PAPER 31

Successful Design of the NICO Grinding Circuit for Unusually Hard Ore

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ABSTRACT

This paper examines test results and grinding mill design for the recent Fortune Minerals' NICO Project, located in the Northwest Territories. SAG milling and rod milling options are compared. Rod milling is clearly shown to be the best option because of the ore's extreme resistance to breakage in a SAG mill environment.

Surprisingly, the Bond Ball Mill Wi was 13 kWh/t for this ore. The Bond Rod Mill Wi was 20 kWh/t, whereas the SAG pinion energy to grind the ore to T80 1.7 mm was 30 kWh/t. The existence of ore with this ratio of SAG hardness to Bond BM Wi has not been previously observed. If not considered, this critical relationship may adversely impact the accuracy of mill design. This paper substantiates the significance of these findings to achieve successful grinding design on ore that is macro-competent during primary size reduction, but relatively normal during secondary grinding.

INTRODUCTION

The NICO Cobalt-Gold-Bismuth-Copper deposit is located 160 km northwest of the City of Yellowknife, Northwest Territories. It is the largest IOCG-type deposit (aka Olympic Dam-type) currently recognized in Canada with Mineral Reserves of 21.8 million tonnes contained within a larger 57 million tonne, lower-grade Mineral Resource. The project, owned 100% by Fortune Minerals Limited, has been assessed in a positive definitive feasibility study, subject to underground test mining and pilot plant testing, and is now in the permitting stage to develop a combined open pit and underground mine and process plant. An updated process flow sheet incorporates conventional crushing, grinding and bulk flotation, followed by filtration for shipment of a concentrate to a purpose-built refinery proposed to be built near Saskatoon, Saskatchewan. At the refinery, separate bismuth and cobalt concentrates will be produced following regrinding. The hydrometallurgical process methods include: pressure acid leach, precipitation, ion exchange, and electro-winning for recovery of cobalt as 99.8% cathode; solvent extraction and electro-winning of by-product copper cathode; ferric chloride leach and electro-winning for recovery of bismuth as 99.5% cathode; and cyanidation of the leach residues for recovery of gold as doré.

The unique nature of NICO ore in the comminution stage of the plant has been observed by various reviewers and analysts, using different testing methods to determine the grinding characteristics and propose suitable grinding circuits. The ore is extremely hard in the SAG mill stage of the process and only moderately hard in the ball milling stage. This presents challenges because traditional simulation methods do not account for the unique properties of this feed. Nevertheless, if SAG hardness measurements are correct, a reasonable result should be possible.

That ore hardness varies as the particle size decreases has been known for years in comparing rod mill and ball mill work indices, but what has never been documented previously is the difference in hardness between SAG mill feed and rod mill feed as determined by the respective tests. It is evident that the Drop Weight Test, the MacPherson Test, and the SAGDesign Test all determine SAG hardness, albeit at different analysis costs, sample size and turnaround time.

The use of simulation to determine grinding mill sizes means that the average engineer cannot determine exact mill sizes or power without the aid of complex computer programs and usually the input of professional people skilled in this particular kind of work. SAGDesign testing has proven to be helpful because mill designs presented in this paper include a calculation method that anyone can check. The introduction of engineering calculations into the SAG - ball mill design field will generate confidence that the mill design work done is accurate and reasonable, and that the mills will work.

This testing was completed at the request of Fortune Minerals to provide confidence in the evaluation of options and design of the NICO grinding circuit. The initial designs for this project were done for grinding capacities of 139 t/h or 3000 t/d, but the plant is now being built to process 215 t/h or 4,644 t/d. Three different methods for designing the mills were used and the two main ones are compared in this paper. They are the MacPherson simulation method and the SAGDesign calculation method.

NICO GRINDING TEST RESULTS

MacPherson Autogenous Work Index, Bond Rod Mill and Bond Ball Mill Work Index tests, JK Dropweight tests, and SAGDesign (SAG with Bond ball mill Wi on SAG ground ore) tests are included in this study. Table 1 presents the initial grinding data that was done prior to completion of the pilot plant conducted by SGS Lakefield for Fortune in 2007.

Table 1: Historical Grinding Test Results

Composite Sample	Ore Density	A	b	A x b	AWi (kg/h)	AWi (kWh/t)	RWi (kWh/t)	BWi (kWh/t)	Ai (g)
NICO 1999 - Upper	2.98	-	-	-	5.4	17.5	17.8	16.1	0.4173
Lower Ore Zone	3.37	100	0.22	22.0	-	-	-	12.1	-
Middle Ore Zone	3.32	100	0.22	22.0	-	-	-	10.5	-
Composite	-	-	-	-	-	-	17.5	-	-
DC-Comp	3.26	-	-	-	4.4	18.6	20.2	13.6	-

The Dropweight test results showed that this ore is in the top 98^{th} % of hardness variability. MacPherson results are Correlated AWi values, and are much lower than the tests actually showed so the ‘correlation’ should be checked again since ore of this nature has not been seen before in testing or in a plant. Certainly the raw measurements would place it in the 98^{th} % of samples encountered with respect to the MacPherson test mill feed rate. The Bond Rod Mill Work Index results range up to about the 75^{th} % of the SGS database variability but are not equal to the hardest ores ever seen in the rod mill test. On the other hand, the Bond Ball Mill Work Index results are very ordinary and are less than the 50^{th} % of the SGS database variability.

During front end engineering, these results were used to size the grinding mills required to treat 3000 t/d in 3 grinding mill configurations: namely SAB, SABC and Rod Ball. At the same time it was agreed by Fortune that more data should be gathered to ensure that the mill design conclusions were correct. SAGDesign tests were then done on 10 composite core samples selected to understand ore variability, including waste dilution. The results are presented below.

Table 2: SAGDesign Test Results

Sample No.	Description	Calc SAG Pinion W kWh/t	SG Solids g/cc	SAG Dis. Bond Wi kWh/t	Calc BM Pinion W kWh/t	TOTAL Pinion W kWh/t
		to 12 M			*to 74µ*	
1	Year 1 - open pit	16.6	3.16	13.5	12.5	29.0
2	Years 2 to 4 open pit & U/G	19.8	3.32	12.7	11.7	31.5
3	Year 1 - underground	29.5	3.26	13.3	12.2	41.8
4	Estimated hard ore years 2 to 4	17.3	2.93	15.1	13.9	31.2
5	Middle Zone - average	29.6	3.44	12.3	11.3	40.9
6	Deepest underground ore	34.9	3.30	13.7	12.6	47.5
7	*Ryolite waste*	*12.6*	*2.61*	*24.1*	*22.1*	*34.7*
8	*Porphyry / dike waste*	*16.4*	*2.74*	*18.0*	*16.5*	*32.9*
9	Year 5, beyond open pit	17.1	3.40	12.9	11.8	29.0
10	Ore bio-amph-schist	29.4	3.19	13.4	12.4	41.8
	Average of 8 ore samples	24.3	3.25	13.4	12.3	36.6

When it was realized that the design SAG pinion energies were in the 98th % of the SAGDesign database variability, it was decided to make three composites of soft, medium and hard ores to check the rod mill hardness in these ranges. The samples chosen and the rod mill data obtained are shown below in Table 3, and are compared with the corresponding SAG pinion energy needed to grind from F80 152mm to T80 1.7mm, and the Bond Wi (from the SAGDesign tests).

Table 3: Rod Mill Work Index on Same Samples as SAGDesign

Ore Composite	SAG W kWh/t	RM Wi kWh/t	BM Wi kWh/t	REMARKS
Hard 2 samples 3 & 5	29.6	19.7	12.8	Hard ore in SAG not detected in RM test, soft in BM
Med 2 samples 2 & 4	18.5	17.4	13.9	All ores are harder in RM Wi test than in BM Wi test
Soft 3 samples 1, 8, 9	16.7	17.6	14.8	Soft ore in SAG is hard in ball mill. SAG, RM ~equal
Feed F80 for Test	19	10	2	SAGDesign F80 is almost double rod mill Wi test

The hard ore composite represents information that has never been identified before – soft Bond BM Wi, quite hard RM Wi, and 'off the charts' for the SAG pinion energy (over the 98th % level). It is significant that both the drop weight and SAGDesign tests correctly identified the relative SAG hardness in the respective databases.

The results were then analyzed in order of increasing hardness and presented in Figure 1 below. Since the hardest sample was waste, it is clear that the average of the next three samples (all over 29 kWh/t of SAG pinion energy to achieve 1.7mm T80) represented the correct design hardness for the NICO project mills. And whether the total pinion energy (SAG plus ball mill) was sorted by increasing SAG, or by increasing total pinion energy, the result was the same.

Taking design numbers from this analysis shows that to grind to a T80 of 1.7mm (from 152mm F80) in a SAG mill will require 29.5 kWh/t in the SAG mill. When ball mill grinding is added, an additional 12.3 kWh/t is needed to grind to a P80 of 74 microns to feed the process.

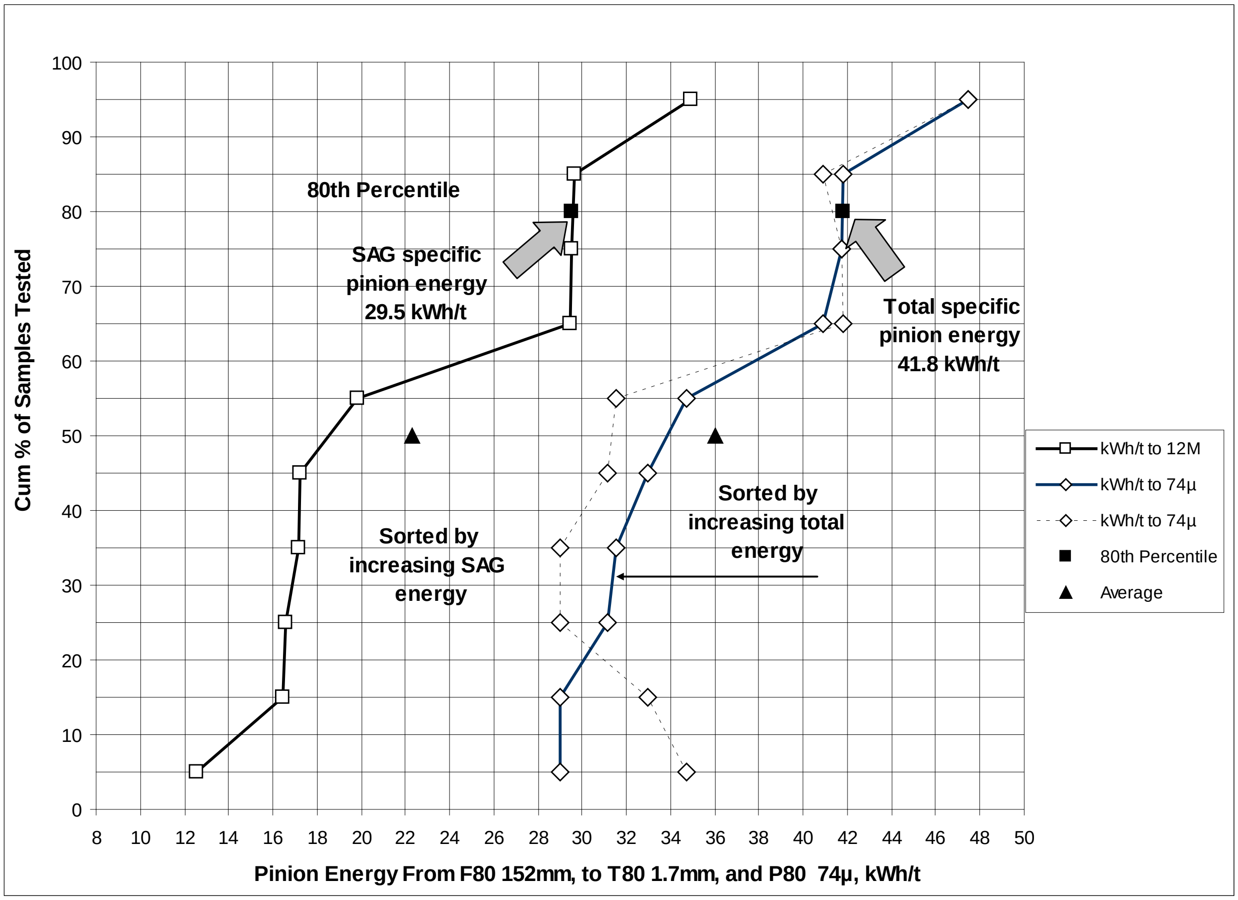

Figure 1 - Pinion Energy Variability for SAG Mill and Total - 10 Samples

DATABASE SHOWING NEW DISCOVERIES

Next, it is important to show how NICO SAGDesign results compare with the database. This is done in Figures 2, 3 and 4 below. Figure 2 shows that the hardest NICO ore (for design) lies above the 98th % of database variability. Figure 3, gives the Bond BM Wi variability. The hard ores in the SAG mill lie below the median Bond Wi hardness while the waste sample is quite soft in the SAG mill but extremely hard in the ball mill. The significance of this waste sample in determining SAG throughput is that the waste will not impede SAG throughput but will cause a larger circulating load and a slightly coarser final cyclone product in the ball mill circuit.

Figures 4 shows the NICO results by plotting the SAG pinion energy against the Bond BM Wi. Because of the shape of this graph, it was concluded that the ratio of SAG pinion energy / Bond BM Wi from the SAGDesign tests would be a key parameter to look at in deciding how to design a SAG circuit and particularly the power split between SAG and ball mill and the T80 relevant to this flowsheet. Figure 5 presents the SAG pinion energy from the SAGDesign test plotted against the SAG / Bond BM Wi ratio. The astonishing range of this parameter from 0.1 to 2.5 is a measure of how important it is to understand and use this ratio when designing mills.

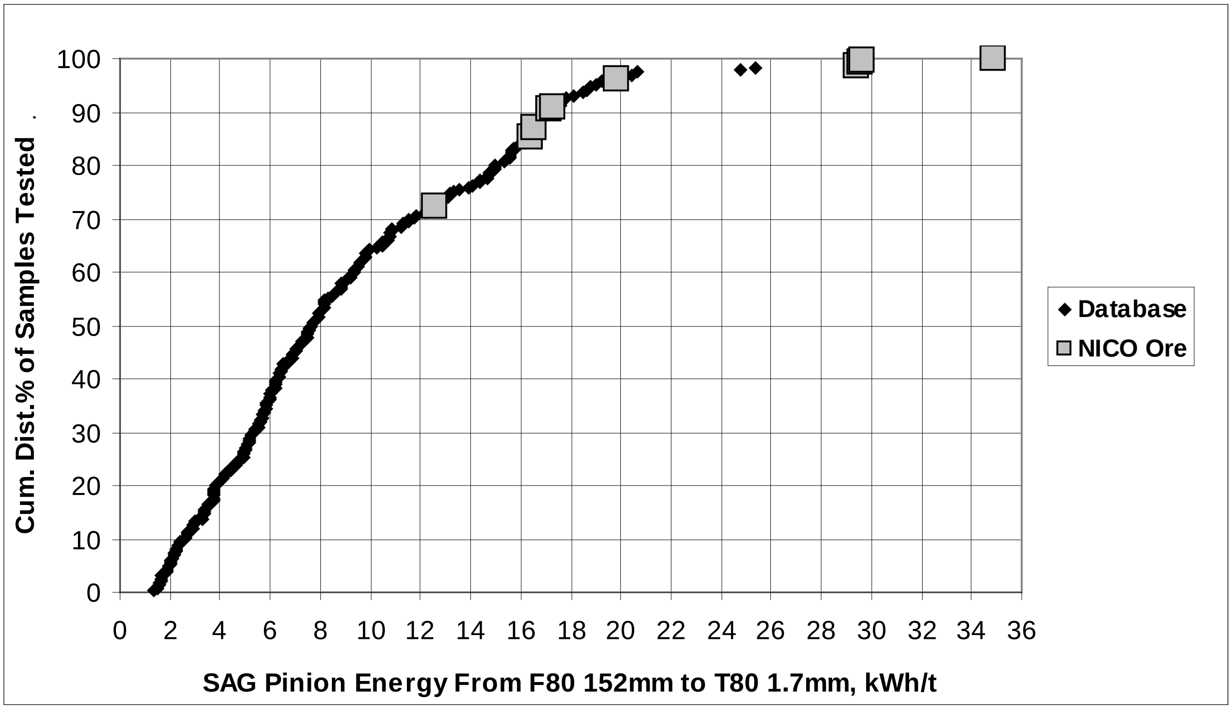

Figure 2: SAG Pinion Energy Vs Cum. Dist.% of Samples Tested

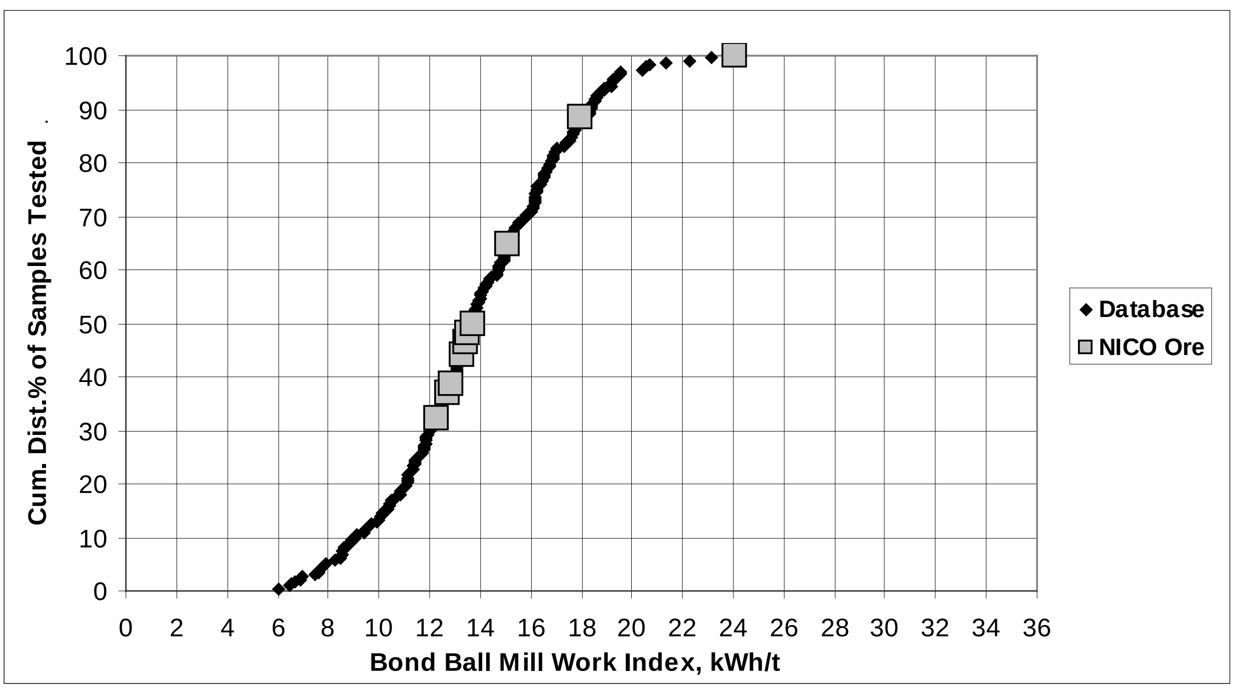

Figure 3: Bond Ball Mill Work Index Vs Cum. Dist% of Samples Tested

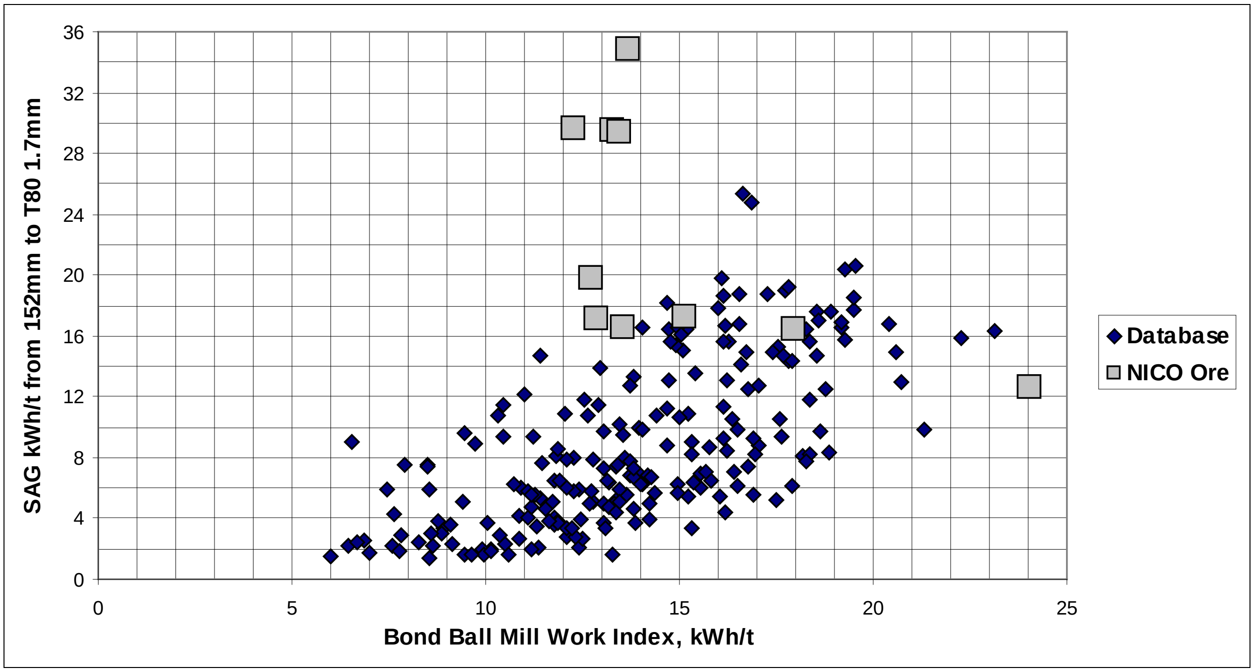

Figure 4 - Database SAG and Bond Data Showing Addition of Hard NICO Ore

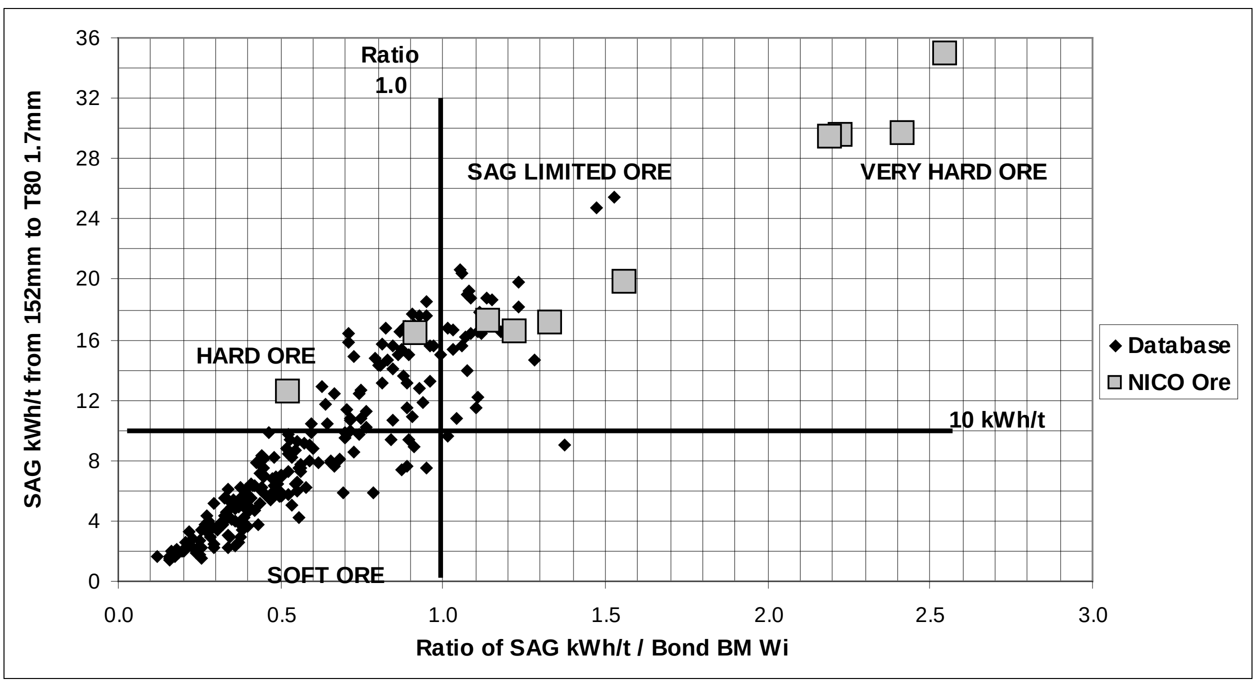

Figure 5 - SAG Pinion Energy Vs Ratio of SAG / Bond BM Wi, including NICO Ore

GRINDING MILL DESIGN AND SELECTION

The original feasibility evaluation was done for 3000 t/d in SAB, SABC, and ROD BALL configured circuits. To show the proper comparisons, the design data from the more recent SAGDesign testing, calculated at 4644 t/d, was reworked for 3000 t/d. The benchmark of 4644 t/d was chosen due to the need to evaluate four mills that Fortune owned at the Golden Giant Mine in Hemlo, Ontario. The results of this mill sizing work are given below in Table 4.

Table 4: Comparison of Various Grinding Mill Designs

CONFIG.	MILL	Diam ft	EGL ft	HP	Diam ft	EGL ft	HP	T80
		SGS MacPherson			S&A SAGDesign			
SAB	**SAG**	27	12	6000	28	12	6700	1700
3000 tpd	**Ball Mill**	13	19	1900	14	21	2300	
		SGS MacPherson			S&A SAGDesign			
SABC	**SAG**	26	10	4600	26	10	4700	1700
3000 tpd	**Ball Mill**	13	20.5	2100	14	21	2300	
		SGS Simulation			S&A Calculation			
ROD BM	**ROD**	11.5	16.5	1000	11	15	900	1266
3000 tpd	**Ball Mill**	14.5	19.5	2500	14	20	2300	
					S&A SAGDesign			
SABC	**SAG**				28	13	7400	1500
4644 tpd	**Ball Mill**				16	22	3400	
					S&A Calculation			
ROD BM	**ROD**				12	17	1300	1500
4644 tpd	**Ball Mill**				16	22	3400	
					S&A Calculation			
ROD BM	**ROD**	*Existing mill from Hemlo*			12	17	1300	1268
4644 tpd	**Ball Mill**	*Existing mill from Hemlo*			12	14	1300	
	Ball Mill	*Existing mill from Hemlo*			12	14	1300	
	Ball Mill	*Existing mill from Hemlo*			12	14	1300	

One main difference for the SAGDesign analysis was that the results were calculated in an Excel spreadsheet, using the T80 to control the required power split. This is based on the knowledge that the ore's comminution energy requirements must be satisfied and that the energy input will have the same variance in the SAG and ball mills (calculated from the Bond BM Wi) in the range of T80's above and below, but not far away from 1.7mm. In practice, this range is 0.3 to 3.4mm. A further estimation used was that the pebble crusher benefit for hard ore such as this would be about 30% of the measured SAG pinion energy determined in the SAGDesign test. For softer ores a lower adjustment (25%) for crushing benefit to SAG mill feed is normally used.

From this analysis in Table 4, the MacPherson simulation method gave slightly smaller mills and power for SAB and SABC circuits but gave a little more power and larger mills for the ROD BALL circuit. The SAB results show that the SAGDesign method provides ~ 14% more pinion energy. The SABC results are closer because a 30% energy reduction was used in the SAGDesign calculation. Close control of the crusher would be needed to achieve this consistently. An extra 9% has been provided in the MacPherson rod/ball simulation but not in the Starkey & Associates case because for the latter, the design criteria were precisely followed.

SUMMARY AND CONCLUSIONS

At 3000 t/d capacity, 9000 HP is required for SAB grinding mills, 7000 HP for the SABC mills (excluding the crusher) and 3200 HP for rod-ball mill configuration (also excluding crushing). The 4644 t/d plant will use 5200 HP connected to the four existing mills purchased from Hemlo.

NICO ore is so competent in SAG milling that the decision to use crush/rod/ball technology was correct in order to save energy in comminution.

The acquisition of the Hemlo grinding mills represented a good fit for the NICO project, even though one of the mills needed to be lengthened to achieve design capacity through the rod mill. The rod mill motor would be increased to 1300 HP, and Metso and General Electric confirmed that these modifications could be completed cost effectively.

The SGS simulation method for sizing the SAG and ball mill resulted in conclusions very close to the SAGDesign method. Both hardness measurements are considered to be accurate; whereas the difference in mill sizing is probably due to the reliance on model data for operational mills that are pushed much harder than recommended for good economics on liner and steel wear.

There are three different hardness ranges involved in grinding NICO ore: fine, medium and coarse, with changes occurring above 2 and 10mm. The rod mill work index value is needed for the rod ball mill circuit design, but it is not used by in the design of the SAG mill because the SAGDesign test covers this range when producing a T80 of 1.7mm in the test mill (and plant).

Dropweight, SAGDesign and MacPherson tests all identified the extreme hard nature of the NICO ore in SAG milling. The use of the correlated AWi (actual test results downgraded) is questioned because the resulting mills were 14% smaller (based on SAGDesign test results).

The SAGDesign method worked well because 10 good samples were taken for the analysis.

The complete correlation between MacPherson and JK Dropweight data was not presented, but the MacPherson results were reported as ‘slightly lower’ in the SGS report.

All methods used to design the NICO mills produced results for SAB and SABC grinding within 14% of total power required for installation. This can be considered as the difference between running steady tonnage and ‘pushing the limit’ to achieve design tonnage.

The SAGDesign method for designing the NICO grinding mills presents a solid case for doing mill design by calculation from empirical results on the client’s ore instead of simulation based on other ores. The method worked well on this very unusual NICO ore.

For best SAG mill design, test results on other ores can be used to complement the design process but are not specifically required for designing greenfield SAG/ball circuits.

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