Comminution Circuit Design, What Test Work is Required for a Bankable Feasibility Study?

COMMINUTION '14

Cape Town, SA

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April 8, 2014

Key Words: Feasibility Study, Comminution Tests Required, Bond Work Indices, Grinding Circuit Design, Ore Hardness Measurements, JK Dropweight, SMC, SPI, SAGDesign Test.

1. ABSTRACT

The 2011 SAG Conference included a paper on Seeking Consensus which discussed what test work is required for a low risk SAG mill design. The concepts presented in that paper have not been challenged or changed since then, except for comments from the floor, where it was suggested that SAGDesign and full JK Dropweight testing were not the only methodologies that could be used alone to design a SAG mill circuit.

This paper is written to follow up specifically on Feasibility Studies, and to offer guidance to clients, financial managers, and professional design engineers in a due diligence review context, on what test data is reasonably the minimum required for a Bankable Feasibility Study, with respect to the scope and size of the project, the accuracy of the design required and the results presented, and the cost of doing the required test work and mill sizing calculations.

It should be no surprise that accuracy of comminution tests need to be questioned, based on the performance of recent new plants. Of the test methods mentioned in the Seeking Consensus paper, several have been tested in multiple labs for accuracy and reproducibility but the results presented are often not complete or convincing. There are exceptions and JK Dropweight and SAGDesign are leaders in this kind of testing and reporting.

The testing method(s) chosen for a Feasibility Study must be capable of producing a grinding circuit design that allows normal production to be achieved within plus or minus 10-15%, and that enough contingency be included to ensure that 100% of design tonnage will be possible by exceeding normal operating parameters, if required due to unforeseen interruptions.

2. INTRODUCTION

Two years ago, at the Comminution 2012 conference, International start-ups were discussed by this author and it was noted that "the importance of accurate grinding mill design for SAG grinding circuits cannot be overstated". Definition needs to be put on this statement, namely how accurate and based on what data. Standard engineering practice shows that various levels of project design each have accuracy targets. Scoping level studies are to be within plus or minus 35%, prefeasibility 25%, feasibility 15%, and definitive cost estimates within plus or minus 5%.

It is obvious that the accuracy of the test chosen to design a grinding circuit should if possible, match the accuracy of the study being conducted. Surprisingly little is known about the accuracy and reproducibility of many of the grinding tests being used today to design grinding mills. A good start to this discussion was presented in the paper "What Can Go Wrong in Comminution Circuit Design". In design reports, accuracy is rarely discussed and only JK Dropweight, SAGDesign, and Bond testing have been subjected to rigorous lab to lab comparison testing. Bond did not propose a specific test for designing SAG mills and JK Dropweight and SMC have done reproducibility tests but results are reported in Axb units and derived kWh/m^3 respectively.

Since the Axb parameter is a non-linear function with respect to pinion energy it has little meaning to discuss accuracy since the hardness of the ore may be a factor in determining the percentage relative error of Axb, as the measurements need to be related to throughput.

The goal in grinding mill design accuracy and in achieving design throughput performance is defining the required kWh/t correctly in order to accomplish the size reduction required for liberation of the values in the ore, in a SAG mill or in a SAG/ball mill circuit configuration. When the needed SAG mill pinion energy is not measured accurately, simulation methods are required to convert test results to mill sizes and it becomes difficult if not impossible to check the design or to define exactly how big the mills need to be and what power is required. Often, little is known about simulation accuracy until after a plant starts up and by then of course, it is too late. A better approach is to define ore hardness by measuring the pinion energy required and calculating a SAG mill size (and a ball mill if needed) that is big enough to draw required power.

In conducting benchmark tests the plant data should fit the testwork with a stated accuracy, without depending on a calibration factor like Axb which might vary depending on ore competency. This is the difference between measured hardness and inferred hardness from SMC or JK Drop-weight testwork. The accuracy of these latter results is difficult to establish.

3. ACCURACY

The tests to be discussed which are used for designing SAG mills are given in Table 1 below. Since 2011, two new tests have been added to provide accurate data at low cost and are included in Table 1. The SVT and BVT are SAG pinion energy and Bond Ball Mill Wi variability tests which use the SAGDesign test method as a basis. Each test is a shortened version of the full SAGDesign test, but at a much lower cost. The SVT test also can be continued to SAGDesign test completion if a suite of samples requires to be upgraded to Feasibility Study accuracy status.

The data used below comes principally from three papers and two NI43-101 studies as noted by reference to the Bibliography attached to this paper. The JKDWT information comes from reference paper, What Can Go Wrong(6), while the SMC Vs JKDWT data comes from published reports in the public domain including 2 NI43-101 reports on the Kami Iron Project(9), the Rainey River Gold project(10) and Reference paper (11) on the Antapaccay Project.

To the best of the author’s knowledge, this comparative accuracy information has never previously been examined before in the context of determining what type of information is suitable for Feasibility studies and what information may only be appropriate in a geo-metallurgical or scoping level context. By updating our knowledge with up to date information on accuracy of the various tests it is now possible to upgrade the accuracy of a Feasibility Study to an acceptable level, by using tests of suitable accuracy and reproducibility.

Table 1 – Comminution Tests Used for SAG Circuit Design

TEST	DESIGN SAG* MILL ALONE	RESULT MEASURED	COMMENT ON +/- ACCURACY
Bond BWi, RWi, CWi	No	Index, kWh/t	Varies by test, in order of 10 to 20%
MacPherson AWi (SAG)	No	Index, kWh/t	Unpublished, samples too large
Protodyakonov (SAG)	No	Relative Units	Unpublished, samples too large
JKDWT (SAG) (6)	Yes*	A and b, A x b	Rel. Std. dev. 4.2% to 5.7%
SMC (SAG) (9), (10), (11)	No	A x b, kWh/m^3	Avg. Rel. error 20% Vs JKDWT
SPI (SAG)	No	Minutes	Rel. Std. dev data is unpublished
SAGDesign (SAG & BM) (8)	Yes*	W_{SAG}, kWh/t	Rel. Std. dev 3.1%, at 8 labs - 2012
	(2 part test)	BWi, kWh/t	Rel. Std, dev. 5.7% SAG ground ore
SVT (SAG)	No	SAG, kWh/t	Avg. Rel. error 5.4%, from data base
BVT (Bond BWi)		BWi, kWh/t	Avg. Rel. error 3.8%, from data base

*From Seeking Consensus paper at SAG 2011[7] No = at least one other design method required.

The table presented at the SAG 2011 Conference paper "Seeking Consensus' as Table 2 is key to this discussion. It is reprinted below to provide context for the present discussion. The number of tests required increases as the stage of the project advances to a more accurate definition of the costs and revenues required to prove that the project is financially viable. The Feasibility Study level is highlighted because in reality, there is almost never enough time to upgrade the Feasibility Study data to final design standards. Long lead times for procuring grinding mills make it unreasonable to delay the project while the design information is upgraded. Therefore in reality, the yellow highlighted data for the Feasibility Study column is the de facto final design data for most newly constructed mining projects today. This can be a problem for mega projects.

The reason for more tests recommended in Table 2 is directly related to the known accuracy of the design method and tests used for that method as seen in Table 1. There are therefore changes required to the table below because the logistics and cost for providing the recommended number of samples in several instances is prohibitive and no reasonable client will spend many times more than is needed to get a result that is not as accurate as what can be done at less cost, if he is properly advised as to the accuracy and total cost of what is proposed.

If the accuracy of the tests used in the early stages of the project is not considered, the final design will be compromised if the tests used have accuracy less than that required for a Feasibility Study, that is, plus or minus 10 to 15%. It is acknowledged that more samples will compensate for lower accuracy, but when low accuracy tests are used, the time delay is increased to get the required data for a secure design, if it has not been provided already in the Feasibility Study.

Table 2 – Number of Grinding Tests Recommended for Best Practice

Test	Number of Tests Recommended					Remarks
	1Scope	2 PEA	3 PFS	4 FS	5 EPC	
Bond BWi, RWi, CWi, Ai *	3	12	40	100	200	New drilling req'd for 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

An approach that is increasing in popularity because it is so effective, is to use the least expensive grinding tests for all the preliminary work, but before completing the Feasibility Study where final financial commitments to the project are made, do a final check of the design using the most accurate method available where the samples are stored, on at least six but not more than ten good composite samples representing the early years of production. This can also be called an 'ombudsman' approach because it uses available drill core to confirm the grinding mill design in a minimum period of time, before the Feasibility Study is completed. If SAGDesign is chosen, the mill design program can be completed within 2 months at the desired accuracy level, as long as sufficient existing drill core is available.

4. DISCUSSION OF GRINDING MILL DESIGN

Key factors in executing a greenfield grinding mill design project are thought to be well known, but judging by recent start-up problems that have been encountered, too often there is a disconnect between what is intended and what happens. When it is considered that all but one method use private technology and computer simulated designs, the reason for using a second method to check the design is apparent. This paper clearly demonstrates that if an accurate method has not been used from the start, it should be used as the final check before the end of a Feasibility Study, and before grinding mills are purchased.

There are a number of projects where the final design has used SAGDesign methodology. Tenke Fungarume, Climax Molybdenum, Mercator, Detour Lake, Lake Shore Gold, Alexandovskoye, and HudBay's Lalor mine are seven recent examples. Of those operating, where start-up has already occurred, none have been judged deficient in achieving design production as determined in the design criteria, by using the selected mills. Only Lalor has not yet started production.

Along with good accuracy goes a minimum number of samples if cost implications are to be considered. A mill design program has to be completed during the Feasibility Study period to provide value to the project. Design method selection starts with the accuracy of the grinding tests used and the minimum cost of the tests being considered. The information presented above shows which test is the most accurate. Previously reported SAGDesign results show a maximum relative error of +/- 4.6% for the SAG part of the test and +/- 9% for the Bond Wi. This is suitable accuracy for Feasibility Study work.

The source of samples needs to be considered. Some tests can be done on any commercial split drill core and these methods are favored for ease of sample selection and time to complete the work. SAGDesign, SPI and Bond test programs have been successfully done on 15 kg samples of 42 mm diameter core. The likelihood of finding suitable existing samples is enhanced by the fact that extra drilling is not required to get proper samples when standard core is available. Methods that require more weight, large core, and more samples, make the logistics of finding suitable samples for a Feasibility Study more difficult.

Parallel with using the most accurate test is the requirement for a minimum number of samples so that the testing can be completed quickly at minimum cost. Test prices can vary from lab to lab for the same tests but generally speaking JK Dropweight is the most expensive test, SAGDesign (including SAG and BWi data) is $4,000 US per SAGDesign test and the other SAG tests are less but require the ball mill data to be added separately as added cost.

To do a Feasibility Study grinding mill design project, a quotation for comminution testing and mill design needs to be requested from the various vendors of these services. Some labs offer test work only while others offer both testing and mill design. The number of samples and time required to complete the work is established in this way. The vendor should also provide validated information on the accuracy of the tests proposed.

All 10 SAGDesign testing laboratories send testwork results to Starkey & Associates Inc. (S&A) for test validation and mill design analysis. To date only TOMS in Irkutsk Russia offers the mill design analysis as well because they are an engineering firm as well as a test laboratory, but even so, S&A checks all final mill design work done by TOMS. Other labs are interested in offering the full mill design service as well and this will happen in the future.

5. WHERE MISTAKES ARE MADE

Execution of a Feasibility Study is a complex exercise involving many disciplines. One of the most frequently missed points is that the selection of the correct SAG mill is the single most important project decision for achieving design production and design revenue. Accuracy is paramount – compromises in mill sizing must be avoided. Production shortfalls wipe out profits, delay the repayment of capital and create havoc for the project's financial administrators.

In the past, uncertainty with regard to the design, especially when using simulation methods, has led project managers to accept available but undersized equipment, to downsize the SAG mill because capital costs are too high, and to accept design and operating parameters that are expensive and rob the new circuit of operating flexibility. Included in this list of parameters are:

1. Unless there is compelling reasons to do differently, design using the 80th percentile of hardness variability for a deposit. This a client's choice and if the mine can deliver blended, average hardness feed, a lower design point may be acceptable.
2. Provide a design that allows the mill production to be pushed higher than normal (say 10%) so that when production problems occur, a way will exist to catch up lost production and meet monthly production targets. If design parameters are already pushed to the limit, catch up will not be possible.
3. Use a design steel load of 10%. When 15% steel or higher is used, high operating costs and lack of flexibility will occur. High steel should only be used for contingent purposes.
4. Use a total load of 26%. When higher loads are tolerated, power demand will be higher than necessary and it will not be possible, especially on harder ores requiring more than about 7 kWh/t, to run design tonnage, because overloading causes lost t/h on hard ores.
5. Use a critical speed of 75% maximum. Design calculations must be done at this speed because efficiency of power usage drops when higher speeds are used. The introduction of vari-speed SAG mills is a blessing and a curse. A blessing when it is only used to protect the liners when soft ore is treated but a curse when it is used as an operating variable. Lifters are set for a specific speed, preferably 75% critical, so operating at other speeds will destroy the SAG mill's ability to operate at optimum performance.
6. Allow for F80 feed of 6 inches or 152 mm. Many design simulations use finer feeds and soft ores will often come out of the primary crusher at a finer size. The problem is that when the ore gets hard, the primary crushed product becomes coarser and so the under-design problem immediately takes over and robs the plant of its ability to produce design tonnage on the hardest ores.

Final decisions on mill sizing, projected throughput, projected revenue, all fall within the scope of the management team, and the mill designer must alert the management team of a mill sizing mistake before a new mill is purchased, not afterwards. In the past this was not always possible but today with the availability of accurate grinding data and calculated mill sizes, it is the correct way to avoid a mistake in the design of a new grinding plant.

A direct result of using an accurate hardness measurement such as SAGDesign, is that meaningful evaluations of alternate mill sizes can be calculated to show the effect on production capability of using different sizes of grinding mills. Mistakes can be immediately identified and avoided, before the grinding mills are purchased.

6. CONCLUSIONS

Before starting a Feasibility Study an owner should demand from the design testing and mill sizing provider, the documented accuracy of the tests to be used and the basis on which the mills will be sized. If this data is not provided, the method proposed should be checked with another method of suitable accuracy before accepting the final result of the mill sizing and power needed.

The total cost of doing a Feasibility Study grinding mill design, is important and should be defined in a proposal. But total cost is not as important as doing the work correctly. This however must not be used as a permission for a mill designer to use more expensive and less accurate techniques to design the grinding mills for a project. The need to provide geo-metallurgical data and examine the whole ore body must also be considered.

SAGDesign technology can confidently be used as the standard checking method for every new SAG grinding circuit designed, before mills are purchased, because it is the most accurate comminution design test available today. In Russia, this testing is standard and is done on every new recent Russian project at either TOMS or Irgiredmet. It is a good model to follow.

Provision in the final grinding mill design needs to be included for the grinding mills to be pushed, if necessary to achieve at least 10% beyond design tonnage for the project. If contingent capacity is not provided, the project will not meet its production target. This design allowance has been largely ignored in the SAG mill era. Adequate design, over design, and under design are terms used to define one's own or someone else's work, but it is the client whose need for steady design production comes first.

Grinding mills are expensive, and for large projects the capital cost of grinding equipment can cost up to $100,000,000 or more. But if this is 5% of the total project capital, it is unreasonable and financially irresponsible to jeopardize the project's revenue by downsizing a SAG mill so that it cannot meet production targets with ease, in order to save say $10,000,000 in capital.

A common error with respect to SAG mill operation is that a SAG mill needs to be pushed to its limit all the time. This is not in an owner's best interest because higher operating costs and optimum financial results will not be achieved if the plant is run this way. When properly designed, a SAG mill easily meets design t/h, and can start-up at full tonnage without an extended ramp up period as discussed is the recent paper presented at Procemin 2013(12).

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