SAGDesign™ – Using Open Technology for Mill Design and Performance Assessments

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ABSTRACT

The advent of direct measurement of required pinion energy for SAG mills has created much controversy as to which method is best for the design of new SAG mills. Direct measurement using open technology is considered preferable to simulated solutions because the client can check the design themselves. To further complicate the issue, many closed and private technologies are used that make checking of a particular design difficult if not impossible without the purchase of expensive software, if available. For this reason, industry consensus among professional engineers demands that new designs be checked by at least two mainstream methods to provide adequate assurance that the design offered will work, and process the design tonnage at desired product size every day in the new plant. Too much faith in simulated design coupled with a lack of experience in its application can also result in increased start-up times due to the mill sizing being inferred and not calculated.

The author's position is unique having invented both SPI and SAGDesign technologies. The former is now private while the latter is open and being taught in universities around the world. The purpose of this paper is therefore to examine the use of SAGDesign technology as a valid method for determining the chamber size and power required for new AGB, SAB and SABC grinding circuits. Test accuracy, benchmark results and database summary information are included.

INTRODUCTION

The methods used to design SAG mills and SAG grinding circuits have been significantly upgraded in the last eight years. Direct measurements of SAG mill and ball mill pinion energy requirements are now available as test results from SAGDesign testing (patented technology). This fact puts the design of new mills in the hands of a client or his engineers and allows mill sizes to be calculated based on measurements of the hardness of the client's own ore. This is a first principles approach, conceived as a way to avoid problems caused by designing a grinding mill through simulations derived from indirect measurement methods, where subtle differences in the ore properties can create a less than optimal design due to the lack of operating parameters which do not exist for a new mill at the design stage. Simulation was originally conceived as a grinding optimization tool and gives very good results for optimization when the SAG mill (and ball mill) operating parameters are known. SAGDesign, on the other hand, was conceived as a grinding design measurement and has been proven to do this job very well because it measures the SAG pinion energy required in a commercial SAG mill and the Bond Ball Mill Work Index (BWI) on SAG ground ore, using the SAG product from the first stage of the laboratory batch test on a constant volume of ore.

The development of this new design system is now complete. The SAGDesign database presented here includes eight years of data on more than one hundred projects covering a wide spectrum of SAG and ball mill hardness variability, ore types, metals to be recovered, fineness of grind required, and tonnage variability from small to very large projects. Reproducibility of the SAGDesign test results is excellent and correlation with plant results is equally explicit in those cases that we have studied to date. The result of SAGDesign test development is a reliable way to measure and understand ore hardness variability, whether testing composites by year of production for design purposes, or testing point hardness samples using the new SAG Variability test to determine geometallurgical hardness profiles for the deposit.

A positive feature of the SAGDesign test that is different from other methods is that it can easily deal with composite samples based on yearly production or by vertical horizon where the advance of the pit face can be tracked to predict how the ore hardness will vary with depth and/or by mine plan. The corollary of this is that when time frames are short, fewer SAGDesign tests can cover the same production areas with fewer (well chosen) samples, to produce the same design result, when compared to other mainstream design methods. There are examples available where clients have used SAGDesign testing to minimize the lead time required to place a mill order for a new project.

SAGDESIGN TEST ACCURACY

The first question about any grinding mill design test work is: How accurate is the test? Test reproducibility in the same lab has shown SAG pinion energy measurements within ± 3% when duplicating the SAG test. When representative cuts of the same ore sample were sent to eight SAGDesign labs world-wide, the SAG pinion energy results showed ± 4.6% relative error, compared to the average SAG result from all eight labs. For the Bond Work Index on the same samples of SAG ground ore in the same eight labs, the maximum variability was ± 9.6% relative error from the average BWI value.

Table 1 SAGDesign test validation results from eight labs

Laboratory	SAGDesign Test Results		
	Specific gravity	W_{SAG} (kWh/t)	BWI (kWh/t)
A	2.85	7.30	8.88
B	2.82	7.71	10.00
C	2.86	7.68	10.52
D	2.86	7.17	9.76
E	2.86	7.28	9.42
F	2.82	7.17	10.32
G	2.85	7.18	9.19
H	2.84	7.51	9.75
Average	2.84	7.38	9.73
$ts/N^{0.5}$ (Cl = 95%)	0.01	0.19	0.46
Std. Deviation	0.02	0.28	0.55
Rel. error min	-1.0%	-2.9%	-9.6%
Rel. error max	0.6%	4.4%	7.5%

Table 1 gives the results for the lab benchmark testing project, sponsored by Outotec. The reproducibility of the SAGDesign test result in any lab is clearly shown by this work.

It is concluded from this validation program that the SAG pinion energy measurement (to grind the ore from F80 152 mm to T80 1.7 mm) for the SAGDesign test is within 5% of the correct mean value while the BWI measurement will be within 10% of the correct mean value. This accuracy for the BWI is standard for BWI and has been presented by others for crushed feed BWI testing. This is the first comparison work showing the reproducibility of SAG ground BWI testing.

BENCHMARK RESULTS

A total of seven benchmark results have been completed to date. One was a pilot plant result from a 1.68 m diameter Nordberg SAG mill test in Hibbing, Minnesota, one is not included in Table 2, and the other five were industrial plants, of which three were single stage SAG mills and two were various configurations of SAG and ball mills as indicated in Table 2 below.

Table 2 Details of plant benchmark testing

Project	Mill	Dimensions, m		SAG Feed		Prod.	Total W, kWh/t		%
No.	Type	Diam.	EGL	t/h	F80, mm	P80, μm	Actual	Predict*	Diff.
1	SAG	1.68	0.84	0.95	133	1049	15.40	16.77	8.9
2	SAG	4.75	1.52	140	51	2600	3.75	3.85	2.7
	+ 2 Ball	3.20	3.66		T80	240	12.41	11.90	-4.1
3	SAG	8.53	4.27	318	94	164	14.52	14.48	-0.3
4	SAG	5.49	9.14	135	142	83	26.00	28.15	8.3
5	SAG	5.49	9.14	131	119	69	31.71	29.42	-7.2
6	2 SAG	9.75	3.66	2204	152	3400	4.74	4.68	-1.3
	+ 4 Ball	6.10	8.53		T80	106	14.21	13.56	-4.6

**From SAGDesign testing of feed*

These results are presented below in graphical format. Figure 1 shows the actual SAG power observed in the plant plotted against the predicted SAG power from SAGDesign testing of the plant feed.

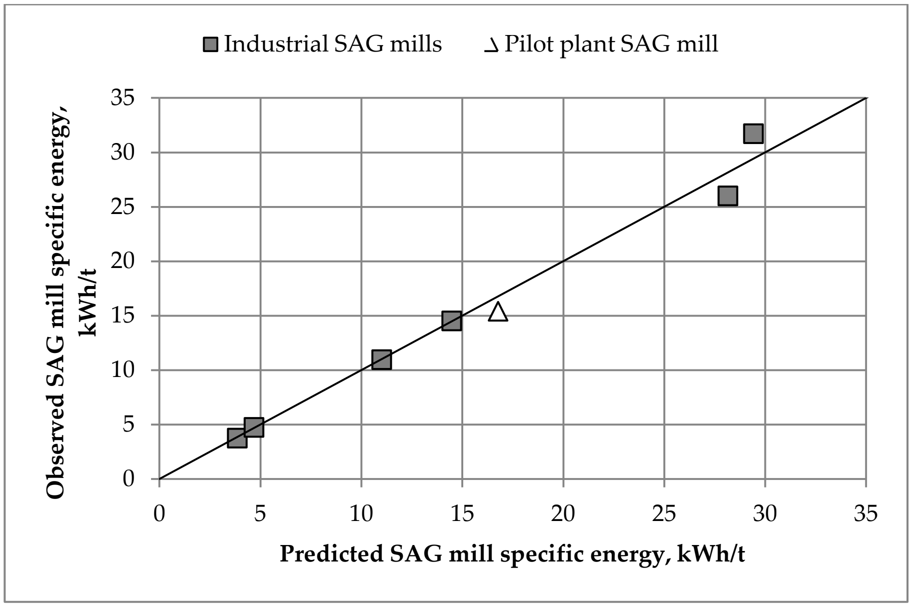

Figure 1 SAG actual vs. predicted power

Figure 2, on the other hand, shows the total observed power for the grinding circuit plotted against the predicted total power from the SAGDesign test on plant feed. The SAGDesign test includes a standard Bond Ball Mill Work Index test on the SAG ground ore from the first stage of the test. This allows one to design a SAG/ball mill circuit from the SAGDesign tests or in this case to confirm the plant performance and compare it to the measured power required to grind the ore.

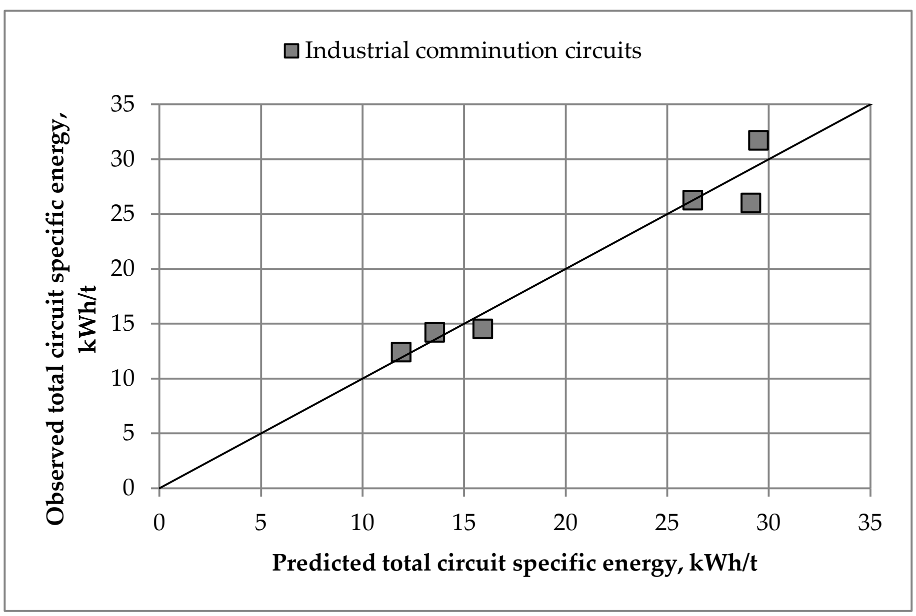

Figure 2 Total actual vs. predicted power

These benchmark results allow one to conclude that the accuracy of the SAGDesign tests shown in the previous section of this report can be duplicated in operating plants. If a plant is operating well, a benchmark test on the SAG mill's performance should not vary by more than 9% from the measured hardness while the total plant pinion energy should be within this limit as well. Considering the accuracy of a single test as proven by the corresponding plant result, it can also be concluded that when ten or more design tests are done on good composite samples representing the ore body by horizon or by mine plan analysis, the design of the grinding mills will be suitable to produce design tonnage from that ore body.

DATABASE SUMMARY

The SAGDesign database presented here includes eight years of data on more than one hundred projects covering a wide spectrum of SAG hardness variability from less than 1 to more than 30 kWh/t of SAG pinion energy that is required to grind an ore from a feed size F80 of 152 mm (6 inches) to a product size T80 of 1.7 mm (12 mesh US Std.), and Bond Ball Mill Work Index (BWI) measurements on SAG ground ore from less than 5 to over 26 kWh/t. It is noted here that BWI testing of SAG ground ore is not the same as BWI testing of crushed ore. Both results are usually close but not the same. Because the crushed BWI test crushes everything to minus 3.35 mm, the result is a little lower than the SAG ground BWI which preferentially grinds the softer materials first in the SAG mill and leaves the harder minerals to be ground in the ball mill.

The SAGDesign database from its inception in 2004 to May 31, 2012 is shown in Figures 3, 4 and 5. Figure 3 shows the results for 612 SAG tests in the SAGDesign database. 10% of all the samples were softer than 3.3 kWh/t, the median hardness is 9.1 kWh/t and 10 % of the samples were harder than 15.8 kWh/t.

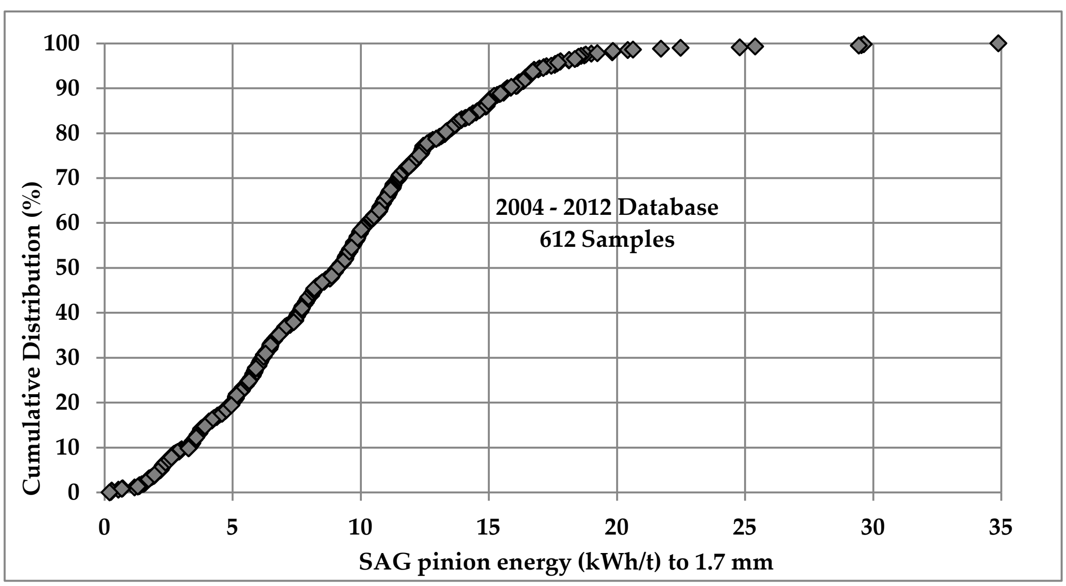

Figure 3 SAGDesign database - cumulative distribution % of SAG pinion energy

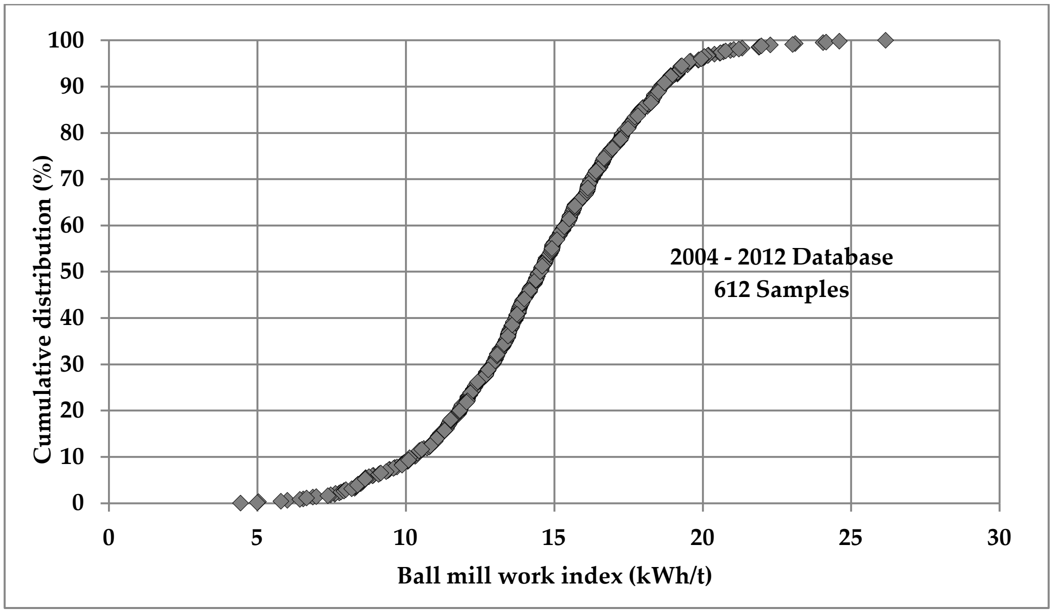

Figure 4 SAGDesign database - cumulative distribution % of Bond BWI

Figure 4 gives the results for the SAG ground BWI on the same 612 samples. 10% of these samples were softer than 10.2 kWh/t, the median hardness was 14.5 kWh/t and 10% of the samples were harder than 18.6 kWh/t. This database information is particularly useful because it includes SAG and BWI data on every sample. Prior to the commencement of SAGDesign testing, this kind of SAG and ball mill hardness data, on every sample in the suite, had never been published before.

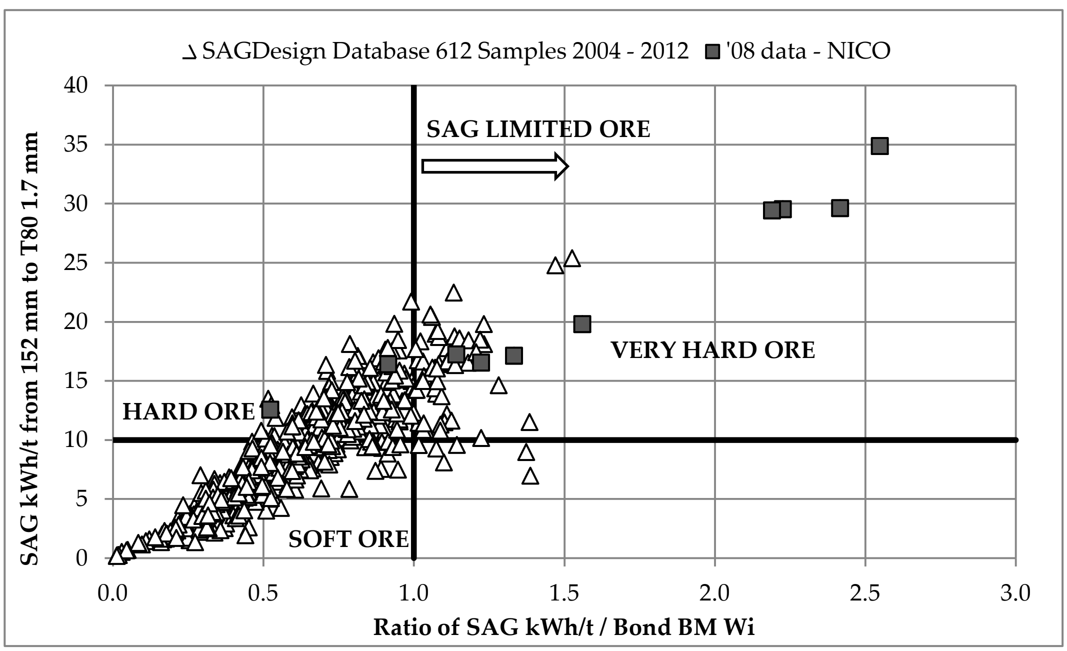

Figure 5 SAGDesign database - SAG kWh/t vs. Ratio of SAG kWh/t/Bond BWI

Figure 5 plots the SAG hardness in kWh/t against the ratio of SAG kWh/t divided by the BWI, also in kWh/t. This ratio when viewed as in Figure 5, shows whether the ore is SAG limited or not and allows classification of the SAG hardness into various ranges from soft to very hard. For the purpose of this discussion, hard ore in a SAG mill is considered to be over 10 kWh/t of pinion energy needed for the standard size reduction (from F80 152 mm to T80 1.7 mm), and very hard ore is harder than the 90th percentile (>15.8 kWh/t).

By understanding the ratio of SAG hardness to BWI, proper choices can be made when selecting the SAG to ball mill power ratio and the transfer size T80 which governs the power split. These measured hardness numbers are used to design the grinding mills, by calculation. By avoiding simulation, the inherent accuracy of SAGDesign testing can be used to good advantage.

MILL DESIGN

The SAGDesign method for designing SAG grinding circuits will now be discussed. The required SAG pinion energy to reduce primary crushed ore to a T80 of 80% passing 1.7 mm is the governing number for SAG mill design. Power adjustments for other T80 values are added or deducted from this basic number by calculation, using the BWI to calculate the adjustment. In the case of a single stage SAG mill the entire power increment to grind the ore to the final product P80 is added to the basic SAG pinion energy, measured by the SAG test. Since the BWI test is done at 100% passing 3.35 mm, adjustments to coarser sizes for the T80 are not straightforward and require additional factors to be added as defined by Bond (1961) in his original published work.

The T80 also determines the SAG/ball mill power split. Adjustments of the SAG T80 up to 3.4 mm and down to 300 microns are common. The balance of the required power is provided by the ball mill. Here, correction factors are applied when needed. The most common are the fines correction factor and the ball mill diameter correction factors. Both are defined by Bond in his original published work. The SAGDesign method uses these factors because field experience dictated that they are real. The benchmark work described above confirms that the diameter correction factor must be used in order not to overdesign the ball mills. When the correct SAG pinion energy is identified, the ball mill design can be done in this way. Required power as measured in the SAGDesign tests' two stages must be provided.

It is one exercise to determine the required SAG grinding energy and another to provide a mill chamber that will draw that power. The SAGDesign method uses in-house power draw calculation tables that were created from first principles to allow the assessment of power changes when ore SG, mill load, steel load or critical speed of the mill are varied. In this way one can quickly determine what effect varying SG or steel load has on the power draw, and how big a chamber is required to draw that power. Because this is open technology, these calculations are included in a report of mill sizing and a client or design engineer working on the project can confirm that the mill sizing is correct and that it will do the intended job.

Another advantage to using the SAGDesign method is that when the hardness variability function for an ore body is properly identified, the design point for the mills can be selected from the variability function. In practice, clients have elected to use hardest ore, 80th percentile, 65th percentile and median values for the SAG mill design point. In the latter case, an underground mine is usually involved because the many workplaces create a well blended feed to the SAG mill.

SUMMARY AND CONCLUSIONS

- The data presented in this paper is typical of what SAGDesign testing is capable of doing and has been doing over the past eight years.
- The establishment of test validity and benchmark testing relevance to operating results justifies use of SAGDesign testing as a grinding mill design method that merits inclusion as one of the two major design methods required in the grinding mill design for any new major project.
- SAGDesign testing is also excellent for performance assessment of existing plants.

NOMENCLATURE

AGB	Autogenous plus ball mill grinding circuit
SAG	Semi-autogenous grinding
SAB	SAG mill plus ball mill grinding circuit
SABC	SAG mill plus ball mill plus pebble crusher grinding circuit
SPI	SAG Power Index
F80, P80	Cumulative 80% passing feed size and product size respectively
T80	Cumulative 80% passing SAG mill discharge (transfer) size
BWI	Bond ball mill work index
W_{SAG}	SAG pinion energy to grind from F80 of 152 mm to T80 of 1.7mm
kWh/t	Electrical energy consumed per tonne of ground ore
SG	Specific gravity

REFERENCES

Bond, F.C. (1961) *Crushing and Grinding Calculations Part I, II,* British Chemical Engineering Press, vol. 6, No 6 and 8.