Commentary on the apparatus of the Bond rod mill work index

Alex Doll, SAGMILLING.COM August, 2023
alex.doll@sagmilling.com

The Bond "Third Theory" of comminution was originally divided into three size classes reflecting the varieties of comminution equipment common during the time period when Bond (and his collaborators) were gathering the information to calibrate comminution models. The middle size class, represented by rod milling, is fitted to a tumbling test, referred to as the Bond rod mill work index (Wi_{RM}, or RWi). The apparatus used to determine this work index was described in 1943 by Bond & Maxson and more recently formalized by the Global Mining Guidelines group. The author has noted there are some laboratories that have deviated from the apparatus specified by Bond & Maxson and there are modern comminution models that are calibrated to this non-standard mill geometry.

Introduction

The specification for the apparatus to determining a "Bond" rod mill work index is first described in Bond & Maxson (1943). It states that the apparatus is a tumbling rod mill to be operated in a locked cycle test at a fixed circulating load. The geometry of the grinding chamber is described as:

- mill inside diameter of 12 inches
- mill grinding chamber length of 22 inches (later revised to 24 inches in SME Mudd Series handbook)
- rods of two size classes, 21 inches long
- mill rotation speed of 46 revolutions per minute (approximately 60% of critical speed)
- a wave liner

The test procedure also describes a "rocking" of the mill every 10 revolutions to avoid coarse particles collecting in the empty space between the end of the grinding rods and the end of the grinding chamber.

The author is aware of two issues with this specification and the actual implementation of the test in commercial laboratories world-wide. Specifically, the use of a smooth liner in some laboratories, and the consistent implementation of the rocking behaviour. Of these issues, the Author believes use of a smooth liner is the most significant with respect to standardization of the test.

Rocking of the laboratory mill

The length of the grinding chamber is longer than the rods, resulting a void space at the ends of the mill where little or no grinding happens. To avoid the collection of coarse material in this space, the test procedure includes "rocking" the mill every 10 revolutions through a 5° rotation "forward" for one revolution and then “backward” for one revolution, after which the mill is returned to a level position for the next ten revolutions before being rocked again.

All but one of the laboratory rod mills in North and South America are all configured to be rocked, and this is the standard procedure that Clients should verify when choosing a laboratory.

Mill liner

A “Bond” rod mill work index is to be determined in an apparatus with a wave liner. The author is aware of six laboratories that offer a rod mill work index test where the lining of the mill is either smooth, or smooth with a small number of primitive lifters that do not constitute a wave liner. Work index values determined by this alternative geometry should not be marketed as “Bond” work index values because they deviate from the specification and calibration of a proper “Bond” rod mill work index.

There are two issues with the smooth liner:

- The energy per revolution is different to the calibration data set used by Bond in his derivation of the Third Theory fitting of the work index formula to the rod mill apparatus.
- The nature of the breakage will be skewed towards abrasion breakage in the smooth liner designs, whereas the wave liner will have more attrition (and possibly crushing) breakage.

The first problem comes from the equation derived by Bond to calibrate a rod mill work index to the parameters of the rod mill tumbling test. The term in the calibrated formula that is affected by the liner is the grams (therefore, the energy) evolved per revolution of the laboratory mill. Since the equation expects a certain amount of energy (Joules) per mill revolution, the equation for a laboratory mill with smooth liner must re-calibrate Bond's empirical equation (below, converted to Wi metric units) to the Joules per revolution generated in a machine with a smooth liner.

$$Wi_{RM} = \frac{(62 \times 1.1023)}{P_{100}^{0.23} \times (gpr)^{0.625} \left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)}$$

The second problem is related to how a rock breaks inside the apparatus. There are generally three mechanisms of breakage recognized as significant in milling: crushing, attrition and abrasion. A particular ore in a particular mill will have a characteristic combination of these three mechanisms that describes both the breakage energy consumed and the size distribution of the mill product. The action of a wave liner in a rod mill is to lift the mill charge and “spread” the charge as the mill rotates. This causes both crushing and attrition action by trapping particles between the rods as they are alternatively lifted and dropped. This lifting action is greatly diminished in a mill with a smooth liner, meaning that the relative amount of crushing and attrition will be less in the smooth liner design; most of the breakage will instead consist of abrasion.

Attempts to “convert” work index determinations from one mill geometry to the other must account for this difference in breakage mechanism. It is not enough to say “deduct 2 kWh/t from the smooth liner result” and expect an equivalent work index for a wave liner design. An empirical conversion determined for a particular type of ore (eg. Paleozoic meta-granitoids) is only valid for rock types that have similar ratios in the resistance to abrasion, attrition and crushing. A completely different rock type (eg. Tertiary andesite) will have a completely different set of ratios, and therefore will likely require a different empirical calibration between the two styles of mill liner.

Bailey et al. (2009) described a rod mill work index round-robin program between different international laboratories with a normalized standard deviation of 12%. It is believed that the round-robin is a mixture of smooth and wave liner designs. The Author is aware of three Australian laboratories have have smooth designs, and these are expected to give higher work index determinations than the wave designs. The paper reveals that the two maximum values are Australian laboratories (therefore, smooth liner designs). If one excludes them and re-calculates the statistics, then the normalized standard deviation drops to 6.3%.

The wave liner specification

The GMG guideline gives the following guidance to what constitutes a properly designed wave liner for a Bond rod mill work index determination:

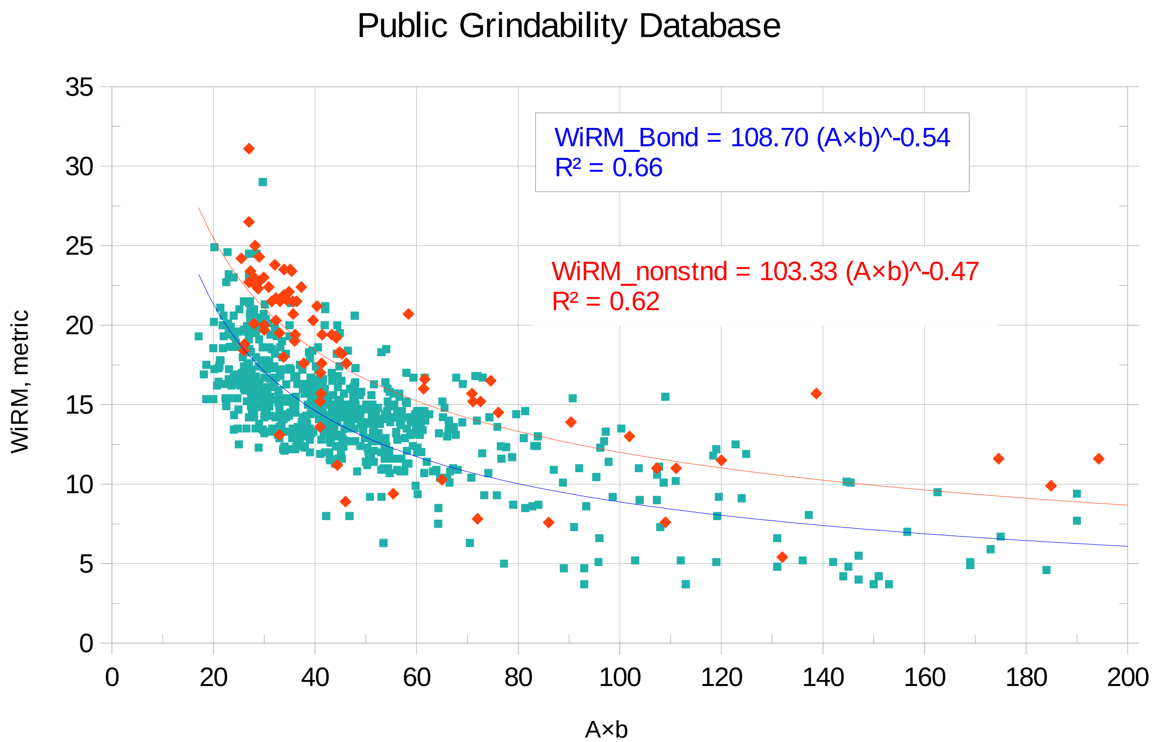
- the liner consists of eight waves,
- the wave height from crest to trough is 12.7 mm measured from the centre-line of the mill.

Final thoughts and recommendations

There are comminution models calibrated to use the smooth liner test results, and it is completely appropriate to use a smooth liner apparatus when using such a model. Calibration is more important than dogma.

- Ask a laboratory what type of liner is in their apparatus as part of a request for quotation. Also ask about the procedure used to rock the mill.
- If you are using a particular consultant for your project, then use the type of testing apparatus suitable for that consultant's model.
- If it is necessary to convert work index results between the wave and smooth liner types, then rely on your consultant to decide how to transform test results.
- Laboratories using a smooth liner should not be marketing their test as a “Bond rod mill work index”. It is reasonable to call such tests a “rod mill work index”, but they should not be using the name “Bond” unless fully compliant with Bond's specification.
- If you use two consultants, expect three opinions.

Variation in the two liner types can be observed in the following graphic where data from the Public Grindability Database is plotted as rod mill work index (Bond in blue, non-standard in red) versus the A×b of a drop weight test (JK DWT or SMC Test).



https://sagmilling.com/articles?topic=testwork

References

Bailey, C., Lane, G., Morrell, S., and Staples, P. (2009) `What can go wrong in comminution circuit design?`, Tenth Mill Operator's Conference, Adelaide, Australia, pp. 143–149

Bond, F.C. and Maxson, W. L (1943) `Standard Grindability Tests and Calculations`, Society of Mining Engineers, Vol 153, pp. 362–372. https://www.onemine.org/documents/standard-grindability-tests-and-calculations

Global Mining Guidelines Group (2021). Determining the Bond Efficiency of Industrial Grinding Circuits. GMG01-MP-2021. https://gmggroup.org/guidelines-and-publications/determining-the-bond-efficiency-of-industrial-grinding-circuits/

Outokumpu Mills Group (2002), `The Science of Comminution`, technical publication p. 39