SAG MILL GRINDING DESIGN VERSUS GEOMETALLURGY – GETTING IT RIGHT FOR COMPETENT ORES

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ABSTRACT

Smarter processing for the future, in the area of SAG mill design involves accurate grinding test data, completing final mill design in less than three months, and at a cost of less than $80 000 US. More detailed variability testing on the other hand takes longer, is more expensive, and is used for throughput optimization for an existing or newly purchased mill. This paper shows that SAGDesign™ testing is excellent for new SAG plant design due to relatively low cost per test and the ability to do more testing for a limited budget on larger projects. It also briefly examines a way to develop proper geometallurgical ore hardness information on every block in the mine model, from the more detailed analysis data.

Keywords: comminution tests, bond work indices, grinding mill design, database, ore hardness measurements, SAGDesign test, JK dropweight test

INTRODUCTION

The selection of SAG and ball milling sizes and configurations for new projects is complicated by the fact that grinding characterisation data is typically limited at best. The use of this grinding characterisation data by different grinding consultants, to specify totally different equipment and or configurations for the same project is becoming a major concern for the industry. This is highlighted by the fact that a number of new projects are following the concept of selecting the largest proven equipment available and then evaluating what the expected throughput will be using the largest SAG and ball mills available.

The task therefore shifts from SAG mill design, to how many tonnes will the given SAG mill grind in one hour. When the difference between design methods used by different consultants reaches a factor of 2, it is time to stop and review the techniques used. If the designers fail to do this, the possibility exists that clients will select alternative technology simply because clients have lost faith in the designer's ability to design the correct mills or accurately predict throughput in a large SAG mill.

Cynicism about SAG milling and tonnage capacity is perhaps best explained by the comment from a senior mining consultant who recently said, "if a SAG mill can process design tonnage, it is overdesigned". In other words, some people are becoming so used to a SAG mill not being able to produce design tonnage that they do not expect it to happen. From an engineering design perspective, it is unacceptable that a client be offered a design where the tonnage is uncertain, or cannot be achieved. The project could be rejected based on the mining economic equation which is driven by throughput. Contrary to common belief, one of the best investments in hardware today is the purchase of enough SAG mill capacity to not only achieve design tonnage all the time but also to reduce steel costs in SAG grinding. With this in mind this paper will examine new information that is relevant to designing and maximizing the profitability of new mines.

SAG MILL GRINDING DESIGN

Significant differences between macro and micro grindability relationships, and the true magnitude of SAG hardness variability have been discovered for SAG mill and ball mill design measurements.

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These new discoveries found using SAGDesign testing allow for improved understanding of the uniqueness of each ore body and the measures that can be taken to achieve design throughput from the first day of operation at a new plant.

Characterisation of ore hardness with SAGDesign testing

SAGDesign testing is set up for using both crushed run-of-mine ore and/or any commercial drill core. A full SAGDesign test characterizes macro and micro ore hardness by means of a SAG mill test and a standard Bond Ball Mill Work Index test (BWi) on SAG ground ore. The SAG test reproduces commercial SAG mill grinding conditions on 4.5 L of ore and determines the SAG mill pinion energy needed to grind ore from 80% passing 152 mm to 80% passing 1.7 mm, herein referred to as macro ore hardness. The SAG mill product is then crushed to 100% passing 3.35 mm and is subjected to a standard BWi grinding test to provide the total pinion energy at the specified grind size for mill design purposes. The full SAGDesign test reports SAG pinion energy in kWh/t, the BWi in kWh/t, as well the ore specific gravity. When the ore variability is considered by doing a number of tests, the information is complete to design the grinding mills for a project. No other test work or computer program is required.

SAGDesign test database

In the past 6 years, starting in 2004 when the SAGDesign test was patented by Outotec, the test work database has grown to include 53 projects and 320 samples on ores of all kinds. Table 1 summarizes the database including all SAGDesign test work results recorded up to and including 2009 and includes the data for ore SG, SAG pinion energy in kWh/t to grind from F80 152 mm to T80 1.7 mm, Bond Ball Mill Work Index in kWh/t, and the ratio of SAG kWh/t to BWi.

TABLE 1

Database summary of SAGDesign test work results.

Description	Ore SG g/cc	SAG kWh/t to 1.7 mm	Bond BM Wi, kWh/t	RATIO SAG/BWi
Min	2.38	1.37	6.01	0.12
Max	4.73	34.89	24.06	2.55
Median	2.81	8.52	14.27	0.59
Average	3.01	9.57	14.31	0.65
Std dev.	0.49	5.72	3.32	0.35

The development of SAGDesign testing results in previous papers (Starkey, J. and Samuels, M., May 2009; Starkey, J., Aug. 2009; Starkey, J., Oct. 2009; Starkey, J. and Samuels, M. 2010) shows the interesting new discoveries, with relationships identified as illustrated in Figures 1 to 4.

Figure 1 highlights ores from two different projects with both soft and hard SAG milling components to grind from a feed F80 of 152 mm to a P80 of 1.7 mm. The soft ore is characterized by 2 kWh/t and hard ore needing 30 kWh/t. As described in Figure 2, these ores were observed to have the same Bond ball mill work index value of approximately 13 kWh/t. This phenomenon suggests that direct measurement of the macro and micro ore hardness is required to get the correct mill design and throughput prediction. Modelling and simulation techniques that do not consider this ratio may produce erroneous results.

It is important to note that the Bond Ball Mill Work Index on SAG ground ore is similar to but not the same as a crushed Bond Ball Mill Work Index. It is ~ 7% higher because the SAG mill grinds the softest components quickly and leaves the harder material to be ground in the ball mill.

Figure 3 presents the graph of SAG pinion energy vs. BWi. The database supports a general trend between SAG and ball mill hardness for the majority of the test work data but the correlation is too low to be useful in sizing a SAG mill from only a BWi measurement. Macro SAG hardness measurements cannot be used alone but only in conjunction with the corresponding micro hardness measurements of the Bond BM Wi.

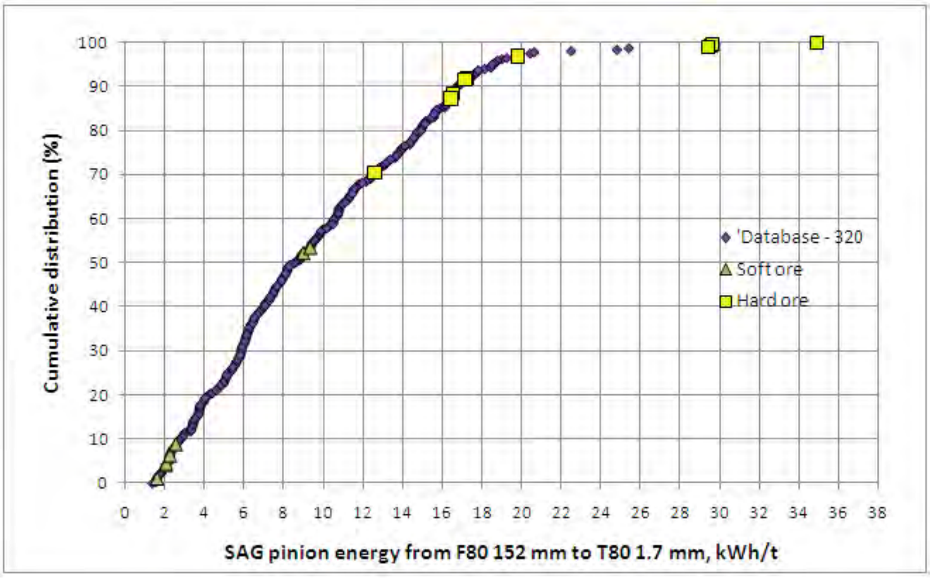

FIG 1 - SAG pinion energy versus cumulative distribution per cent of samples tested.

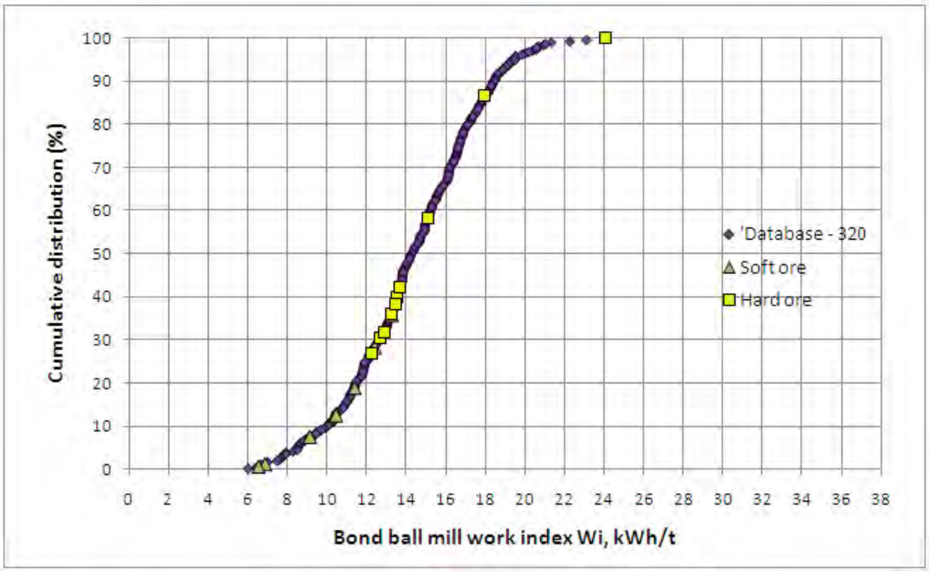

FIG 2 - Bond ball mill work index versus cumulative distribution per cent of samples tested.

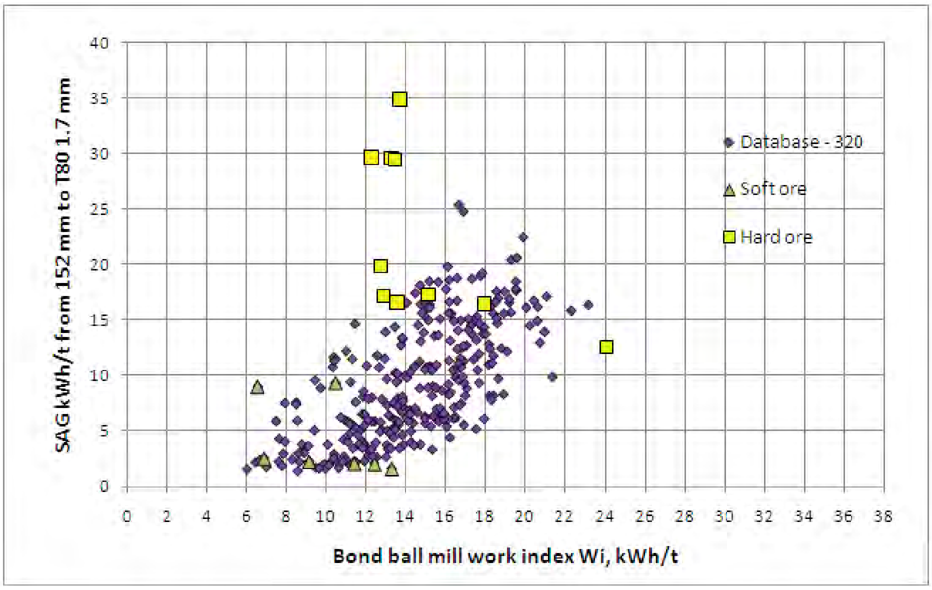

FIG 3 - Database SAG and bond data 2004 - 2009 with soft and hard ores added.

Figure 4 illustrates the usefulness in using the SAG to BWi ratio to determine power splits for new mills. Ore can be placed in a category that identifies what mode of flow sheet design is best. The soft ore quadrant (lower left) in general does not need pebble crushing because of its limited value in reducing SAG energy. On the other hand, ore in the upper right hand quadrant of Figure 4 should always use a pebble crusher to mitigate the high SAG energy requirement and to balance the work done in the two mills. Ores in the upper left quadrant are hard and competent but because the ratio does not exceed unity, there are a number of ways to design the mills. One good way is to design with no pebble crusher for ease of operation and leave a place in the layout to add a pebble crusher in the future if extra capacity is required.

The significant variability of the SAG to Bond BM Wi ratio, from 0.1 to 2.5 is a key to understanding what data is really required to design a new grinding plant. These measurements alone on a client's ore are needed. And by using calculation instead of simulation, any errors associated with comparing non similar ores are avoided.

Validation of SAGDesign test quality

An issue in data analysis for comminution circuit design is test work quality, which can be based on the accuracy and precision of the measurement. These analytical criteria are evaluated through test work reproducibility studies and benchmark projects.

Testwork reproducibility

In terms of precision, the reproducibility of the SAG test results has been verified 5 times to date.

Table 2 describes the existing SAGDesign test reproducibility studies. With reference to the table, the average absolute difference was calculated to be 1.2%. As defined by Starkey & Associates Inc., the acceptable relative error on any SAG test is 3.0%.

Benchmark projects

Currently, three benchmark projects have been performed. The objective of each project was to compare the SAGDesign test work results with the observed plant performance. The first benchmark project (S7) was performed with a 5.5 ft diameter pilot Nordberg SAG mill and the other projects (S36 and S53) were with commercial SAG mills of 16.5 ft and 28 ft diameter respectively. Table 3 presents a summary of the benchmark project results.

For each analysis, grind size requirements and ore feed rates were equated so that the comparison between SAGDesign results and observed SAG mill plant performance was based solely on the reported specific grind energy (kWh/t). The relative error between the plant data and SAGDesign results for the pilot plant mill and two commercial SAG mills were 8.2%, 2.7% and 1.5% respectively. The results from the 2 plant benchmark projects indicate that the accuracy of SAGDesign test results and mill sizing calculations are similar to reproducibility, i.e. +/- < 3%.

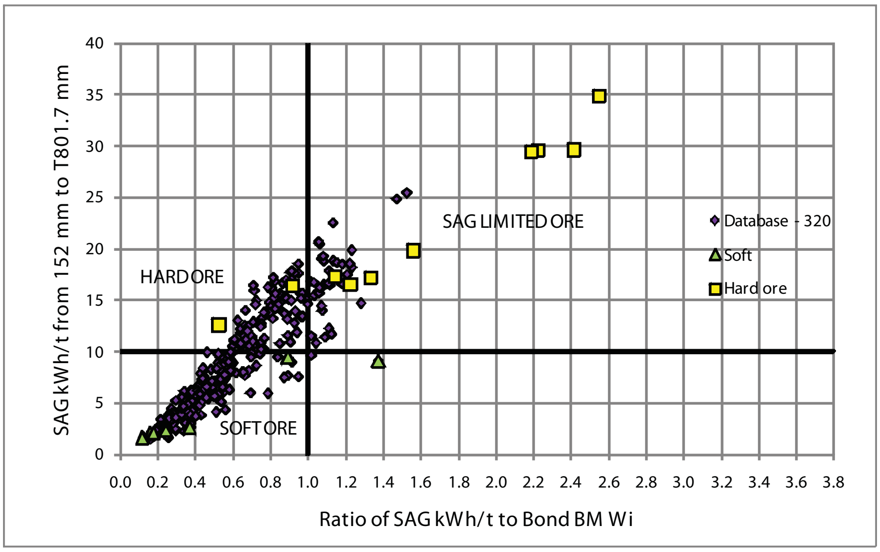

FIG 4 - SAG pinion energy versus ratio of SAG/bond BM Wi, with soft and hard ore added.

TABLE 2

SAGDesign test reproducibility.

Project Lab	Sample ID	SAG W	Relative Error
S3 – Dawson	Test 1	15.59	
	Repeat	15.63	0.3%
S5 – Dawson	Test 1	16.43	
	Repeat	16.58	0.9%
	Test 2	18.73	
	Repeat	18.79	0.3%
	Test 3	15.65	
	Repeat	16.13	3.0%
S46 – Starkey	Test 1	10.95	
	Repeat	10.77	-1.6%

TABLE 3

Benchmark sample SAGDesign results.

Proj.	Info source	Type of Feed	Feed (t/h)	Total (kW)	Sp. W (kWh/t)	F80 (mm)	T80 (mm)	Remarks
S7	Lab	3″ pieces from belt			14.97	152	1.70	Std. W for 6″ feed. Adjust lab to pilot plant sizes. Error ~ 8.2% Vs pilot plant
		(5.5 ft dia SAG mill)			15.44	127	1.00	
	Pilot	Crushed ore c/w fines	0.95	13.55	14.26	127	1.00	
S36	Lab	3″ pieces from belt			5.52	152	1.70	Std. W for 6″ feed. Adjust lab - 20% fine fd.+ 6% motor. Error ~ 2.7% Vs planT
		(16.5 ft dia SAG mill)			3.85	51	2.60	
	Plant	Crushed ore c/w fines	140	525	3.75	51	2.60	
S53	Lab	3m belt cut, crushed, split			14.15	152	0.16	Std. W for 6″ feed. Adjust lab - 10% fine fd.+10% motor Error ~ 1.5% Vs lab
		(28 ft dia SAG mill)			14.74	94	0.16	
	Plant	Crushed ore c/w fines	318	4613	14.52	94	0.16	

In addition, the credibility of the SAGDesign test has also been validated against other comminution testing methods. For project S34, the "hard" ore identified in Figures 1 to 4 was classified at the 98th percentile level of hardness in the SAGDesign, JK Dropweight and MacPherson databases respectively (Starkey & Samuels, 2010).

In 2009, the SAGDesign test work was acknowledged at the 2009 Australian Operator's Conference as follows:

> *"On recent projects dealing with competent ores, the SAGDesign approach has yielded similar outcomes to those using Morrell's approach (Morrell, 2008), and Ausenco's in-house design approach based on Bond work indices, A x b values and an empirical model of operating efficiency." (Bailey, Lane, Morrell, and Staples, 2009, p. 145)*

Effectiveness of test work and mill design program

SAG mill grinding design requires a simple concept: measure the coarse and fine hardness variability on every sample tested in an ore body and design a grinding mill circuit to match that ore body by first principles calculations. Accurate SAG pinion energy measurements can now be determined on any and all ores with the submission of a 15 kg sample for SAGDesign testing. The technology to make accurate mill designs for SAG and ball mills when used together is now available by testing 6 to 10 samples. This program is ideal for junior mining companies.

SAGDesign testing is a comminution test patented by Outotec, with numerous advantages: high degree of accuracy and precision; fast turnaround time with 2 months from purchase order to final design; cost effective at $3900 per design test and discounts available for variability tests (over

20 with a minimum of 40 tests); and guaranteed throughput and grind for Outotec supplied grinding mills designed by Starkey & Associates Inc. based on SAGDesign test data and protocols.

That a SAGDesign test is a "Standard Autogenous Grinding Design Test" has now been verified. (Starkey, J. *et al*, 2006). It works on all ores, is affordable because few tests are needed, and can be completed quickly.

GEOMETALLURGY

Geometallurgy, in the sense of measuring grinding hardness variability, is often misunderstood because the grinding hardness data used today is too expensive and time consuming to relate to every block of ore in a mine model. Sampling for grinding design is discussed above in this paper. The next level of detail is obtaining more variability data and some projects use as many as 200 or more samples for grinding testwork. But this is not geometallurgy unless the hardness variability measurements are correlated to a more basic assay or assays to give the correlation.

Wikipedia states that;

> *"Geometallurgy relates to the practice of combining geology or geostatistics with metallurgy, or, more specifically, extractive metallurgy, to create a spatially, or geologically based predictive model for mineral processing plants. It is used in the hard rock mining industry for risk management and mitigation, during mineral processing plant design. It is also used, to a lesser extent, for production planning in highly variable ore deposits." (Wikepedia 2010).*

This is a limited view of geometallurgy because if the measurements taken are not spaced at geo-statistically significant distances apart, the result will not be as accurate as hoped for. So while the above statement is helpful in describing what needs to be done to relate hardness to geology, the creation of an accurate predictive model may be incomplete in some cases.

There are two problems with using geometallurgy in the grinding field as it is practiced today. The first is cost - cost per test, and the number of tests required to be significant. The second is accuracy. To be valid for the stated purpose above, the grinding tests used must be accurate over the entire range of hardness variability for the deposit in question.

For a number of SAG hardness tests available, accuracy cannot be easily checked, only the relative SAG hardness when compared to other measurements from the same data set. To be valid, hardness measurements need to be checked by SAGDesign testing (or equal), to adjust the results to an accurate measure of SAG pinion energy required to grind the ore to 1.7 mm T80, and to determine the Bond BM Wi. For SPI testing, SAG hardness is underestimated in the hard ore range. For Dropweight and SMC testing, the SAG results can be higher than any operating plants (or "off the charts") when compared to operating mills. Simulations in either case are approximate, and especially if the ore is harder than treated by any plant in the JK Tech database.

It is recommended that the term geometallurgy be used with caution. To be valid, the actual hardness tests completed must be within acceptable spatial limits. There is value in defining ore hardness variability in greater detail with as many as 200 tests but even so, these results are not really a geometallurgical analysis until every block in the mine plan is represented by a real test or an inferred value based on correlation with an assay or some other much less expensive test.

For true geometallurgical analysis, many, more accurate, and less expensive measurements are needed. According to a respected industry expert, the cost to determine ore hardness variability should be in the order of $50 per test for the proper application of geometallurgy to grinding tonnage prediction in a large deposit. Looking ahead, the only way this might be possible today is for a number of accurate hardness measurements to be made and correlated with chemical analyses on the same samples. If a correlation can be found between assays, mineralogy, ore type and hardness, it may be possible to use this method to develop a true geometallurgical model for the mine. This has not happened yet but is being studied. The cost of doing accurate grinding tests such as SAGDesign for geometallurgy, would be justified in this context.

OUR CHALLENGE FOR THE FUTURE

The current indications in the industry are such that depending upon grinding consultant used, a different predicted plant throughput through the same equipment could be obtained. While it is desirable to select the most optimistic throughput this may in fact be proven to be foolhardy after construction.

The challenge currently faced by the grinding consulting industry is a lack of consistency and an erosion in the client's confidence in our ability to reduce risk through providing confidence in predictions made.

An industry standard set of grinding characterisation testing protocols backed up with benchmarking on operating plants and confirmed scaleup of paramaters is required.

Until consensus is reached, it is important that new grinding installations should be designed by using at least two technologies. One of these should be SAGDesign. It is the only SAG mill design technology being taught in Universities today. It is a hands on method involving the student as the designer. Only SAGDesign test results, and a personal computer with excel spreadsheet software are required. Simulation is not needed or the programs that power that method; the results will be the best available; and the mills will produce design tonnage if good samples were taken.

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