - Bauxite	0.51	0.51	0.51	0.51	0.51	0.51
Rod WI (kwh/t) - corrected	8.6	9.2	9.2	9.2	9.2	9.2
F_{80} (μm) - sample	56195	280	405	1800	3690	4930
F_{80} (μm) - used	-	4930	4930	4930	4930	4930
P_{80} (μm) - coarse fraction	-	**	**	1961	1892	1928
P_{80} (μm) - resulting	1806	**	**	733	1393	1928
Feed rate dry basis (t/h) – Coarse fraction	-	**	**	245.0	235.5	240.0
Feed rate dry basis (t/h) – Resulting	231.4	**	**	490.0	314.0	240.0
Required power (kW)	401	**	**	401	401	401
Ball Compartment						
Ball WI (kwh/t) - sample	11.1	*	4.6	8.1	9.2	11.1
K Factor - Bauxite	0.68	0.68	0.68	0.68	0.68	0.68
Ball WI (kwh/t) - corrected	7.5	*	3.1	5.5	6.2	7.5
F_{80} (μm)	1806	**	**	733	1393	1928
P_{80} (μm)	280	**	**	300	300	300
Feed rate dry basis (t/h)	231.4	**	**	490.0	314.0	240.0
Required power (kW)	753	**	**	753	753	753

* Inconclusive test results due to excessive fines in the sample.
* Not recommended to feed the mill due to the excess of fines in the sample.

Working with Blends 4 and 5 for mill feed is thought to have no significant negative effects on performance. Calculations for Blend 3 showed that it is possible to process it at a higher rate and obtain the final product P_{80} of 300 μm with the available power, however in this scenario, the change in viscosity of the slurry may adversely affect the grinding process. Therefore, although the calculations show that it is possible to process Blend 3 at a higher rate under these conditions, it is not recommended.

New scenarios with WI variation and size distribution (F_{80}) were considered. The WI for a feed blend must be determined by laboratory testing, despite knowing the WI of each ore type in the blend, therefore a WI value was assigned to each blend. For new scenarios, the rod and ball compartments were evaluated in isolation with a fixed transfer size (1.8 mm). The results are shown in **Figure 3** and Figure 4.

For a given F80 in rod grinding, the feed rate decreases as the WI increases, i.e. for a harder ore the capacity of the rod mill drops considering the same P80 (1.8 mm) and consumed power (401 kW) (**Figure 3**). When comparing curves for different feed sizes, smaller WI values appear to process more material when the F_{80} is higher, with limitations. This behaviour changes when the WI is between 9 and 13 kWh/t and the curve with a lower F80 (5 mm) has a higher feed rate compared to other F80 values. This behaviour is influenced by the low reduction ratio, assumption of fixed transfer size (P80) and the energy required to break larger particles. For finer feed, the reduction ratio is low, which leads to larger correction factors for the energy calculation in the Bond equation.

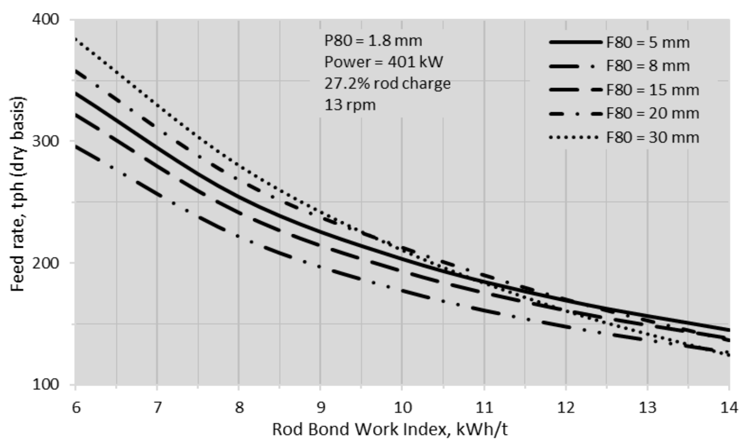

Figure 3 Results of the evaluation of new scenarios for the rod compartment

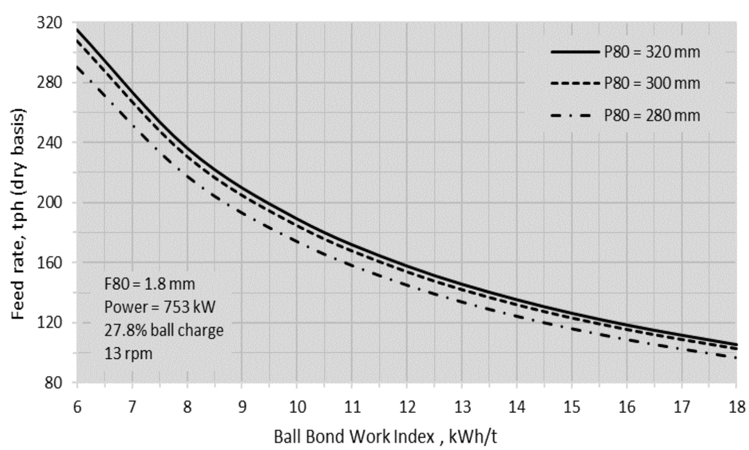

Figure 4 Results of the evaluation of new scenarios for the ball compartment

For a given P_{80} in ball grinding, the feed rate is reduced by increasing the WI, as shown in Figure 4. Considering different P_{80}'s (280, 300 and 320 μm), as expected the lower the desired P_{80}, the lower the feed rate in the ball compartment. In general, Figure 4 shows the feed rates estimated by varying WI and P_{80} for a given F_{80} of 1800 µm, however it does not take into account that when working with excessive fines in the mill, the slurry viscosity and consequently the rheology (deformation and flow of fluid) would be altered, which may interfere with charge movement and the resulting grinding.

CONCLUSION

Blends 1 and 2 presented an extremely fine F_{80}, with size distributions close to that required downstream. It is not recommended to feed the mill with these blends as rod grinding is not effective for fine grinding and the ball milling stage would cause excessive over grinding. Blend 3 is also not recommended since change in viscosity of the slurry may adversely affect the grinding process. In conclusion, it is recommended that the optimal Blends are 4 and 5, to ensure no slurry viscosity issues in the mill.

The results presented for different scenarios with varying F_{80}, Wi and P_{80} in the rod and ball compartments while assuming a constant transfer size between rod and ball compartment showed the feed rate variation in the mill. In general, if the Wi and/or F_{80} of the sample/blend increases, the feed rate of the mill is expected to be lower, but there are exceptions in the rod compartment. Likewise, for the same Wi and F_{80}, the feed rate is reduced if it is necessary to produce a finer material.

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