ABBRIEVATED TEST FOR QUICK DETERMINATION OF BOND’S WORK INDEX

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Abstract

The grindability of an ore in the process of mineral dressing can be determined by use of the Bond work index (Wi). This index is determined on a laboratory scale using a Bond ball mill and by simulating dry grinding in a closed circuit until the 250% circulating load has been obtained. This happens only after 7-10 grinding cycles, which shows that the procedure is a lengthy and complex one and is therefore susceptible to procedural errors.

Starting from the first-order grinding kinetics defined by means of the Bond ball mill, this paper discusses a simplified procedure for a rapid determination of the work index by just three grinding tests! The applicability of the simplified procedure has been proved on samples of copper ore, andesite and bauxite.

Keywords: Bond’s index, grinding, kinetics

1. INTRODUCTION

According to the standard Bond test, the Work index (Wi) is found by simulating dry grinding in a closed circuit in a Bond ball mill until the 250% circulating load has been achieved (Bond, 1949, 1952, 1961). The feed is a
minus 3.327 mm, 700 cm³ sample. The first grinding test is stalled with an arbitrarily chosen number of mill revolutions. At the end of each grinding cycle, the entire product discharged from the mill and is screened on a test sieve.

Fresh feed material is added to the over-size to bring the total weight back to that of the original charge. This charge is then returned to the mill. The number of revolutions in the second grinding cycle is calculated so as to gradually produce the 250% circulating load. After the second cycle, the same procedure of screening and grinding is continued until the test sieve under size produced per mill revolution becomes constant for the last grinding cycles. This will give the 250% circulating load. The Bond test takes 7-10 cycles. The test-sieve under size from the last grinding cycle is analyzed by screening.

To calculate the work index (Wi) in a laboratory-scale ball mill, Bond first derived the equation:

\[ W_i = 1.1 \cdot \frac{16}{G^{0.82}} \cdot \sqrt[100]{P_c} \]  

(1)

and thereafter derived the revised formula that is currently in use:

\[ W_i = 1.1 \cdot \frac{44.5}{P_c^{0.23} \cdot G^{0.82} \cdot \left( \frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}} \right)} \]  

(2)

where:

Wi - Bond work index (kWh t⁻¹);
Pc - test sieve mesh size (µm);
G - weight of the test-sieve fresh under-size per mill revolution (g min⁻¹);
F - test-sieve mesh size passing 80% of the feed before grinding (µm);
P - opening of the tested sieve size passing 80% of the last cycle sieve under size product

The Bond work index has been widely used in designing full scale mills but the Bond test is rather complex, lengthy and susceptible to procedural errors.
and this is why attempts have been made to abbreviate and simplify Bond’s test procedure.

Berry and Bruce (1966) have given an approximative procedure, which reduces to comparison of grindability of an un-known ore with the known grindability of the reference ore. Similar, but a slightly longer procedure has been given by Horst and Bassarear (1976). In both procedures, grinding of samples of reference ore and of the ore for which Bond’s work index is determined, does not have to be made in Bond’s mill; but in’ any kind of laboratory ball mill; The mean square relative difference between values of work index determined by the standard Bond’s test and the approximative test of Berry and Bruce amounts to about 8%.

Smith and Lee (1968) compared Bond grindability with straight batch-type grindability. Their results; show that the two ore are empirically related; hence, it is possible to estimate Bond grindability from batch tests.

Kapur (1970) analyzed the batch grinding cycles involved in Bond grindability tests and then developed a mathematical algorithm for “stage-wise” simulation of this test and an assessment of the Bond work index.

According to the results, obtained for several different types of ore, Kapur states that the mean square relative difference between values of work index obtained by the standard Bond’s test and his test amounts to 9.7%.

Karra (1981) has given a mathematical algorithm of simulation of the standard Bond’s test based on results obtained in the first two grinding tests. This is a modified procedure of Kapur, since Karra has taken into the consideration the fact that the circulating charge in the standard Bond’s test is harder than the fresh sample and therefore it grinds more slowly. For several different types of ore, Karra states that the mean square relative differences between values of work index obtained by the standard Bond’s and his test amounts to 4.8%.

Magdalinovic (1989) has given and abbreviated procedure for determination of work index in ball-mill, which includes only two grinding tests. The mean square relative error of differences between values of work index obtained by the standard Bond’s test and the abbreviated procedure of Magdalinovic, for 12 tests on three different types of ore, amounts to 4.9%.

Yan and Eaton (1994) have concluded that Bond’s standard test can give erroneous conclusion about the grindability of ore if the ore contains soft and
hard components. In this case, the hard component of the ore in the standard Bond’s test concentrates in circulating load and one obtains a larger value of work index compared to a realistic one. Yan and Eaton, using samples of the mixture of hard and soft components, have carried out determination of work index by the standard Bond’s test and the abbreviated test of Magdalinovic gives more realistic values of work index.

Lewis et al. (1990) have given a mathematical algorythm of simulation of the standard Bond’s test, based upon results from the first test of the standard procedure, which is based upon the grinding model given by Austin. The authors state that their procedure is shorter for 60% and gives better results, which differ for up to 6.2% from results obtained from the standard Bond’s test.

2. THEORETICAL BASES OF SIMULATION OF THE STANDARD BOND’S TEST

The author of this paper has been dealing with the question of determination of grindability of ore for 20 years. He has researched grinding kinetics in Bond’s ball-mill for a large number of different types of ores and rocks (copper, lead and zinc, bauxite, andesite, magnesite ores, limestones etc.) and has established that in all cases the grinding proceeds according to the law of the first- order kinetics

\[ R = R_0 \cdot e^{-kt} \]  

where:

- \( R \)-test-sieve over -size at the time \((t)\);
- \( R_0 \)-test-sieve over-size at the beginning of grinding \((t=0)\);
- \( k \)-grinding rate constant;
- \( t \)-grinding time.

The grinding rate constant \( k \) can be determined from just one grinding test. From eq. 3 it follows that:
The essence of the abbreviated procedure for determination of work index, which the author states in this paper reduces to the usage of the grinding speed constant \( k \) from the preceding test for calculation of mill RPM in the succeeding test, which should provide the circulating charge of 250\%, required by the standard Bond’s test.

Grinding rate constant \((k_1)\) in the first test from the standard Bond’s procedure is:

\[
k_1 = \frac{\ln M - \ln R_1}{t} = \frac{\ln M - \ln R_1}{N_1} = n \cdot \frac{\ln M - \ln R_1}{N_1}
\]

where:

\( M \) - weight of the starting sample (g)
\( X \) - content of the class +Pc in the starting sample (fractions of unity);
\( R_1 \) - weight of the over-size on the comparative test-sieve after the first grinding test (g)
\( n \) - mill RPM (min\(^{-1}\))
\( N_1 \) – total number of mill revolutions.

For the second grinding test, the mill is charged with the over-size on the comparative test-sieve \((R_1)\) together with the fresh sample of weight \((M-R_1)\), so that the weight of the sample in the mill is again \((M)\)

The weight of the sample of class +Pc for the second grinding test is:

\[
R_{02} = R_1 + (M - R_1) \cdot X
\]

In the second grinding test, the mill RPM is calculated from the condition that the circulating charge should be 250\%, i.e. that the over-size on the comparative test-sieve should be \(R_2 = (2.5/3.5)M\). Consequently, the formula
(3) for the second grinding test is:

\[
\frac{2.5}{3.5} M = \left[ R_1 + (M - R_1)X \right] e^{k_2 \frac{N_2}{n}}
\]  

(7)

from which it follows:

\[
N_2 = n \cdot \frac{\ln \left[ R_1 + (M - R_1)X \right] - \ln \frac{2.5}{3.5} M}{k_1}
\]

(8)

Grinding rate constant in the second test \( k_2 \) is:

\[
k_2 = \frac{\ln R_{02} - \ln R_2}{N_2/n} = n \cdot \frac{\ln \left[ R_1 + (M - R_1)X \right] - \ln R_3}{N_2/n}
\]

(9)

The constant \( k_2 \) is always slightly smaller than \( k_1 \) since the over-size \( R_1 \) in the second test grinds more slowly than the coarse class \(+Pc\) from the fresh sample. Consequently, in the second test it is not possible to achieve the circulating charge of 250%. That is the reason why the third grinding test is performed, and the mill RPM \( N_3 \) is calculated from the condition that the oversize on the comparative test sieve should amount to \( R_3 = (2.5/3.5)M \), which corresponds to the circulating charge of 250%.

For the third grinding test, the mill is charged with the over size on the comparative test sieve from the second test \( R_2 \) and the fresh sample of weight \( (M-R_2) \).

The formula (3) for the third grinding test is:

\[
\frac{2.5}{3.5} M = \left[ R_2 + (M - R_2)X \right] e^{k_3 \frac{N_3}{n}}
\]

(10)

from which it follows:
After the third grinding test the condition \( R_3 = (2.5/3.5)M \) is always achieved, which confirms the stability of the cycle with the circulating charge of 250%. The under-size from the comparative test sieve from the third test is \( Z_3 = (1/3.5)M \). The weight of the newly formed under size per one mill revolution in the third grinding test \( G_3 \) is calculated according to the formula:

\[
G_3 = \frac{Z_3 \cdot (M - R_2) \cdot (1 - X)}{N_3}
\]  

(12)

3. THE PROCEDURE FOR PERFORMANCE OF THE ABBREVIATED TEST AND RESULTS

The abbreviated test for determination of work index, comprises the following operations:

Prepare the sample as for the standard Bond’s test (grind to 100% minus 3.327 mm).

Determine the size distribution of the sample and the starting size \( F \) (µm) and contribution of sample of larger size than the mesh of comparative test-sieve \( X \) (fractions of unity).

Take the sample of volume 700 cm³, determine its weight \( M \) (g) charge it into Bond’s ball-mill and grind at arbitrary mill RPM \( N_2 \) (\( N_1 = 50, 100 \) or 150 revolutions).

After grinding, screen the sample on comparative test-sieve and determine the weight of the over-size \( R_1 \) (g).

According to the formula (5) calculate \( k_1 \) and then according to the formula (8) calculate mill RPM \( N_2 \) for the second grinding test.

Add fresh sample to the over-size (\( R_1 \)) of weight (\( M - R_1 \)), charge it into the
mill and grind it for duration of \( N_2 \) mill RPM.

After grinding, screen the sample on comparative test-sieve and determine its weight \( R_2 \) (g).

According to the formula (9) calculate \( k_2 \) and then according to the formula (1) calculate mill RPM \( N_3 \) for the third grinding test.

Add fresh sample of weight \((M-R_2)\) to the over-size \((R_2)\) charge into mill and grind for the duration of mill RPM, \( N_3 \).

After grinding, screen the sample on comparative test-sieve and determine the weight of under-size of comparative test-sieve \( Z_3 \) (g).

Determine granulometric composition of over size of comparative test sieve from the third grinding test and determine the size of the over-size product \( P \) (\( \mu m \)).

According to the formula (12), calculate the weight of newly formed over size product per one mill revolution in the third grinding test \( G_3 \).

Calculate work index \( W_4 \) according to Bond’s equation (2).

Based on samples of copper ore, andesite and bauxite, work index \( W_i \) has been determined according to the standard Bond’s test and abbreviated test which is proposed in this paper. Results are shown in Table 1.

Results from table 1 show that differences in values of work index according to both tests are very small. The mean square relative difference is only 2.75% which is within the limits of reproducibility of the standard Bond’s test, which have been established by Lewis et al (1990).

4. CONCLUSION

Grinding in laboratory Bond’s ball mill proceeds according to the first order kinetics. This fact allows that the standard Bond’s test for determination of work index of ore \( W_i \) could be simplified and abbreviated to only three grinding tests.

With the abbreviated test presented in this paper, the values of work index are obtained, which show slight difference from values obtained by the standard Bond’s test. The mean square relative difference is only 2.75%, which is within the limits of reproducibility of the standard Bond’s test.
Abbreviated test for quick determination of bond’s work index

Table 1. Comparative values of work index according to the standard Bond’s test and the abbreviated test.

<table>
<thead>
<tr>
<th>Material</th>
<th>Pc (µm)</th>
<th>Bond's test Wi (kWh/t)</th>
<th>Magdalinovic's test Wi (kWh/t)</th>
<th>Difference ∆(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper ore</td>
<td>500</td>
<td>16.79</td>
<td>17.04</td>
<td>-1.49</td>
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<tr>
<td></td>
<td>315</td>
<td>13.44</td>
<td>13.77</td>
<td>2.45</td>
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<td></td>
<td>160</td>
<td>13.76</td>
<td>13.46</td>
<td>-2.18</td>
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<td></td>
<td>80</td>
<td>13.99</td>
<td>14.48</td>
<td>3.50</td>
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<tr>
<td>Andesite</td>
<td>500</td>
<td>22.62</td>
<td>23.19</td>
<td>-2.52</td>
</tr>
<tr>
<td></td>
<td>315</td>
<td>18.58</td>
<td>18.13</td>
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<td></td>
<td>160</td>
<td>18.45</td>
<td>18.36</td>
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</tr>
<tr>
<td>Bauxite</td>
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<td>19.27</td>
<td>18.60</td>
<td>3.48</td>
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<td></td>
<td>500</td>
<td>9.87</td>
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<td>Mean square relative difference</td>
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<td>2.75</td>
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References