A Comparison of Test Procedures for Estimating the Bond Ball Work Index on Zambian/DRC Copper–Cobalt Ores and Evaluation of Suitability for Use in Geometallurgical Studies

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Two shortened test procedures for estimating the Bond ball work index are compared for suitability of use on Zambian/DRC-type copper–cobalt ores. The first procedure is based on a batch milling test while the second procedure is based on a limited locked-cycle test. Both procedures were conducted using a standard Bond test mill.

INTRODUCTION

The Bond ball work index is widely used in the field of minerals processing as an indicator of ore grindability. The work index is determined by means of a locked-cycle test procedure that typically requires seven to eight cycles to stabilise at a re-circulating load of 250%. A typical test requires between three to four kilogram of ore sample and around eight hours of operator time. For geometallurgical test work applications, where a large number of variability samples are to be tested, it would be highly beneficial to use a test procedure that requires less sample mass and operator time. Certain test work laboratories, for example SGS and JK Tech, are already offering various types of shortened test procedures for estimating the Bond ball work index. This paper discusses a comparison of two shortened test procedures that were evaluated for suitability of use on Zambian/DRC-type copper–cobalt ores.

EXPERIMENTAL

Test Procedure 1 – Batch Milling

The first test procedure is derived from a batch milling approach proposed by the University of Hacettepe (Aksani, 2000). Some modifications were, however, made to the data analysis method from that originally proposed. During this test procedure, a 700 mL volume of sample is milled in a standard Bond test mill for a pre-determined number of revolutions. The feed and product particle size distributions are measured for each test. These results are then used to back-calculate a cumulative breakage rate parameter (k) for each particle size, according to the following formula:

$$W_{(x,t)} = W_{(x,0)} \cdot exp(-k \cdot t) \qquad [1]$$

where t represents time in units of min, $W_{(x,t)}$ represents the cumulative percentage of oversize material of particle size x at time t in the product and $W_{(x,0)}$ represents the cumulative percentage of oversize material of particle size x in the feed, corresponding to t = 0. The parameter k represents the cumulative breakage rate constant in units of min^{-1}. The model described in Equation 1 is then used to conduct a mathematical simulation of a Bond locked-cycle milling test. In the simulation, the number of revolutions is varied to allow the simulated test to stabilise to a re-circulating load of 250%. The predicted grindability (gbp) is calculated as the net screen undersize produced per revolution at steady state. The F_{80} and predicted P_{80} particle size are calculated and the Bond ball work index is then calculated using the standard Bond ball work index formula:

$$W_i = \frac{44.5}{P^{0.23} \cdot gbp^{0.82} \cdot \left[\frac{10}{\sqrt{P_{80}}} \cdot \frac{10}{\sqrt{F_{80}}}\right]} \qquad [2]$$

where W_i represents the Bond ball work index, F_{80} and P_{80} are the feed and product particle sizes, respectively, expressed in μm where 80% of the material passes, P is the limiting screen size and gbp is the mass of undersize produced per mill revolution expressed in gram.

The attractive feature of this batch test procedure is that work indices can be simulated for various different limiting screen sizes based on the results of only one batch test. This offers significant flexibility in the interpretation of test results, especially when applied to geometallurgical test work.

Test Procedure 2 – Limited Cycle Bond Test

The second procedure is based on a standard Bond work index test but, rather than running the test to stability, the test is terminated after only three cycles. The grindability (gbp) of the last cycle, in conjunction with the feed and product particle size distributions, is used to calculate the work index according to Equation 2. The three-cycle test approach is more limited than the batch test approach in that a separate test needs to be conducted for each limiting screen size to be evaluated. The three-cycle test procedure, however, still provides a benefit over the full Bond work index test in that both the sample mass required and the time required to conduct the test work are typically halved.

Experimental Setup

Comparative test work on the two methods was conducted on three copper–cobalt samples originating from the Zambian/DRC Copperbelt. The samples are referred to as samples A, B, and C, respectively. Limiting screen sizes of 106 μm and 212 μm were considered. Results from the two methods were compared with the actual Bond work index determined from a full cycle test.

RESULTS AND DISCUSSION

Prediction Error

The errors associated with the predictions using Procedure 1 and Procedure 2 are presented in Table I. On the samples tested, the three-cycle test (Procedure 2) provided superior prediction results compared with those of the batch milling approach (Procedure 1). The error associated with the predictions using the three-cycle test method ranged from –3.74% to 1.49% while the prediction accuracy of the batch milling approach ranged from –20.81% to –0.21%. The largest error associated with Procedure 1 was observed on Sample B.

Table I. Error % for predictions of Bond ball work index using Procedures 1 and 2.

Sample Identification	Limiting screen (μm)	Prediction Error (%) Procedure 1	Prediction Error (%) Procedure 2
Sample A	106	–0.21	–0.76
Sample A	212	–7.62	1.49
Sample B	106	–20.81	–3.74
Sample B	212	–15.35	–1.97
Sample C	106	–4.22	0.46
Sample C	212	–8.85	–2.84

Grindability (gbp)

Measured versus predicted grindability (gbp) for Procedures 1 and 2 are presented in Figures 1 and 2, respectively. The trends indicate that the predicted grindability associated with the three-cycle test (Procedure 2) is significantly closer to the measured value compared with the predictions associated with the batch test approach (Procedure 1).

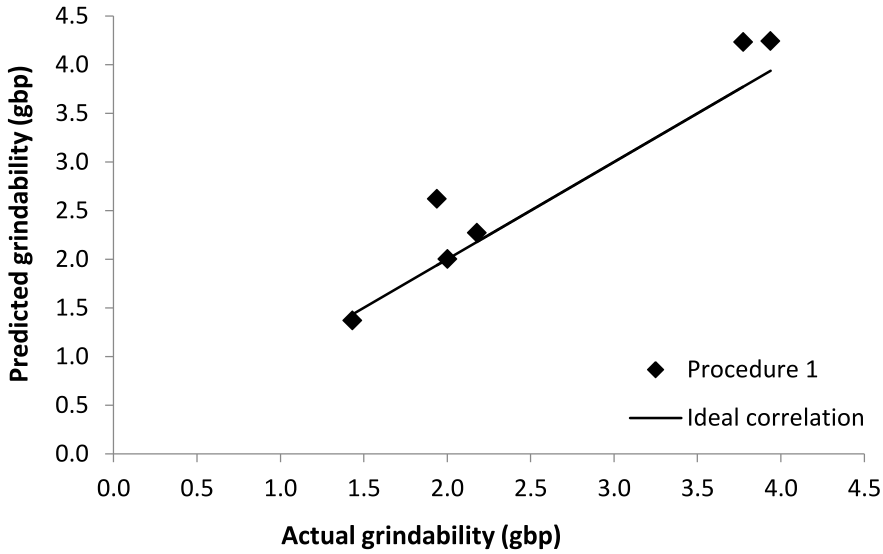

Figure 1. Predicted versus actual grindability (gbp) for test Procedure 1.

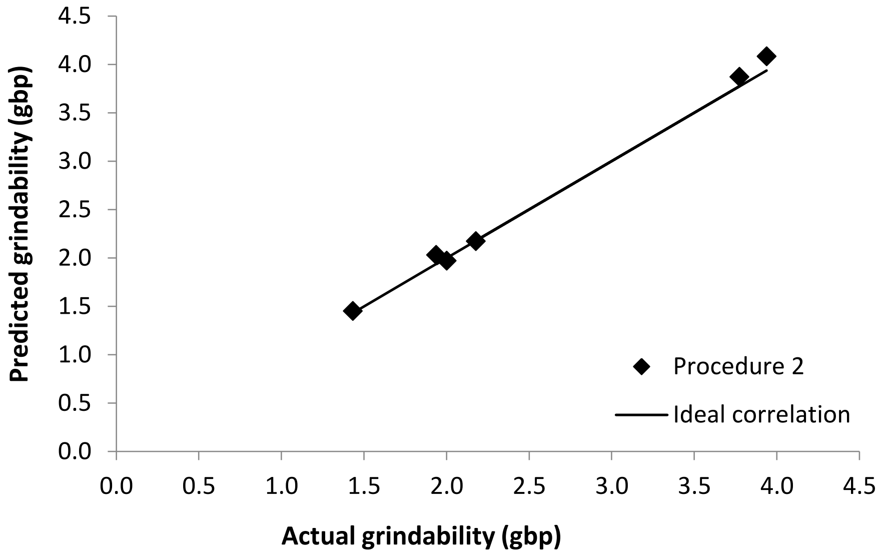

Figure 2. Predicted versus actual grindability (gbp) for test Procedure 2.

In some instances, the batch milling approach tends to over-estimate the grindability of the material. This observation could be due to the fact that, during locked-cycle testing, some of the harder ore components might build up in the circulating load, thereby increasing the grindability of the load in the mill during each successive cycle. However, this observation could also be associated with the fact that the batch model employed is based on a cumulative breakage rate. The breakage rates determined from the batch testing could be sensitive to changes in mill feed particle size distribution. While the reasons for the observed difference in predicted versus measured grindability were not explored in this current study, this could be a topic for further research.

CONCLUSIONS

The results presented show that it could be possible to predict the Bond ball work index for Zambian/DRC copper–cobalt ores within a reasonable degree of accuracy with the use of a shortened test procedure. Since different test procedures provided differing degrees of accuracy, the choice of test procedure would be dependent on the accuracy required.

It should be noted, however, that the results presented in this paper were limited to three samples tested at two limiting screen sizes each. When applying this approach for the purpose of geometallurgical evaluation, it is recommended that upfront method validation work should be conducted on material originating from the deposit being evaluated. It is advisable that validation test work should include test work in triplicate to show reproducibility of the data. The validation programme should also include testing at different material hardness ranges.

REFERENCES

Aksani, B. and Sönmez, B. (2000). Simulation of Bond grindability test by using cumulative based kinetic model. *Minerals Engineering*, 13 (6), 673–677.

JK Tech SMI Technology Transfer (2015). JK Bond ball lite test. http://www.jktech.com.au/jk-bond-ball-lite-test-jk-bbl [accessed 12 Mar. 2015].

SGS (2015). ModBond grindability test. http://www.sgs.co.za/en/Mining/Metallurgy-and-Process-Design/Unit-Operations-and-Metallurgical-Services/Comminution-and-Beneficiation/Bond-Tests.aspxv [accessed 12 Mar. 2015].