SEEKING CONSENSUS – HOW MANY SAMPLES AND WHAT TESTWORK IS REQUIRED FOR A LOW RISK SAG CIRCUIT DESIGN

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ABSTRACT

In Canada and other countries, legislation dealing with accurate factual disclosure for mining projects is being expanded to include more metallurgical design information. Grinding characteristics, metallurgical recovery of contained metal and environmental hazards associated with tailings disposal will be part of the Canadian package. This paper will examine only that portion of the plant design standard practice that relates to grinding – in SAG mills and ball mills that grind ore from as received crushed material to final ground product that is fed to downstream plant recovery processes. Since grinding plants represent a significant portion of the overall concentrator cost, accountability in grinding design should no longer be left to chance, opinion, or hidden proprietary information. This is the 21st century. It is reasonable to expect that a factual basis will be needed so that a Qualified Person (QP) reviewing the grinding mill design can understand it. That will also involve how many and what quality of samples are taken to define the characteristics of the deposit, the accuracy of the tests used to measure ore hardness and the method by which the dimensions and power of the mills are determined. If these criteria are not met, the QP may have no choice but to call attention to the lack of convincing information regarding the grinding mill design for the project. At the same time clients are expected to demand getting the correct design information at a cheaper price, results in a more timely way, and accurate design to the point where the risk of tonnage shortfalls are reduced or eliminated.

Tables will be presented to show how this can be done to current standards using existing technologies. At the same time it is acknowledged that current standards are ill-defined and that to achieve consensus among those involved in SAG mill design work, it may require that a consortium funded project be set up to establish what tests and methods for grinding design are suitable to meet the new standards for metallurgical disclosure. By running parallel design methods on several major projects over a period of 5 years, the process of how to design grinding circuits will be better understood because the projects will start at the design stage, include procurement of the mills and will end with a benchmark test on the plant.

Selecting the samples and the best schedule for doing test work on core samples submitted and mill design, will be discussed in this paper. The issue of completing the grinding design in time for early procurement decisions is on the critical path for most major projects. Discussions between mining engineers, geologists and process engineers are needed early in the development cycle, at the scoping study level (SS), preliminary engineering assessment (PEA), prefeasibility study (PFS), and at the feasibility study stage (FS), to ensure that proper planning for design sample selection is done. Using adequate sampling and testing methods in a timely way allows early procurement of the grinding mills and minimizes project risk.

KEYWORDS

Ball mill design, Bond Work Index, JK Dropweight, MacPherson, Protodyakonov, Qualified Person, SAGDesign, SAG mill design, SMC, SPI, Standard practice.

INTRODUCTION

The practice of designing grinding mills lies at the heart of the success or failure for any mining project. While not as critical as the tonnage of reserves and the amount of contained metal, the production capability of new grinding mills ranks high on the list of critical things needed for a new project to succeed. That grinding mills are the most expensive equipment used in most process plants, has led many cost conscious managers and controllers to limit the size of the grinding equipment in order to reduce the capital cost of their projects. What is sometimes overlooked is the fact that in addition to being costly, the grinding mills are at the centre of allowing design tonnage to be achieved, design fineness of grind to be met, and as a result, maximum metal recovery to be obtained. Standard practice then is critical to understand, because the metallurgist designing the grinding mills needs to have the tools to design the required mills and this design needs to be of such quality that it is possible to calculate the losses that will occur if the designed grinding equipment size is not purchased.

The corollary of this is that the Qualified Person reviewing any project has the right to understand what method was used to design the grinding mills and whether that design procedure is acceptable according to a peer review. In the year 2011, it is clear that there is not yet a universally agreed procedure available to design grinding mills. At the same time it must be stated that many designs are inadequate in some cases and risky in others. What then are the criteria by which a QP will rule on whether a design is adequate or not? Since every mill design provider has his own method for performing a mill design, and many of these methods are proprietary, it is necessary to review what clients have accepted in the past, to look at which projects did not meet their tonnage expectation and what a QP can recommend to protect clients' and investors' interests from inadequate mill designs.

This will not be the final word on this subject. The real purpose of this paper is to provide a reference document for Qualified Persons and industry leaders and to start a dialogue which will result in the adoption of protocols for the management of comminution test programs as well as the standardization of criteria for adequate mill design. It is not our purpose to make this decision at this conference but rather to identify some of the parameters involved by which a QP can judge whether a design is adequate or not and to provide for QPs worldwide, a reference point by which they can make this judgement. By publishing such a reference point, new ideas will be generated and hopefully will lead to peer and client consensus because the ideas contained are understandable and valid from an engineering point of view.

HOW MANY SAMPLES

This is one of the most frequently asked questions and probably the most important one as well. To begin we need to consider what stage the project is at, what is the likelihood that the mine will be built and how much time can be allowed to make the decision on the test program. It is fine to say that method A is the best but if the method A testwork cannot be done in less than one year, the value of that method to the client is greatly diminished in an environment where the lead time to purchase new grinding equipment is already two years or more. The accuracy of the test method also comes into play. If test B is more accurate than test A, then fewer samples can yield the correct result, and be completed in a shorter period of time and fit better into a client's procurement schedule.

Another issue needs to be addressed here. Some call it geo-metallurgy but in the context of grinding design for a large orebody, variability testing is a better term. The need for variability testing relates to the testing method used, the size and structure of the orebody, and the amount of time required to do the recommended number of samples. In the writer's opinion, variability testing should not be confused with design sampling and testing because of its cost and time delay to obtain geo-metallurgical data.

SUMMARY OF CURRENT PRACTICE

Current practice involves the use of many tests, and many methods. Most of the tests listed below are well known, but many of the methods are not well known because of the proprietary nature of the technologies used to size the grinding mills.

Tests used today to design SAG mills include but are not limited to (in alphabetical order):

- Bond BWi, RWi, CWi and Ai tests. Wi test results are expressed in kWh/t,\; Ai is in grams. (Note that none of these are a SAG test per se.)
- JK Dropweight test. Results are expressed as A and b where A and b are the parameters.
- MacPherson Autogenous Grinding test. AWi is the test result in kWh/t to a specified product size.

- Protodyakonov Index test – local to projects in Russia* Results are expressed as a relative hardness number, increasing from soft to hard.
- SAGDesign test – which includes a SAG test and a Bond BWi on SAG ground ore. Results are expressed as SAG specific pinion energy to grind from F80 152 mm to T80 1.7 mm in kWh/t, and BWi in kWh/t.
- SAG Power Index (SPI) test. Results are in minutes (to grind the sample to P80 1.7 mm).
- SMC test – modified from JKDWT. Results are expressed as A x b where A and b are the parameters.

Note: *Protodyakonov compressive strength test used in Russia

Unconfined compressive strength tests and point load index tests are sometimes used by current SAG mill designers. But since these measurements relate more to crusher design than SAG mill design, they are not needed to design a SAG mill.

The methods for sizing mills from these tests are well known to some but not all, and specialized knowledge is required to size the grinding mills especially when using the proprietary technologies. The typical number of tests used per project is noted below for each testing method.

Table 1: Number of Grinding Samples Tested, Current Practice

Test	Approximate Number			Remarks
	Min	Ave	Max	
Bond (BWi, RWi, CWi, Ai)*	1	20	100-200	Often limited by material available
JKDWT	1	10	100	Often limited by material available
MacPherson AWI*	1	3	6	Each test requires ~200 kg composite
Protodyakonov*	1	3	6	Limited information available
SAGDesign	1	10	50	Composite or point samples
SPI*	1	30	200	Composite or point samples
SMC*	1	30	160	Point hardness samples only

Note: *These tests need to be checked by at least one other method to be sure the design is correct. Current practice is to use two or three different methods to be sure that the design is correct. In the case of the SMC tests, calibration of every 15th to 20th SMC tests with one DWT, need to be done.

This is not a complete list. It only covers projects that the author has seen or been directly involved with. Very often, the sampling done for a scoping study, preliminary engineering assessment or a prefeasibility study is never upgraded and the grinding mills are purchased based on whatever hardness data is available. This is one cause of difficult start ups and undersized grinding mills.

RECOMMENDED BEST PRACTICES

The above table demonstrates the variety of ways that grinding mills have been designed in the past and perhaps explains why and how inadequate designs are built and put into production. For a QP to decide what designs are adequate, the following table represents a recommended level of effort for every stage in a project and for each method of testing used. Included here are 5 levels of project development, each level requiring more work to be done to adequately deal with the uncertainties that may exist.

The levels of progress in project development included here are as follows:

1. Scoping Study – The first pass at determining the economics of a project. Generally unregulated.
2. Preliminary Engineering Assessment – First stage of regulated reporting for a project in Canada.
3. Prefeasibility Study – Full assessment of ore reserves, metallurgy, costs and economics.

4. Feasibility Study – Definitive cost estimate. Planning complete. Costs defined. Economics known.
5. EPCM Construction Stage - Purchase of process equipment.

Obviously the sooner that the feasibility study level of work is done, the better the project is defined and the faster the mills can be ordered when a production decision is made. The difference between feasibility study and construction stage can be explained as risk reduction. When new capital is raised in the marketplace, it is prudent to expand the grinding test work basis to eliminate or reduce the risk of failing to meet design production. If a client is spending treasury dollars, the situation is different. But it will be dangerous in any context to do less work than is required for Feasibility Study testing and it is recommended that the design be based on the standards shown in this paper to ensure robust financial results.

It is assumed for this discussion that the final design of the mills to be purchased is done at the completion of the feasibility study stage. But for fast track projects this does not work. In this case the grinding test work must be escalated to EPCM level at the feasibility study stage. Otherwise the mills cannot be ordered on the completion of the feasibility study because the risk may be too high until the final testing is done. The cost of the test work often causes clients to defer the final design testing expense until later to protect against the project economics not being favourable. When economics are favourable, there is tremendous pressure to order the mills quickly. This then, is one example of how mistakes in grinding design occur.

The following table is based on major projects involving 100 million tons of reserves or more. For projects in the 5 to 10 million tonne range, the number of samples can be reduced to about 40% of those shown for a feasibility study. For deposits in the billion tonne range, the work done should be proportional to the size of the deposit and the cost of the mills to be purchased. These latter projects need to be tested and have the mills designed to suit the ore body with testing requirements decided on a case by case basis.

Table 2: Number of Grinding Tests Recommended for Best Practices (Project levels defined above)

Test	**Number of Tests Recommended**					**Remarks**
	1 Scope	**2 PEA**	**3 PFS**	**4 FS**	**5 EPC**	
Bond (BWi, RWi, CWi, Ai)*	3	12	40	100	200	New drilling required to get samples
JKDWT	1	6	20	50	100	Limited by material available
MacPherson AWI*	1	2	6	15	30	Large composite samples req.
Protodyakonov*	1	2	6	15	30	Large composite samples req.
SAGDesign	1	3	10	25	50	Composite or point samples
SPI*	3	12	40	100	200	Composite or point samples
SMC*	3	12	40	100	200	Point hardness samples only

Note: *Should be used with at least one other method.

There are reasons why more SPI and SMC tests are required than the other SAG testing methods. SPI tests can be done on composite samples but the 2 kg test is so small that more tests are required to duplicate the accuracy of other tests. SMC tests require that the samples tested be point hardness samples, taken from one intersection per sample. When composite samples are taken, there is usually between 3 and 6 different drill hole intersections included in the composite. This is why fewer samples are needed when composite samples are tested in a more robust SAG test than SPI or SMC.

The above is a guide and is intended to provide grinding mill designs that have minimum risk involved after a plant is built. Since the subject of this paper is how to provide low risk designs, this table will be helpful to achieve this goal.

There will be exceptions to the above noted samples requirements. Simple homogenous ore bodies such as iron ore deposits will require fewer samples, while complex lens type or multi-zone deposits will require more samples to achieve the same level of low risk in the grinding mill design. Clients and QPs however need a guideline upon which to base their judgement as to whether a grinding mill design is adequate or not compared to peer review standards. This paper was prepared to provide that guideline.

This presentation is based on the use of SPI and SAGDesign technology, as a way to design grinding mills, based on personal experience of the author. The relative strengths and weaknesses of every method have been discussed in previous publications and so will not be repeated here. The fact is that all of these tests are used today and therefore a QP must understand how to deal with the assessment of a grinding circuit design, especially when that design has not been done up to an acceptable standard.

The GRINDPOWER method for designing SAG mills has been used for the past twenty five years and involves using other tests including the Bond rod mill, ball mill, crusher work index and abrasion index testing, to design SAG mills. This approach has been successful when compared to two or more other methods. The cost of sampling and testing, delay in getting results and the possibility of error by not measuring SAG hardness specifically, make this method the least attractive of those listed.

Other items to note with regard to Best Practices include the use of a broad or extensive grinding sampling program at the preliminary engineering assessment and/or prefeasibility study levels, and to perform at least two different series of tests on these samples. This will put the grinding mill design on a definitive capital cost basis if the recommended number of samples are taken.

DISCUSSION

The data required to show conclusively which tests are best and how many of each are required to do a proper risk free final grinding mill design is not available at this time. It is best therefore to continue using at least two mainstream technologies when grinding circuits are being designed. In this way any errors in one method will be picked up by the duplicated work. One of these methods should be SAGDesign because it has been shown to be the most robust predictor of required grinding mill pinion energy when compared to other technologies. It is also open technology and therefore mill sizing can be more easily checked for accuracy than any other method.

To achieve consensus among those involved in SAG mill design work, it may require that a consortium funded project be set up to establish what tests and methods for grinding design are suitable to meet the new standards for metallurgical disclosure and which are not. By running parallel design methods on three major projects over a period of 5 years, the process of how to design grinding circuits will be better understood because the projects will start at the design stage, include procurement of the mills and will end with a formal benchmark test on the plant operation.

CONCLUSIONS

Several important conclusions have been made from this analysis.

The completion of final design grinding test work in a timely way is important because otherwise, mill purchase needs to be delayed until the required testing is complete. If the test work is done earlier in the project in a proactive way, this problem would be eliminated.

Collecting representative samples of ore to be mined by year or horizon is key to the start of the mill design process and should include co-ordination between geological, mining and metallurgical groups.

Cutting costs of test work and over accelerating test programs can backfire and induces risk in the grinding process design. This ultimately can result in a prolonged plant start up.

By doing less expensive test programs involving less but more accurate tests, the cost and timing for receiving final design results would be improved, allowing lower overall testing costs and earlier receipt of results. This in turn would accelerate the issuance of the grinding mill purchase orders.

The failure to follow rigorous design standards lies at the heart of every unsuccessful SAG mill start up because failure to achieve design tonnage in a SAG mill at start up is one of the most serious problems in the mining industry today. This problem can be corrected if proper protocols are followed as outlined herein.

A thorough study of alternate methods and tests for mill design, funded by industry, and including benchmarking of the completed plants, would be a definitive way to show what is the best way to design a SAG grinding circuit.

In the meantime, until consensus is reached where industry leaders can agree to a recommended procedure needed to design low risk SAG grinding circuits, clients should continue to use two major methods in parallel to design their grinding mills.

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