TESTWORK PROGRAMS THAT DELIVER MULTIPLE DATA SETS OF COMMINUTION PARAMETERS FOR USE IN MINE PLANNING AND PROJECT ENGINEERING

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ABSTRACT

Mining projects are applying the age-old notion of "check your work" against comminution circuit design, mill power requirement estimates and mill throughput estimates. The best way to test the results of one comminution modelling system is to replicate the calculation in a different modelling system. Unfortunately, the most common comminution modelling systems require largely incompatible test programs to provide input parameters.

This paper presents some example protocols for sample collection and preparation from drillcore that simultaneously returns comminution datasets suitable for a Bond Work Index based method (DJB Consultants), an A × b dataset (JK SimMet), and a set of SPI results (Minnovex). By carefully collecting data for all three methods, high quality geometallurgical datasets can be created for three commonly used comminution models. The results of the three models may then be compared during a Feasibility Study.

A preferred method can then be selected for a Project Engineering Analysis and Mill Throughput Studies using comminution model results as input to a Mine Model and Mine Production Plan based on ore lithology and alteration types.

INTRODUCTION

The grinding circuit throughput is often the rate-limiting step in a process plant. There are a small number of comminution calculations that are commonly used to determine the capacity of a given grinding circuit. Unfortunately, those calculations are often opaque, and sometimes are proprietary to a particular consultant. Therefore, an individual calculation generally cannot be checked without running a different calculation method against the same material and comparing the results of the two calculations. This is made difficult because each of the commonly used calculations requires testwork that is largely incompatible with the other calculations. If the two calculation methods provide vastly different answers, then a third method may be necessary as a tie-breaker, and the testwork to support that third method must be in place at the beginning of the test program.

This paper identifies a method to collect complimentary information for three comminution calculation methods, resource assay information, and bench flotation charge samples from a single drill hole. The three comminution calculation methods are the “Bond” suite (used by DJB and others), the JK suite (used with the JK Tech software JK SimMet) and the Minnovex suite (used by SGS with their proprietary CEET software). The drill core is assumed to be HQ size, approximately 63 mm diameter, with greater than 95% core recovery and a bulk density of approximately 2.4 t/m^3.

Though this paper assumes HQ size core (63 mm diameter), PQ size (85 mm diameter) is preferred for metallurgical testing. The lengths of PQ intervals would be shorter than presented to make up the target sample weights from the larger diameter core.

Table 1: Tests used for each calculation method

Calculation Method	**Parameters Returned from Testwork**
1. Barratt (Millpower 2000)	Wi_C, Wi_{RM}, Wi_{BM}, density
2. JK Tech (JK SimMet with drop weight test)	A, b, t_a, density
2 (a) Morrell (SMC test)	A×b, DWI, MIA, t_{10}, density
3. SGS Minnovex	CI, SPI, Mod BWI, density

METHODOLOGY

Geometallurgy programs are used to distribute comminution parameters into mine production block models using methods pioneered for use in creating resource estimates.

In order to be useful in developing a geometallurgical model, test results must satisfy the following:

1. Results must reflect the properties of a “small”, identifiable interval of drill core.
2. The location of the interval must be identifiable in three-dimensional space (to connect it to the block model).
3. The values being distributed through the orebody must be reasonably additive, allowing unknown blocks in the model to be estimated by interpolating two or more known samples.

The Tests

Mass desired for each test is given in Table 2. The quantity of material that is subjected to testing is usually less than indicated, and varies with the nature of the ore undergoing testing. The JK Drop Weight Test, in particular, requires a small number of carefully sized pieces, and the 100 kg sample weight is typically the quantity of rock that must be received to confidently generate the required number of correctly dimensioned samples.

Table 2: Sample Mass Required for Each Test

Test Series	Test	Drill Core Composite Interval	Desired Sample Weight
Generic	Resource Assay	1.5 m	¼ core over 1.5 metres
	Ai	45+ m	5 kg
	Point Load Index	not applicable	nil
	Flotation test charge	15 m	2 kg (several)
Bond	Wi_C	45+ m	20 kg
	Wi_{RM}	45+ m	15 kg
	Wi_{BM}	45+ m	10 kg
JK	SMC	15 m	20 kg
	DWT	not applicable	100 kg
Minnovex	SPI & CI	30 m (15 m × 2)	10-30 kg
	Mod BWI	30 m (15 m × 2)	2 kg

The Composite Intervals

Samples are collected on different interval lengths depending upon the mass of sample required for testing. The smallest composite size is the resource assay, which is assumed to be from a 1.5 metre length. This composite size may be modified to follow the project's geological resource assaying protocol – if so, then the length of the other samples must be adjusted to be a multiple of the resource assay length.

The SPI and SMC samples are each based on a 15 metre interval length (which is an easy multiple of the assay interval). This length gives enough material for a SMC test on a single interval, and a SPI test on combined pairs of intervals. The mass required for an SPI test is somewhat iterative as the feed preparation step uses a scalped screen fraction – check with the comminution laboratory after delivering the samples to confirm that the combination is required to achieve the necessary sample mass.

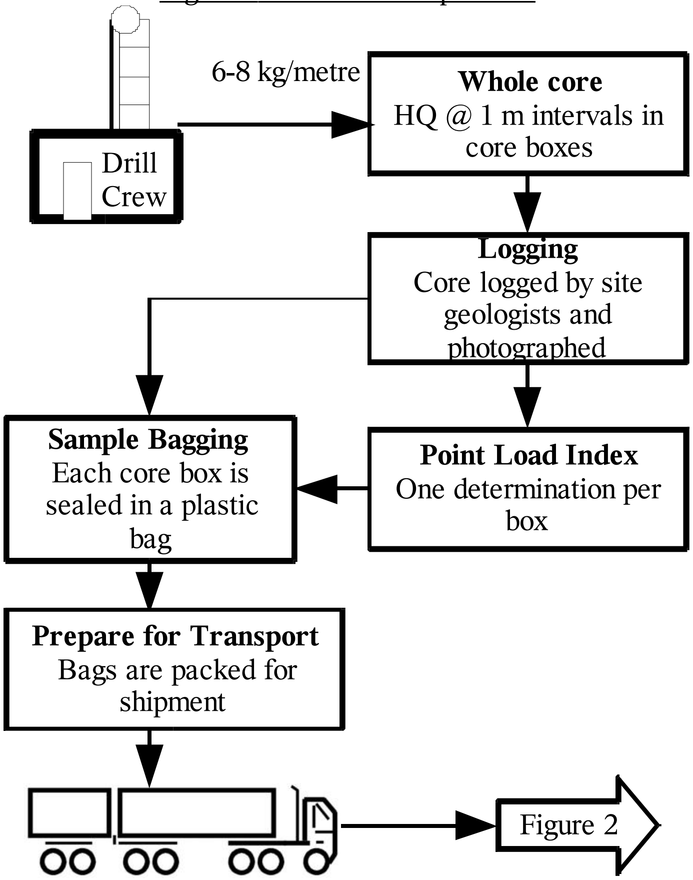
The Bond samples are a composite of multiple (at least three) 15 metre intervals for SMC and SPI where the multiples are contiguous and have similar lithology and alteration characteristics. In a typical porphyry, for example, a Bond sample may be a composite of between 45 metres and 105 metres length. The Bond sample will be a measured mass of mixed material from each 15 metre interval such that the mass from each interval is representative and the total sample mass is in the range of 30 kg to 35 kg.

The procedure for obtaining the Bond sample must be modified in a heterogeneous deposit where too many contiguous lengths contain changes of lithological domain. Such a procedure is outside the scope of this paper.

Sample Collection Protocol

Figures 1 through 5 outline the sample collection protocol from drill core. The protocol should be modified when different core size is available (HQ is assumed) or when a different number of tests is desired. Figures 1 through 5 are repeated in the Appendix for ease of reference.

Figure 1: Drill Core Preparation

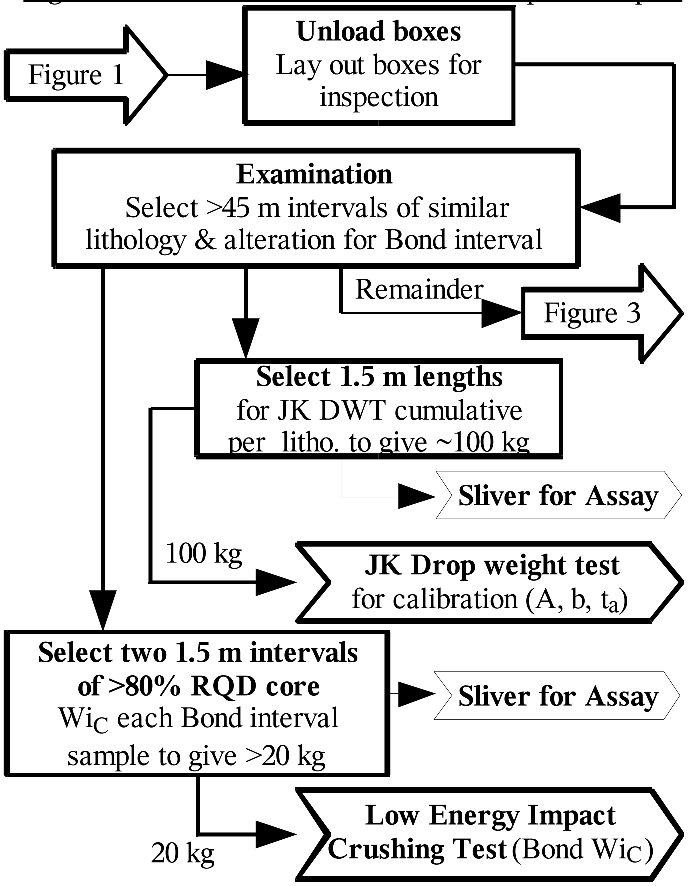


Core at the drill site is examined by geologists per the project’s regular resource program, but it is not to be cut or sampled at the drill site except for the taking of one optional point-load index per box for geotechnical purposes. Core boxes are each wrapped in a plastic bag and shipped. If one of the core boxes were damaged in transit, the location of the core in sequence will not be lost thanks to the bagging.

The length of a metallurgical sample must be a multiple of the sample length as dictated by the project’s geological resource assaying protocol. For example, if the assay interval length is 1.5 metres, then all metallurgical samples can be taken in intervals of 15 or 45 metres (multiples of 1.5 metres).

Core Examination and Whole-Core Samples

Figure 2: Whole Core Examination and Impact Samples



The Bond samples are collected over reasonably long lengths of core (45-100 metres) of similar lithology, alteration, and other relevant properties. Examine the geological logs prepared at the drill site, and then inspect the core in boxes at the laboratory to develop the intervals for compositing into Bond samples. Set the beginning and end of the intervals to be a multiple of the 1.5 metre intervals required for assay samples.

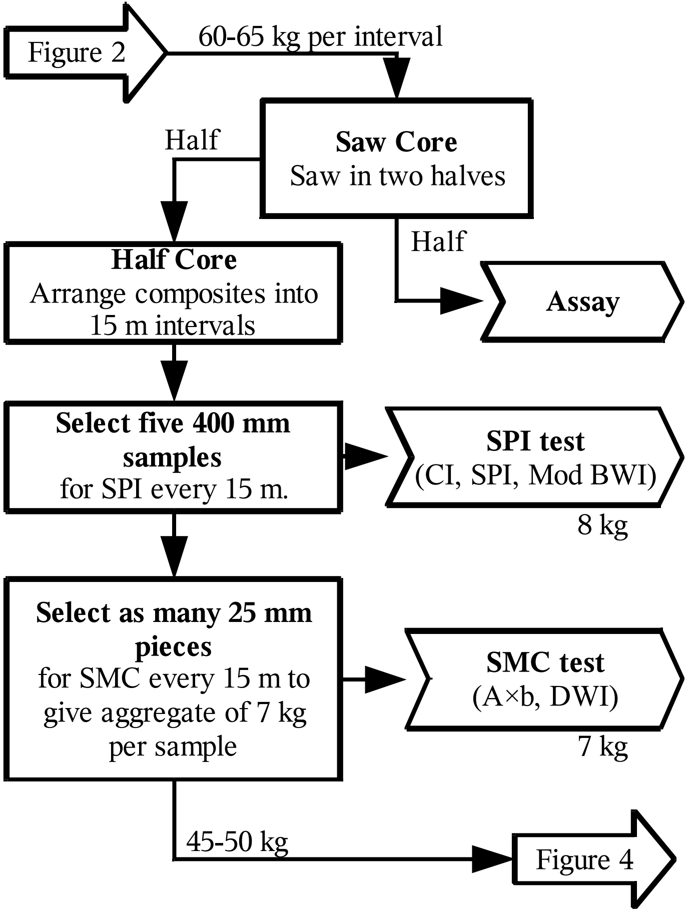
Within each Bond composite, choose two 1.5 metre intervals with reasonably whole, competent core. Take these samples from the box and cut a 10 mm sliver longitudinally down the length of the core and submit the sliver for resource assay (refer to Figure 6). Submit the remaining core for the low energy impact crushing test (Wi_C).

Set aside some 1.5 metre intervals from different drill holes to create a 100 kg sample of each major lithology and alteration combination for JK drop weight testing. Drop weight tests are needed to calibrate the SMC A and b values and to provide a t_a parameter for JK SimMet modelling. Cut a 10 mm sliver longitudinally down each 1.5 metre length of the core in the DWT sample and submit the sliver for resource assay.

When taking sliver samples, an entire assay interval length must be taken. Do not mix a sliver sample with half-core to make an assay sample – each assay sample must be one or the other.

Core Sawing and Half-Core Samples

Figure 3: Core Sawing, SPI and SMC samples



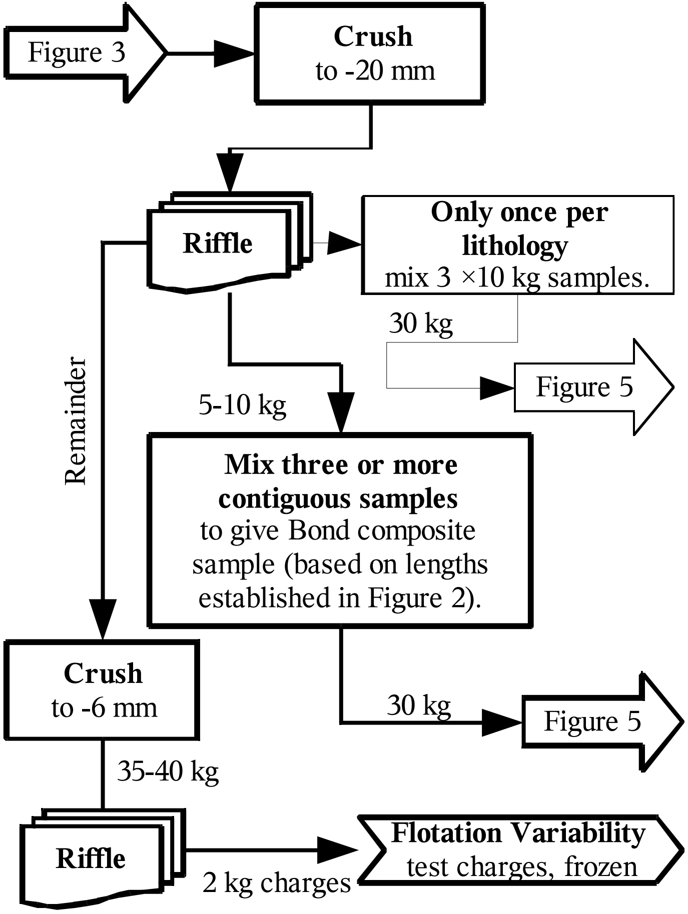
The remaining core is sawn in half. The first half is sent for resource assay as 1.5 metre intervals and the second half is retained in the boxes for metallurgical sampling. Where the core is already broken and is not feasible to saw, take a representative sample of half the broken material.

Select five 400 mm intervals of core uniformly per 15 metre interval. Combine the five intervals to create a SPI sample. Contiguous pairs of 15 metre intervals may be combined at the comminution laboratory to generate the required mass of sample for testing.

From the remaining half-core (and broken rock), take an SMC sample consisting of individual rocks of greater than 25 mm diameter from regularly spaced locations down the same 15 metre interval as the SPI sample. The sum of the mass of this sample should total at least 7 kg. Do not include finer material with this sample, but longer pieces of half-core are acceptable so long as they don't bias the 15 metre sample to a particular location in the interval.

Crushed Samples and Bond Composites

Figure 4: Crushing, Riffling and Flotation Samples



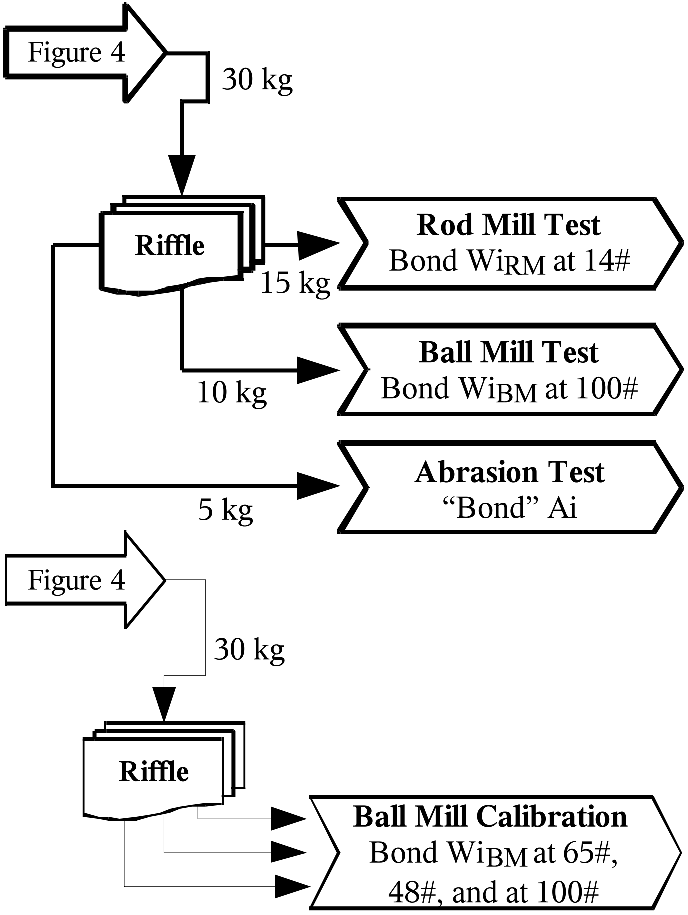
Crush the remaining material in the 15 metre interval to less than 20 mm and mix thoroughly. Take a consistent and representative mass from each 15 metre interval to make a total Bond sample weight of between 30 kg and 35 kg. For example, if a Bond sample consists of four 15 metre intervals (the Bond sample represents 60 metres of a reasonably uniform lithology and alteration), then 8 kg is taken from each of the 15 metre intervals to make a Bond sample of 32 kg (Wi_{RM}, Wi_{BM} at 100# and Ai).

Take a ball mill calibration sample for each major lithology/alteration combination. This sample contains material from the -20 mm riffling step taken from different drill holes, at least three different locations in the deposit. These samples are combined to create a single 30 kg to 35 kg ball mill calibration sample for the specified lithology and alteration combination. For example, if long intervals of a lithology appears in five different drill holes, and is altered by the same alteration style in all five locations, then the ball mill calibration sample would consist of approximately 6.5 kg from each of the five locations mixed to create a 32.5 kg calibration sample (Wi_{BM} at 48#, 65# and 100#).

The remaining crushed material in the 15 metre interval is crushed to less than 6 mm, mixed again and riffled into flotation variability samples of 2 kg. These samples should be sealed in plastic bags and, if possible, stored frozen until needed for bench flotation tests.

Individual Bond Tests on Composites

Figure 5: Bond Work Index Samples



The two work index samples are riffled to a sample size needed for conducting each test and then the individual tests are performed.

RESULTS AND DISCUSSION

The three sampling protocols return information suitable for generating geometallurgical models. The SPI and SMC results will be returned on a uniform 15 metre interval (or 30 metre intervals if SPI samples require combining), whereas the Bond results are returned on lithology/alteration composite basis. All three methods should provide comparable results once distributed into a block model, and it is recommended that at least two methods are run into block models so that areas of the mine with unusual comminution properties (where the two methods return different results) can be identified.

Example Block Model Calculation

The example presented uses the Bond series, per DJB Consultants Inc using the method by Barratt in Reference 1.

Barratt's method uses three hardness parameters that are measured by testwork: the low energy impact (crushing) work index (Wi_C), the rod mill work index (Wi_{RM}) and the ball mill work index (Wi_{BM}). These three values reflect the energy required to break rocks at three size ranges, coarse to fine, respectively.

The values of work indices are generally not additive and are not suitable for distribution into a block model directly. In Barratt's method, any one sample will have a preferred size to break to in the SAG mill (the transfer size, T_{80}). This affects the denominator of the Bond equation making the power split between SAG and ball mills inconsistent between samples. So rather than use work indices, the method calculates the grinding specific power for the grinding as kWh/tonne. Power is additive, thus the specific power of samples may be interpolated. Given the usable power of the grinding circuit "at the mill shell", the maximum throughput of a block in the mine model will be:

$$\frac{\text{tonnes}}{\text{hour}} = \frac{\sum \text{power at mill shells, kW}}{\text{specific power, } \frac{\text{kW} \cdot \text{h}}{\text{tonne}}} \times [\mathit{utilization}] \times [\mathit{contingency}]$$

The mine model will include a density of each block and the volume is known, thus the minimum processing time of a block may be determined. Mining engineers may feed the mill as many mine blocks as appropriate for a time period, assuming there is no other process restriction than the grinding circuit. If there are other constraints, such as flotation throughput, then these constraints may either be programmed into the mine totalizing algorithm (if the limitation is constant) or be populated into the mine model as a second process parameter (if the limitation varies).

Comminution Operating costs

The two most significant operating costs are grinding power and steel wear.

The calculation methods for mill sizing also provide estimates of grinding power that are suitable for operating costs. The grinding power at the mill shell (or at the pinion) must be increased to include the system losses in order to calculate the power at the electricity meter. Figure 7 provides a listing of the individual losses, or efficiency factors, that must be multiplied to generate an overall system loss which is suitable for determining the amount of power that must be presented at the power supply (used to prepare operating costs) based on the mill demand.

For example, a 20 MW gearless mill drive would actually draw:
20 MW ÷ (1.0 × 0.97 × 0.98 × 0.99 × 0.98 × 1.0) = 20 MW ÷ (0.92) = 21.7 MW as payable power at the substation.

Electrical losses are provided as "typical". Losses are affected by factors such as conductor length, conductor thickness, altitude, presence of step-down transformers and power factor corrections.

Steel wear is estimated using a measured abrasion parameter, for example, the Ai in the Bond series. Many practitioners derate the steel consumption predicted by the original Bond formula by approximately 50% due to the improved metallurgy of grinding media versus the media from when the formula was derived in the mid-1950's. Barratt's method accounts for the interaction of rock-on rock in a SAG Mill and finished material from the SAG Mill into the Ball Mill Circuit.

CONCLUSIONS

Although three of the most commonly used grinding circuit throughput calculations require different testwork protocols, it is possible to sample a set of drill core in such a manner as to provide comparable data sets for all. In addition, results may be obtained that are suitable for resource assay, operating cost estimates, and a geotechnical parameter.

NOMENCLATURE

Ai	Abrasion Index, commonly considered one of the "Bond" parameters.
Wi_{RM}	"Bond" rod mill work index to a specified mesh, used in the standard Bond power formula; its value is regarded as a critical parameter in the calculation of specific power consumption for the SAG Mill, particularly for harder ore types.
Wi_{BM}	"Bond" ball mill work index to a specified mesh, used in the standard Bond power formula.
Wi_{C}	"Bond" low energy impact (crushing) work index used in the standard Bond power formula.
CI	Minnovex crushing index, a SGS CEET® parameter for feed size.
SPI	Minnovex SAG power index, a SGS CEET® parameter for SAG mill power draw.
Mod BWI	Minnovex modified ball mill work index, an open circuit ball mill work index test.

A	Energy parameter versus appearance size for the JK Tech energy model.
b	Energy exponent versus appearance size for the JK Tech energy model.
A× b	Commonly used product of the JK Tech A and b parameters.
DWI	Drop weight index, can infer A× b from a smaller sample than a full DWT.
SMC	Abbreviated drop weight test used to determine a DWI
DWT	Drop weight test, provides JK Tech A and b values
t_a	Abrasion parameter determined in a DWT and used in JK SimMet

REFERENCES

D. J. Barratt (1989). "An Update on Testing, Scale-up and Sizing Equipment for Autogenous and Semi-autogenous Grinding Circuits". Proceedings of the 1989 SAG Conference, Vancouver, Canada.

A. McKen, S. Williams (2006). "An Overview Of The Small-Scale Tests Available To Characterise Ore Grindability". Proceedings of the 2006 SAG Conference, Vancouver, Canada

SGS Lakefield (2006). "Comminution Testwork Handbook", SGS 2006

M. N. Brodie (2007). Drive and electrical component efficiency, personal communication

APPENDIX

Figure 1: Drill Core Preparation

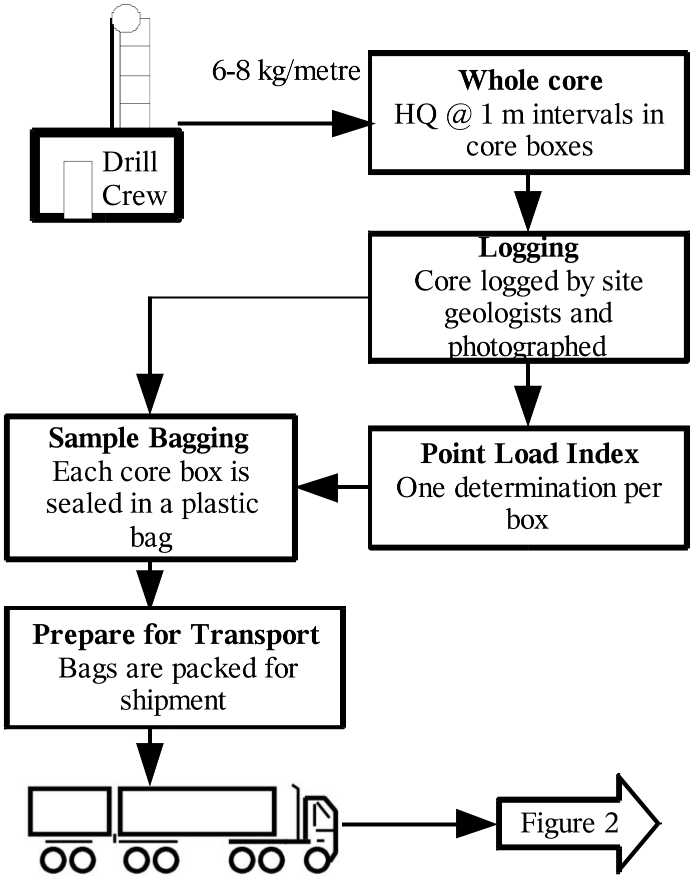


Figure 2: Whole Core Examination and Impact Samples

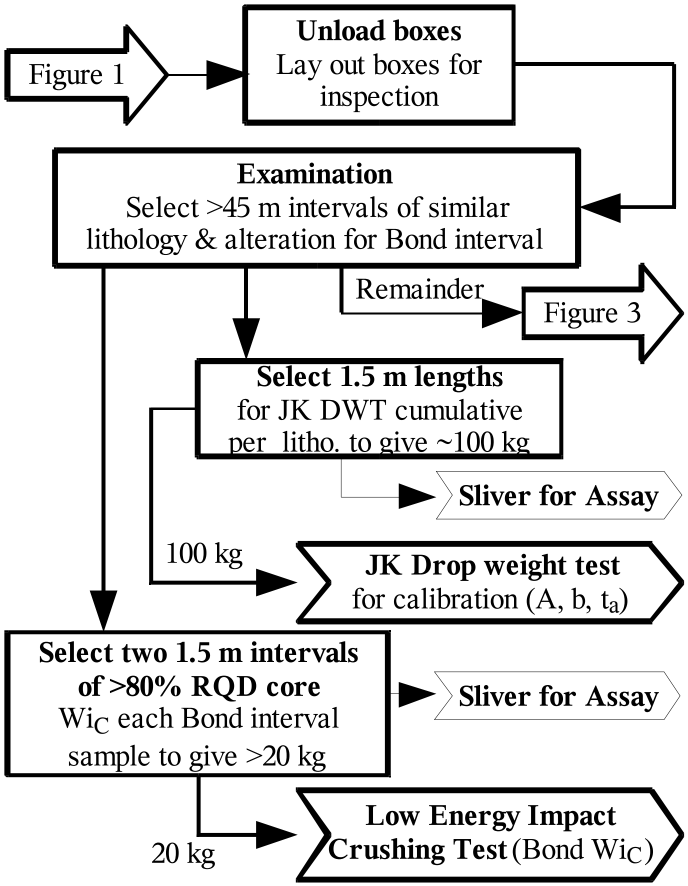


Figure 3: Core Sawing, SPI and SMC samples

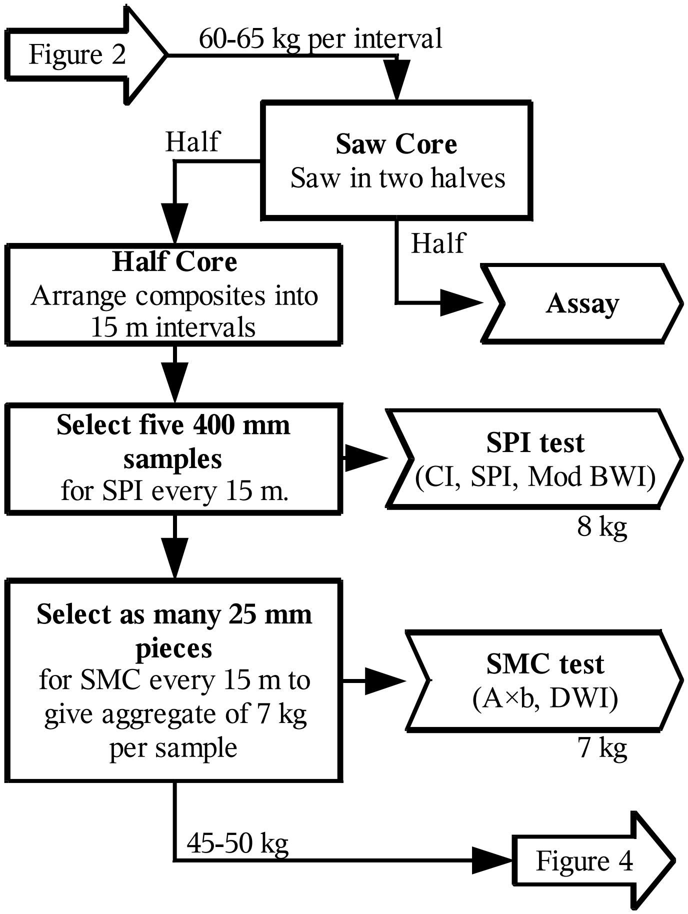


Figure 4: Crushing, Riffling and Flotation Samples

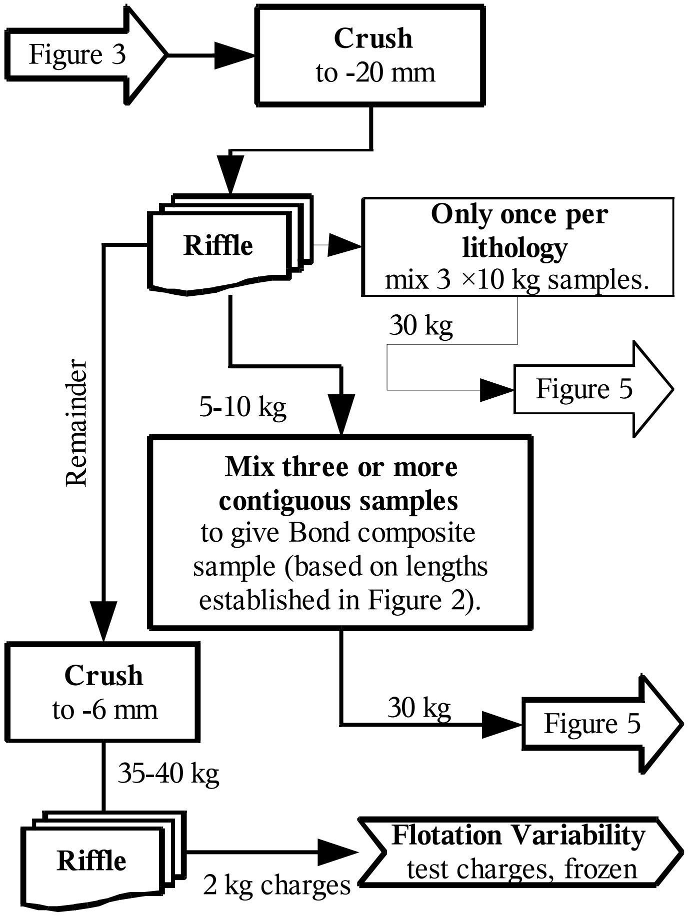


Figure 5: Bond Work Index Samples

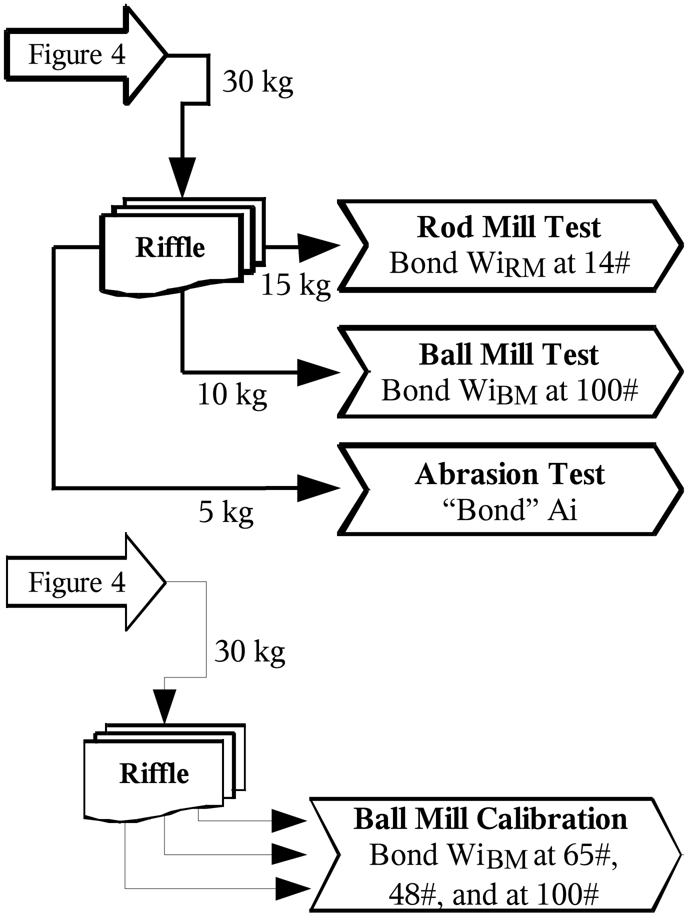


Figure 6: Sliver Assay Sample from Whole Core Samples

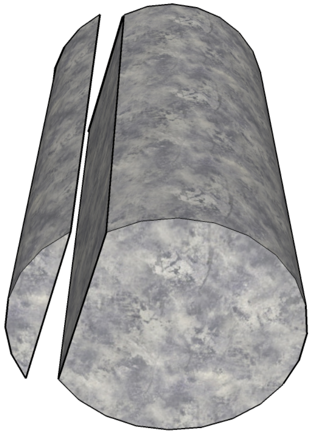


Figure 7: Typical Electrical Losses of Mill Drives

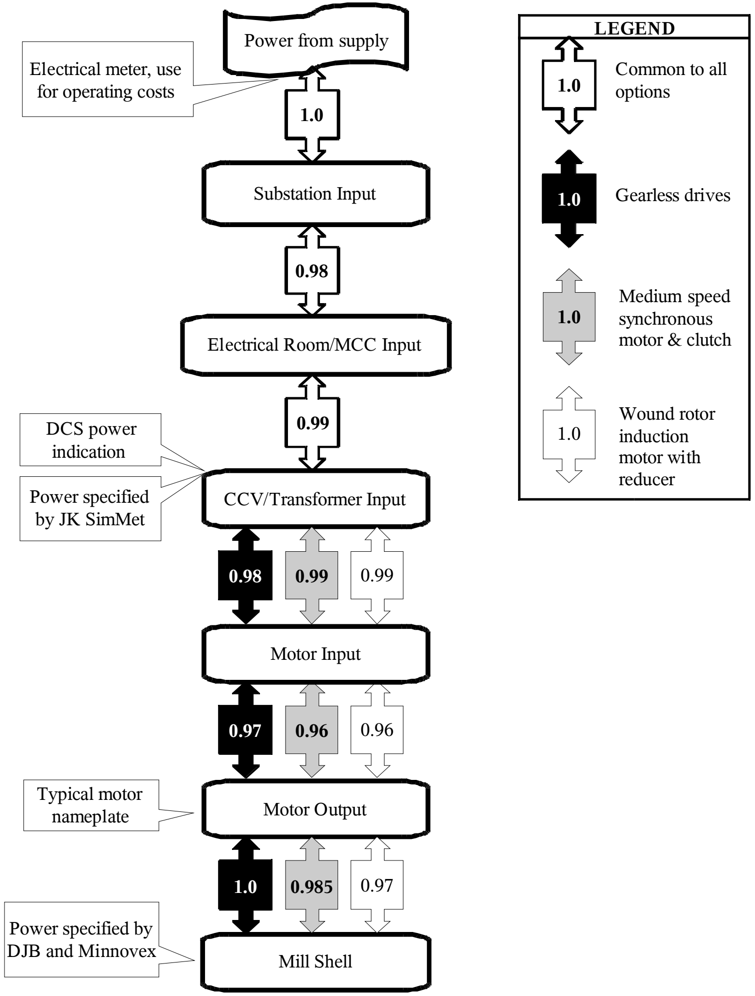


Figure 8: Core During Whole Core Examination

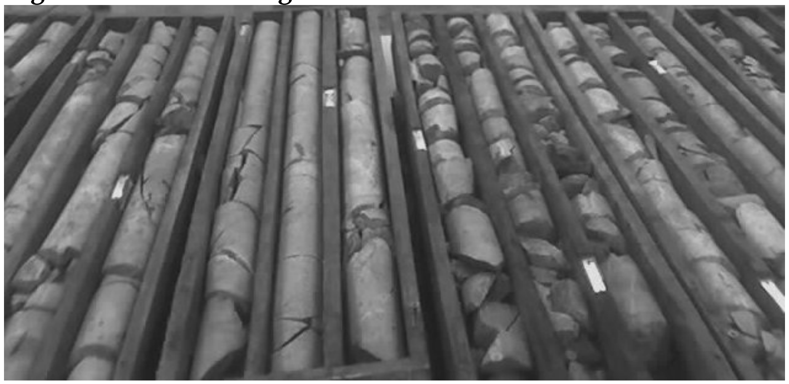


Figure 9: Half Core After Cutting (left side of photo)

Figure 10: Core After Assay, SPI & SMC Samples Removed