# Designing an optimal comminution sampling program for geometallurgy

**A.G. Doll**[1*]
*1. Consultant/ SAGMILLING.com/ Canada*

## ABSTRACT

Breakage characteristics of rocks will change as a function of size; this is one reason why there are so many different grindability metrics in use by the Industry. Designing a geometallurgical sampling program for grindability requires understanding a mine's ore breakage characteristics as a function of size so that the optimal mass and dimension of each sample is collected. This requires a multi-stage, iterative procedure where the initial programs collect a wider range of data that will, if possible, be reduced in later programs as the ore breakage is better understood. A procedure is offered where two initial programs are used to design a third "optimal" program.

The first program will use feed conveyor belt cuts, bulk samples collected from tunnels, or composites of large diameter drill core to "map" the rock breakage characteristics by size. This program requires some coarse samples; for example, whole HQ-diameter core.

The second program is a reduced variability sampling program that will ultimately become part of the overall geometallurgy data set interpolated into the mine model. Results of this initial variability program are examined to identify if any size classes are redundant and may be excluded from future sample collection.

The final program is the optimized variability sampling program that draws on the two earlier programs to use only the necessary laboratory testing at the smallest sample dimension. The combined results of the second and third programs become the overall geometallurgy data set.

This iterative procedure drives toward smaller sample dimensions and minimum laboratory testing, yielding the optimal program costs without sacrificing quality.

## INTRODUCTION

The purpose of a geometallurgy comminution program is to interpolate grindability metrics (specific energy consumption values) into a geological block model used for mine planning. Empirical power-based models of mineral grinding are used to convert laboratory test results (Eg. the three Bond work indices) into specific energy consumption and throughput predictions. All empirical models are calibrated to a particular "training data set" and may not be suitable for every ore type that exists – there are ore bodies that confuse one of the commonly used power-based models – requiring that multiple models be run in the early stages of a geometallurgy program.

The types of laboratory tests chosen for a program will dictate the dimensions and mass of samples required for collection. Coarse samples – such as the Bond impact crushing work index – require whole diameter HQ or PQ diameter core which is expensive to procure and does not leave behind a fraction of the core as a geological record. Some ore types require this coarse test and models that exclude a coarse test will fail to replicate the industrial plant performance (Doll & Becerra, 2017). An ultimate program should include these coarse tests only after it has been determined that no reasonable way to interpolate the coarse behaviour is available to the project.

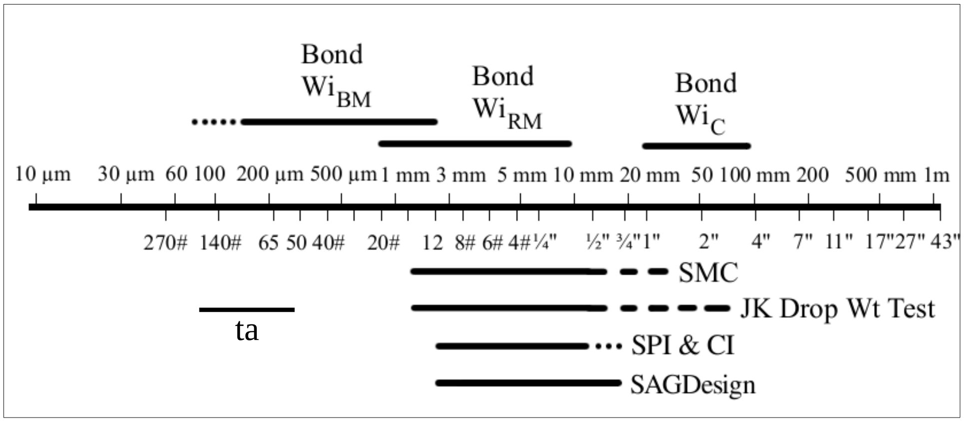
Many tests exist at the medium size class, roughly starting with a feed size of 15 mm to 25 mm and producing a product of about 1 mm to 5 mm. These tests frequently provide results that appear to be related to each other (Doll & Barratt, 2011; Doll, 2016), so it is advantageous to establish and exploit such relationships when constructing geometallurgy programs.

Discussion of the various empirical power-based models is beyond the scope of this paper, but examples of such models are a Bond-based model by Barratt (Barratt, 1986), a Mi-based model by Morrell (Global Mining Standards Group, 2016b) and an SGI based model by Amelunxen, 2013.

### *Comminution tests*

The laboratory tests can generally be grouped into three classes according to Figure 1, a coarse class, a medium size class and a fine size class (Doll & Barratt, 2011). Each test roughly shows the size range where the test is conducted, from its nominal feed size down to a nominal product size (or range of nominal sizes indicated by the broken lines).

**Figure 1:** Size ranges applicable to grindability tests




The three Bond work index tests (top section of Figure 1) operate with the same units of measurement across the whole size range, so are the easiest metrics to use when comparing grindability over a wide range of particle sizes. The middle size range, roughly 20 mm down to 1 mm, can be characterized by several tests: the Bond rod mill work index ($Wi_{RM}$), SMC Test™, JK Drop Weight Test, SPI™, SGI and SAGDesign all operate in a similar size range.

## METHODOLOGY

The procedure to develop a geometallurgy program for an operating mine site is broken into three main phases:

1. Ore characterization and plant surveys;

2. Initial variability sampling of the ore body and testing by a variety of laboratory comminution test methods;

3. Ultimate variability sampling procedures for long-term laboratory testing using the minimum number of test methods.

A mine design project does not yet have a plant to survey, so the first "ore characterization" step is done using drill core and the plant surveys are omitted. The second and third phases are the same for a mine design as they are for an operating mine.

### *1. Ore characterization and plant surveys*

The objective of this phase of work is to establish which types of comminution models will work best in the plant, and sets which metrics will be measured in subsequent phases of the program. One major goal is to establish the "map" of grindability by size class and observe if a three-parameter model (such as the Bond/Barratt model) is required or if a two-parameter model (such as the Amelunxen SGI or Morrell Mi) will be sufficient. The Global Mining Standards Group (2016a) provides a good guideline for conducting a plant sampling program.

Collect a half-dozen samples of primary crushed material (belt cut samples) including coarse rocks – or drill large diameter HQ or PQ core samples for an exploration program – where samples are of different lithology and alteration domains. Perform a laboratory program consisting of:

- The Bond impact crushing work index on coarse (+100 mm to -150 mm) specimens.
- Any two of the following on a representative sub-sample of material crushed to a medium size class (approx -30 mm); pick the tests that correspond to the models you intend to calculate:
  - The Bond rod mill work index (using an apparatus with a wave-type liner) – always include this test as it is important to the interpretation below,
  - The SMC Test™ (the JK DWT generally fits here, but includes some "coarser" specimens),
  - The SAG Grindability Index or SAG Power Index (SPI™),
  - The SAGDesign test.
- Three Bond ball mill work index tests at different closing sizes on representative sub-samples of material crushed to -3.3 mm:
  - The first test should be at the closing mesh size suitable to give a product $P_{80}$ size approximately what you want to operate the plant at. For example, if you want a 100 µm product $P_{80}$ size, then choose a 150 µm (100 Tyler Mesh) screen; if you want a 180 µm product $P_{80}$ size, then choose a 212 µm (65 Tyler Mesh) screen.
  - Perform a second test at the next standard screen size coarser and a third test at the next standard screen size finer.

Plot the laboratory work index versus product size of the five Bond tests (use a value between 25–50 mm as the product of the Bond crushing test, use the actual test $P_{80}$ for the rod mill and ball mill tests). The key questions:

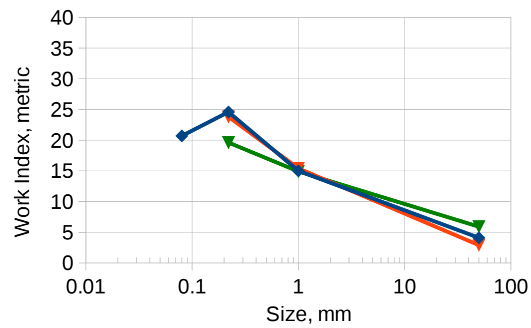
- Are there any inflection points where the work index changes between increasing and decreasing? If yes, and if the inflection happens in the ball mill size range (100 µm up to 2 mm), then make sure in future program to choose the closing screen to give as close as possible a $P_{80}$ in the ball mill test to your operating plant.
- If the inflection point happens in the rod mill or crushing range (1 mm up to 100 mm), then the Bond model is probably the only model that will provide reasonable estimates of ore grindability. Both the SMC Test and the SGI/SPI tests interpolate the behaviour in the crushing size range from measurements done in the rod mill size range – the inflection point confuses those interpolations and can lead to poor predictions (Doll & Becerra, 2017).

The following Figures 2 & 3 describe example interpretations of work index mapping by size.

Figure 2 demonstrates a porphyry deposit where all the samples tested have roughly the same crushing work index, and the work index is low (around 5 metric units). This is pretty typical for porphyries and means that power-based models calibrated to porphyries should work well.

- The Bond/Barratt model was originally calibrated to porphyries in Canada and Chile. It would be a good choice for this deposit.
- The Amelunxen SGI model was originally calibrated to porphyries in Canada, USA and Perú. It is another good choice.

**Figure 2:** Example Wi map for Ajax Project

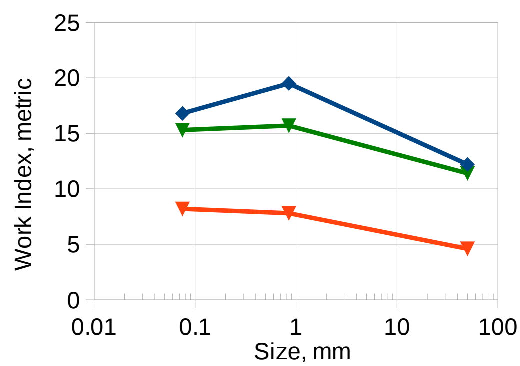



Source: Abacus Mining Corp, 2016

Figure 3 demonstrates an ore type that has a significant range in crushing work index values, between 5 and 12 metric units. This characteristic is common for hydrothermal deposits in shield-type geologic provinces, such as Western Australia. Power-based models calibrated to Australian ores should work well.

- The Morrell Mi model would be a good choice for this deposit as it was probably calibrated to Australian and African ore types, including hydrothermal deposits (the actual mines in the calibration data set have never been published).
- The variation in crushing work index will be captured in a Bond-type model, so one calibrated to Australian ores is a reasonable second choice for this deposit.

**Figure 3:** Example Wi map for Bomboré Gold




Source: Orezone Mining Corp, 2015

## *2. Initial variability program*

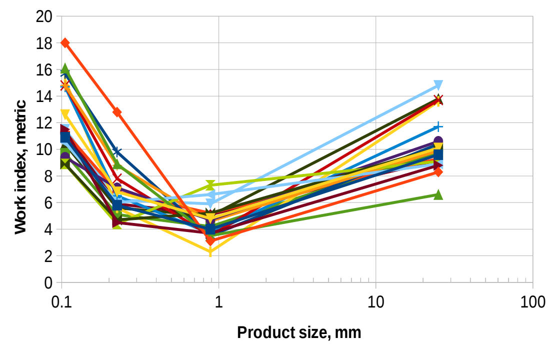
The objective of this phase of work is to collect grindability parameters for a variety of samples collected across the whole range of ore types and spatial dimensions of an ore body, and then interrogate those parameters to see which are related and which are not. Related parameters are useful because one can be estimated from the other, meaning that one test can be eliminated from future sampling.

The tests chosen for this test program are influenced by the Wi map from Stage 1. The crushing work index is only required if that metric is highly variable and if it cannot be interpolated from other sources. Figure 2 demonstrates a deposit where there is no need to collect the coarse crushing specimens on all future test programs. The ore in Figure 3 is irregular enough that crushing work index samples must be collected on most Stage 2 samples.

Figure 4 demonstrate the Stage 2 results of a highly irregular deposit where the crushing work index demonstrates a wide range, between 6 and 15 metric units; and where the crushing work index is not related to the other work index measurements.

This deposit requires collection of coarse crushing work index specimens for all samples of all future sampling programs. There is no way to interpolate the value of the crushing work index by using any of the other work index metrics.

**Figure 4:** Example Wi map for Kami Project




Source: Alderon Iron Ore Corp, 2012

Some ore bodies have a relationship between grindability and the assay of a significant mineral. This is most common in iron ore deposits, such as IOCGs where %Fe can predict grindability, or massive sulphide deposits where %S or sample density can predict grindability. If geologic domains can be identified where these "process mineralogy" relationships exist, then use the relationships in future work as a proxy for grindability. This stage of work is complete if process mineralogy can be used.

### *3. Ultimate variability program*

The objective of this phase of work is increase the density of samples in the geometallurgical database to "in-fill" and populate the geologic block model. Two power-based models will be used for throughput predictions, a primary model and a secondary model used for quality-assurance. The exception to this rule is when "process mineralogy" will be used; no further core drilling is required as the resource assays provide the proxy needed to estimate grindability.

For cases where process mineralogy is not used, the Ultimate variability program will collect one set of grindability metrics for the "primary" power-based calculation method and will use relationships established in Stage 2 for interpolating the grindability metrics for the "secondary" power-based calculation method.

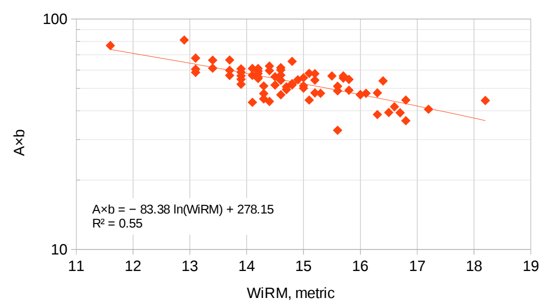
Consideration for each of the three size classes:

- **Fine size:** Only the Bond ball mill work index test is commonly used at this size class and no QA duplicates are usually necessary. The closing mesh size of the test should be chosen using the data from Stage 1 to give the product $P_{80}$ size closest to the target for the industrial plant.

- **Medium size:** Several tests are available in this size class and each modelling method will usually have its preferred grindability test. A primary model, chosen based on the earlier stages, will determine the primary medium size class test, and the secondary model, also based on earlier stages, will determine which test should be interpolated from the primary test.

  For example, the Dumont Project may select a model based on a rod mill work index as the primary calculation method and a drop weight A×b value as the secondary method. The Stage 2 program provides the grindability metric relationship in Figure 5 which allows a rod mill work index value to be converted into an A×b value. The Ultimate Variability Program would collect rod mill work index on all samples, and would then interpolate A×b using the relationship.

  **Figure 5:** Grindability metric relationship for the Dumont Project

  Source: Royal Nickel Corp, 2012

  The relationship in Figure 5 is not particularly good, so it may be sensible to collect drop weight test samples (Eg. SMC Test™) on a large fraction of the samples, say 35%.

- **Coarse size:** Only the Bond crushing work index test is generally used at this size, but it is only necessary to collect samples for this test if two conditions are met: first is that a Bond-type model is being used as either the primary or secondary modelling method, and second is that there were no decent proxies indicated in the earlier work. Figure 2 suggests that the Ajax project can use a constant proxy value of "5" metric units, and therefore avoid collecting this sample. Figure 4 suggests that the Kami project cannot use a proxy to predict the Bond crushing work index, therefore the test is required on all samples.

A typical Ultimate Program should include a QA component of secondary tests (drop weight tests in the previous example) on a fraction of the Ultimate samples to validate (and add to) the relationship in Figure 5. The $R^2$ dictates how many duplicates must be collected for the QA grindability tests; a high $R^2$ above 0.7 suggests a small number of duplicates, say 10%. A low $R^2$ should include more duplicates, such as 35% in the example above.

## RESULTS AND DISCUSSION

A three-stage approach to building a long-term geometallurgy program should generate the maximum amount of usable data at the least cost. Couët et al (2015) demonstrate that there is more value in a geometallurgy program built from a larger number of (cheap) smaller-precision tests than from a smaller number of (expensive) higher-precision tests. The approach provided in this work gives a guide to determining when tests may be omitted from programs. Redundant data that can be generated from existing test results will free up budget to collect more samples versus generating more laboratory information on existing samples.

The ultimate variability program should be validated periodically by doing some spot checks similar to Stage 1. These are best combined with mill surveys, such as a crash-stop and grind-out for mill filling measurements.

## CONCLUSIONS

The procedure to develop an optimal geometallurgy program for an operating mine site is broken into three main phases:

1. Ore characterization and plant surveys which will provide insight into which model methodologies and size classes of grindability testing are useful for a particular ore;

2. Initial variability sampling of the ore body and testing by a variety of laboratory comminution test methods to determine which grindability results are related, and therefore can be treated as proxies;

3. Ultimate variability sampling procedures for long-term laboratory testing using the minimum number of test methods. Two modelling methods are done as a quality control check, but the proxy relationship established in Stage 2 minimizes the quantity of laboratory work required to provide input to the two models.

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