

ARE SAG MILLS LOSING MARKET CONFIDENCE?

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ABSTRACT

Autogenous (AG) and semi-autogenous (SAG) grinding mills are considered a mature technology, so why are we seeing a number of recent projects not achieving nameplate capacity and is SAG technology losing market confidence, particularly in financial circles? This paper presents a critical review of underperforming AG/SAG mills based on public domain information comparing design expectations with actual operational performance. Actions taken in operations to mitigate the issues and optimise mill performance are listed, including a high level discussion on capital and operating costs.

KEYWORDS

AG/SAG mills, circuit design, plant performance, optimization

INTRODUCTION

AG or SAG mills have been in use in comminution circuits since the 1950's and are considered a mature technology in most countries. However, a reasonable number of recent SAG mill based projects have under-performed and not achieved throughput targets under their design conditions. This has resulted in reduction in confidence amongst project financiers in the ability of engineers' and consultants' to predict plant throughput for SAG mill-based projects, particularly in North America.

There are several well-established methodologies for designing and predicting energy requirements of AG/SAG based circuits. The recent problems originate either from unrepresentative sampling, poor testing protocols, inappropriate interpretation of data and definition of design criteria, wrong mill sizing methodologies, poor project management decisions or a combination of these.

Mining companies tend to invest more in understanding resources than in understanding metallurgy, of which comminution testing is a component. If the test work program is not adequately executed and interpreted, there are risks of establishing wrong design criteria and compromising the front end design.

The consequences of this are:

- A number of projects have underperformed and have resorted to spending additional capital to mitigate the problem (e.g. secondary crushing, high intensity blasting and/or barren pebble rejection).
- Some financiers are expressing less confidence in the designer's ability to predict the performance of AG/SAG mill based circuits and this has impacted on the ability of companies to obtain funding.

Bailey et al. (2009) published guidelines on the use of typical SAG mill-based circuit design methods, with particular focus on the use (and misuse) of JKSimMet. A follow up paper by Lane et al. in 2010 provided examples from three unnamed projects, then in development, that appeared to have under-predicted the required SAG mill specific energy and were likely to not reach design throughput.

This paper provides analysis and commentary on recent reports of under-performing projects based on data that is in the public domain.

UNDER PERFORMING PROJECTS

In the main, the throughput of copper concentrators is limited by one of the following principal causes:

- Lack of ore from the mine
- Lack of water, through design or natural causes
- Issues with power supply
- Major mechanical failure, or
- Under estimation of the capacity of the crushing and/or grinding circuit.

Whilst downstream limitations, such as concentrate or tailings handling capacity occur occasionally, these have not been as prevalent as under estimation of the capacity of the crushing and grinding circuit.

Historical Examples

Barrett (1983) stated that “the milling rate is the most significant parameter, next to mineral recovery, which is watched closely by senior executives and financial managers”. However, despite this widespread recognition of the significance of throughput on the financial performance of a project, there remain a small but significant proportion of projects, both historically and in recent times, that have failed to achieve the nominated design throughput in a timely manner, often requiring expensive and time consuming plant modifications before the project design parameters are achieved.

There are numerous projects that have underperformed to some degree in the past, albeit that most projects using AG and SAG mills have performed to expectations. Three examples of similar scale are discussed below, one from each of Australia (Cadia), South America (Sossego) and North America (Phoenix). Cadia was commissioned in 1998 (Dunne et al., 1999, 2001), Sossego in 2004 (Delboni et al., 2006) and Phoenix in 2006 (Castillo & Bissue, 2011). Pilot plant trials were conducted on ore from each of the projects. Summary design criteria are provided in Table 1.

Design ore competency increased from Cadia to Sossego to Phoenix. Cadia’s issues were associated with scale up of pilot plant data (including the impact of pilot sample selection method). Sossego’s issues were similar to Cadia’s, but compounded by liner and grate design issues. Unlike Cadia and Sossego, Phoenix’s issues were only overcome with the addition of secondary crushing prior to SAG milling.

Table 1 - Summary of design criteria for the Cadia, Sossego and Phoenix projects.

Parameter	Unit	Cadia ¹	Sossego ²	Phoenix ³
Throughput	kt/d	na	41.0	33.6
	t/h	2065	1841	na
Breakage properties				
A x b		36	33	na
ta		0.5	na	na
CWi	kWh/t	23.6 *	na	na
RWi	kWh/t	16.3 *	na	na
BWi	kWh/t	17.1	16	na
Ai	g	na	0.48	na
Circuit type		SABC	SABC	SABC
Target P80	µm	150	210	na
Primary crusher				
Number	#	1	1	1
Model	pol	60 x 113	60 x 89	50 x 60
SAG mill				
Number	#	1	1	1
Diameter	m	12.0	11.6	11.0
EGL	m	6.1	7.0	5.0
Power	MW	20	20	13.4
Specific energy	kWh/t	7.8	10.8	na
Pebble crusher				
Number	#	2	2	1
Model		MP1000	MP800	MP800
Ball mills				
Number	#	2	2	2
Diameter	m	6.7	6.7	6.4
EGL	m	9.5	9.8	10.0
Power	MW	9	16	7
Specific energy	kWh/t	7.95	8.7	na

Note: Adapted from:

¹ Dunne et al. (1999, 2001), Engelhardt et al. (2011)

² Delboni et al. (2006)

³ Castillo & Bissue (2011)

* calculated average for monzonite ore, the actual design RWI was 19 kWh/t

Cadia

The Cadia project (Dunne et al., 1999, 2001) treated a low grade (0.17% Cu and 0.74 g/t Au) and competent (A x b = 36, BWI = 17.1 kWh/t) ore. Pilot trials were completed on samples obtained from adits and benchscale test work was conducted on a range of samples. The project required a low capital cost approach and opted for a single line based on a 20 MW SAG mill instead of two parallel lines of smaller

SAG mills. The design SAG mill specific energy was calculated on the basis of the pilot plant results, supported by analysis of the bench-scale test work. Estimates of SAG mill power requirements had varied greatly, from as low as 13 MW to more than the 20 MW that was installed. A 20% “contingency” was applied to the pilot plant data when selecting the SAG mill shell and motor size. Upon resolution of issues related to the mill motor and lifter design, the project only just managed to achieve the target throughput of 17 Mt/y (Figure 1). The contributing factors to higher than expected SAG mill specific energy (lower throughput) were:

- the low pebble recycle rate in the plant (an average of 24% of new feed) when compared to design (35% of new feed) and up to 60% of new feed in the pilot plant,
- the energy intensive blasting and resultant size distribution of the pilot plant feed,
- poor understanding of scale-up factors from 6 foot diameter pilot plant mills to 40 foot diameter plant mills.

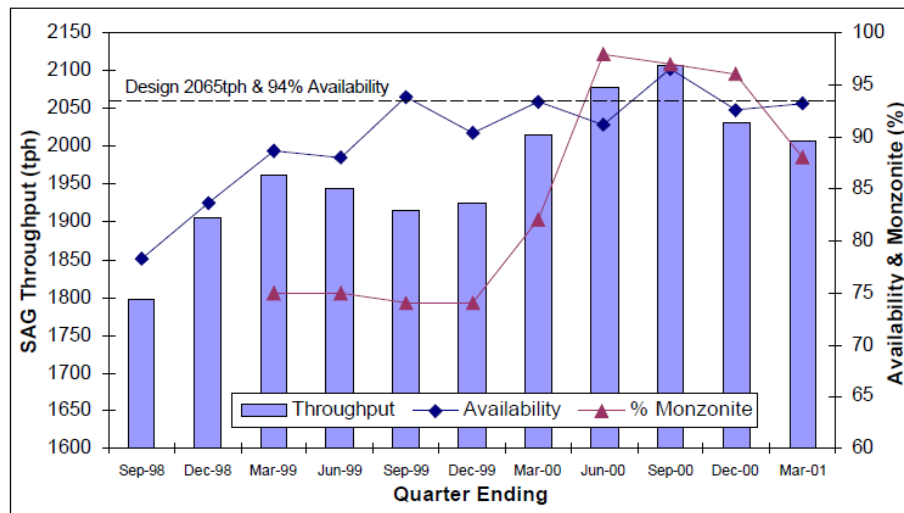


Figure 1 – Cadia throughput and availability during ramp up. Reprinted from Hart et al. (2001).

Pilot plant mills can have very different breakage and discharge functions than large mills and the impact of this on specific energy can be significant, particularly if the discharge performance in the SAG mill is not carefully considered.

Sossego

The Sossego project (Delboni et al., 2006 and Bergerman et al., 2009) treated a higher copper grade (1.0% Cu and 0.3 g/t Au) and competent ($A \times b=33$, $BWI=16$ kWh/t) ore. A comprehensive pilot plant campaign was carried out under various grinding circuit configurations and operating conditions, using Sossego and Sequeirinho ore samples. The use of high ball charge and pebble porting was adopted for increasing the overall performance of the circuit. The project was the first copper operation for Vale and opted for a single SABC line with one 20 MW SAG mill and two 8 MW ball mills, which was supported by analysis of the pilot scale test work.

The Sossego plant ramp-up period started in the beginning of 2004 and by the second half of that year, only low throughputs were being achieved in the grinding circuit. The main factors attributed to the underperforming mill were reported as:

- coarse size distribution from the primary crusher due to the high abrasiveness of some ores,
- limitations in SAG mill speed due to severe breakage of mill liners at higher speeds,

- low rate of pebble extraction and several modifications in the grate design and grate open area,
- high variability in ore characteristics, resulting in large variations of circulating loads at both grinding stages.

Different combinations of SAG mill ball charge and grate open area were tested until 2006. A higher load level was achieved after several changes in the grate design that prevented both liner and grate breakage. Upon resolution of issues related to the mill grate design, the project achieved the target throughput of 41 kt/d.

Phoenix

The Phoenix project (Castillo & Bissue, 2011) treated a low copper grade (0.18% Cu, 0.79 g/t Au and 8.43 g/t Ag) and highly competent ore with DWI values in the range of 8.2 - 9.9 kWh/m³, equivalent to Axb values less than 30. A single SABC line was selected for the grinding circuit, with the SAG mill motor rated at 13.4 MW and two ball mills each powered by a 7 MW motor. The plant ramp-up period started in 2006 and in 2009 the design throughput was yet to be achieved. The reported contributing factors were reported as:

- the high primary crusher liner wear due to the excessive hardness and abrasiveness of the ore,
- the uneven size distribution obtained from different feeders of the coarse ore stockpile,
- lack of impact breakage due to a high rock to ball ratio,
- inability to choke feed the pebble crusher,
- inefficient operation of the ball mills due to high circulating load and high bypass of fines in the cyclones.

A Mine-to-Mill study was conducted to improve the grinding circuit operation and the main recommended actions included:

- the use of a variable primary crusher closed-side-setting (CSS) depending on the ore type,
- control of the grinding media volume based on wear rates within the SAG mill,
- increasing the grinding media load in the SAG mill,
- the use of a blend of ball mill balls to increase finer size particles and smaller cyclone apex.

These recommendations did not result in improvement in mill throughput after implementation. Therefore in 2010, Phoenix project conducted industrial trials of a secondary crushing stage which resulted in a 7% increase in throughput. Further simulation studies showed that a 13% increase in mill throughput could be achieved and that the secondary crushing was effective in handling very hard ores.

The common theme with these projects was that the ore was competent and the pilot plant data predicted lower SAG mill specific energy outcomes than the plants achieved with SABC circuits.

Recent Projects That Have Underperformed at Start-up

Five recent major projects that reportedly did not meet design throughput on start-up are:

- Copper Mountain
- Andacollo
- Mt Milligan
- Esperanza
- Malartic

Scotia Bank (2012) outlined the benefits of secondary crushing for “debottlenecking” Copper Mountain, Malartic and Andacollo due to lower than expected throughput.

The above projects, including the historical cohort, represent a minority of the projects developed using SAG mills in comminution circuits. However, all of the listed projects treated ore of above average competency, are generally of modest head grade and, hence very sensitive to project capital and operating costs.

Copper Mountain

The Copper Mountain project (Chance et al., 2009; Marks et al., 2011) was designed to treat a copper and gold (0.45% Cu and 0.13 g/t Au) competent ore. The criteria for the plant design were based on a combination of metallurgical test work results and historical operational data experience from other similar operations. Breakage testwork indicated A x b values of 23 for ores from pit 2 and 20 for ores from pit 3, with ta values of 0.19 and 0.16, respectively. The selected circuit configuration was SABC and mill design parameters are presented in Table 3. The Copper Mountain concentrator, which started operation in the summer of 2011, had problems reaching the design throughput of 35 kt/d. The experiences at Copper Mountain were discussed in various articles as summarised below.

Scotia Bank (2013) described some of the site experiences at the time: “Their 34’ SAG mill was supposed to do 38.0 kt/d but due to what Jim O’Rourke calls ‘friability’ of the hornfels and albitized-metamorphic rocks at Copper Mountain – fracturing of their ore is not as efficient as what was expected. Now the focus on ‘efficient size reduction’ starts with the mine by increasing the powder factor from 0.3 kg/t to 0.6 kg/t while tightening the blast grid. ... the company believes both the ‘high intensity blasting’ coupled with contractor crushing should push tonnage towards the design capacity...”

Gager (2014) stated that the main issues at Copper Mountain were both the operating time in the plant and also achieving the target design milling rate. He also stated that “...a number of changes to provide a finer feed to the SAG mill were made and that resulted in improved throughput.” This included utilizing three portable crushers to crush the fraction of the ore from the primary crusher that is minus 6-inch size to minus 2-inch material, which improved the tonnage that the facility could process daily. Throughput increased from approximately 25 kt/d during the first quarter of 2013 to an average of 32.7 kt/d in December; a 30 percent improvement. However, engineering studies confirmed that a permanent secondary crusher was required to allow Copper Mountain to achieve the design target or better.

In 2014, Scotia Bank (2014a) published that “... on August 20th (2014) – the operation was cruising at between 1,500 to 1,700 t/h or 36.0 to 41 kt/d.”

Figure 2 illustrates the impact of the proportion of minus 25 mm material on SAG mill throughput, with the throughput at 30% passing 25 mm nearly half that at 52% passing 25 mm. Typical SAG mill feed from a large primary gyratory crusher for ore this competent is at the coarse end of the range.

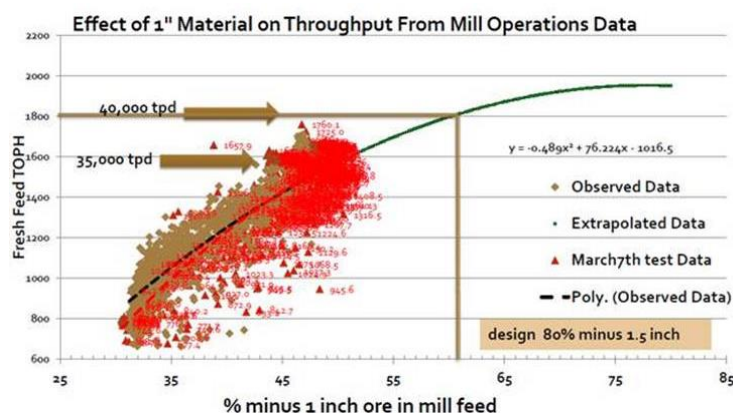


Figure 2 – SAG mill throughput versus feed size. Reprinted from Scotia Bank (2014b).

In summary, the high competency of the ore resulted in below design mill throughput being achieved and required considerable remedial actions, including high intensity blasting, the installation of partial and finally full secondary crushing to produce a finer SAG mill feed and reduce the SAG mill feed size to allow the operation to achieve design throughput.

More recently, Jim O'Rourke, president and CEO of Copper Mountain (2015), remarked "We are very pleased with the increased SAG mill throughput being achieved with the finer feed from ... secondary crusher. Mill throughput of 37.7 kt/d average ... is a 29% increase in tonnage over the first quarter of last year. The steady improvements in mill throughput and reduced site operating costs achieved this quarter position the Company well going forward."

Andacollo

The Andacollo project (Watson, 2010; Griffith & Libby, 2006; Gonzalez, 2010) treats a low grade (0.38% Cu and 0.13 g/t Au), competent ($A \times b = 23.8$, $BWI = 14.9$ kWh/t) ore. Samples obtained from the existing mining operation were used for pilot plant testwork. The hypogene material characteristics were utilised as input for designing the processing plant. The selected circuit configuration was SABC and mill design parameters are presented in Table 2. The Andacollo concentrator, which started operation in the beginning of 2010, had a design throughput of 55 kt/d. During the mill ramp-up this operation struggled to reach target throughput, as shown in the Figure 3. Design throughput was finally achieved after the introduction of secondary crushing.

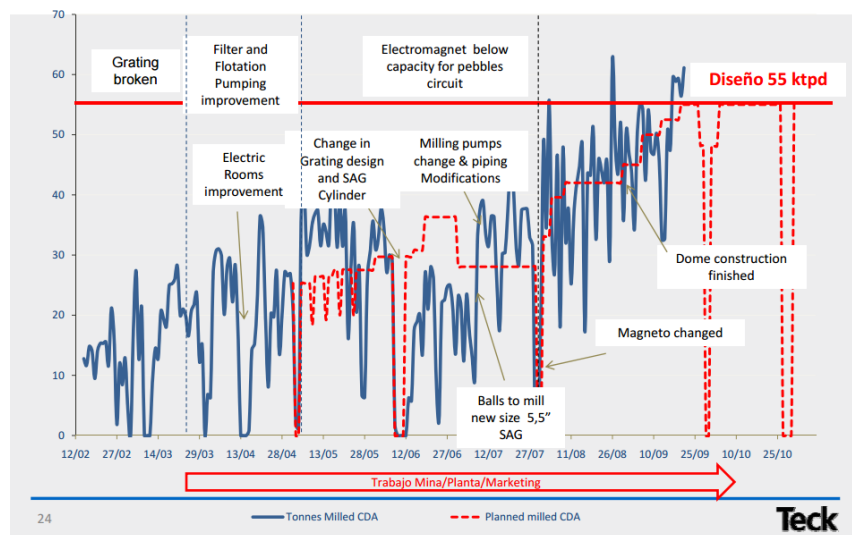


Figure 3 – Andacollo throughput during ramp-up. Reproduced from Gonzalez (2010).

Mt Milligan

Mt Milligan (Mills et al., 2009) has a low grade (0.20% Cu and 0.39 g/t Au) and competent ore. Between 1989 and 2007, various metallurgical testing facilities undertook test work to determine the grinding characteristics of the ores from various mineralization zones as well as a pilot-plant grinding test program consisting of three pilot-plant runs.

The breakage parameters presented in the report for testwork on composite samples conducted in 1995 indicates an $A \times b$ of 21.3 for one composite sample and 24.2 for another composite sample, both

with BWIs of 19.9 kWh/t. The design parameters obtained from this testwork and the main features of the equipment selected for the SABC circuit are summarised in Table 2.

The SABC grinding circuit had a design rate of 60 kt/d (Moore, 2014). Production started in mid-2013. However, the operation did not manage to achieve anywhere near target throughput within the 6 months of operation, as shown in Figure 4.

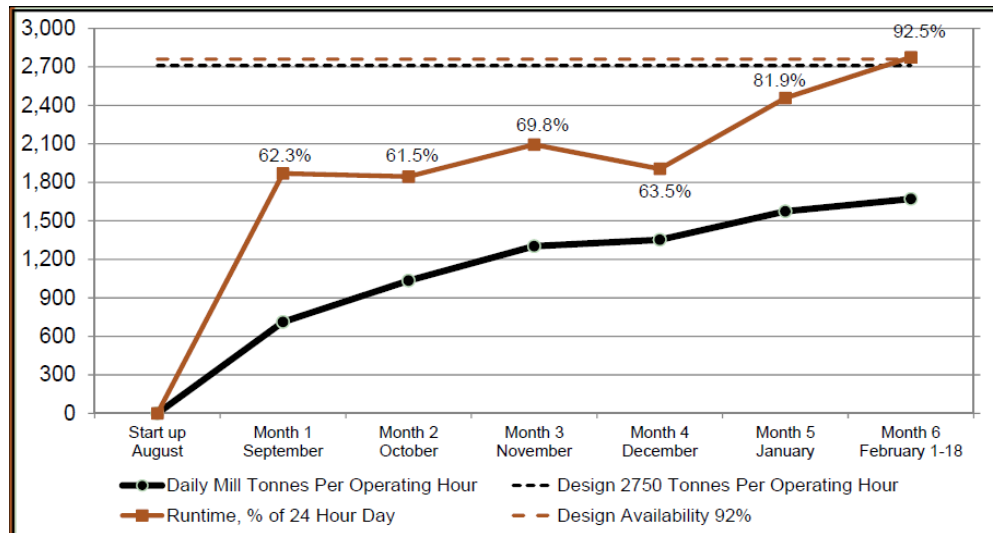


Figure 4 – Mt Milligan throughput during ramp-up. Reproduced from Thompson Creek (2014).

Esperanza

The Esperanza project (Villanueva & Soto, 2014; Ahumada, 2012) was designed to treat a low grade copper (0.5% Cu) and competent ore at high daily throughput of 97 kt/d. Upon resolution of issues related to the tailings thickener, the project only just managed to achieve the target throughput. The contributing factors were:

- highly variable ore competency as measured by JKDWT A x b parameter, ranging from 25 to 50,
- SAG mill performance was highly dependent on feed size, which varied according to the level of macro fracturing in the ore body.

Although Esperanza only managed to reach an average throughput of 86 kt/d in 2013, the project was seeking to increase the approved processing rate of 97 kt/d to an average of 105 kt/d, with the maximum set at 110 kt/d. The optimizations planned for this purpose include constructing a new fine crushing plant, implementing a new cleaning stage into the operation and incorporating a 3.2 MW backup power plant for the tailings thickening area, along with various other infrastructure improvements (Demo-Dananberg, 2013).

Malartic

The Malartic project (Osisko, 2008) treats a medium gold grade ore (1.07 g/t Au and 1.69 g/t Ag). Samples were selected to give a good representation of the ore zones in the deposit and submitted to breakage tests (SMC, DWT and BWi). The breakage testwork indicated moderate to competent ores, with an average A x b of 38.2, average BWI of 14.2 kWh/t and average Ai of 0.56 g.

The project commenced its production in early 2011 when they experienced high production costs due to low head grade ore (0.65 g/t Au) and inefficiencies of the plant during the ramp-up period (Osisko

Mining Corporation, 2011), as presented in Figure 5. Design throughput was achieved after almost a year of operation.

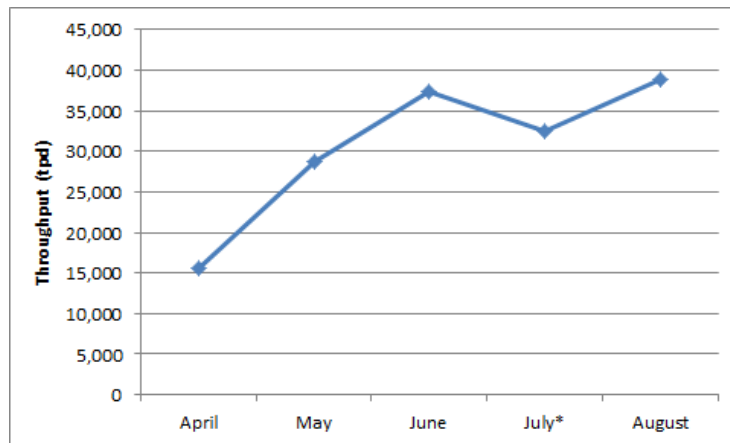


Figure 5 – Malartic throughput during ramp-up. Adapted from Osisko Mining Corporation (2011).

To address the throughput issue, Malartic installed a second pebble crusher well as two secondary cone crushers in 2012 to allow for throughput expansion to 60 kt/d (Lazenby, 2012).

Table 2 – Summary of design parameters and equipment data of recent projects.

Parameter	Unit	Andacollo ¹	Mt Milligan ²	Esperanza ³	Malartic ⁴
Throughput	kt/d	55.0	60.0	97.0	55.0
Breakage properties					
SPI	min	94	na	na	na
A x b		23.8	na	na	38 ⁵
ta		0.31	na	na	na
CWi	kWh/t	5.7	na	na	na
RWi	kWh/t	16.2	na	na	na
BWi	kWh/t	14.9	20	na	16.1
Ai	g	0.18	0.254	na	na
Circuit type		SABC	SABC	SABC	SABC
Target P80	µm	150	220	212	64
Primary crusher					
Number	#	1	1	1	1
Model	pol	60 x 89	60 x 110	60 x 113	60 x 89
SAG mill					
Number	#	1	1	1	1
Diameter	m	11.0	12.2	12.2	11.6
EGL	m	5.8	6.7	7.9	6.4
Power	MW	13.4	22.0	22.4	19.4
Pebble crusher					
Number	#	2	2	3	2
Model		na	na	na	na
Ball mills					
Number	#	2	2	2	3 *
Diameter	m	7.6	7.3	6.7	7.3
EGL	m	12.0	12.5	14.3	11.1
Power	MW	2 x 7.1	13.0	18.6	2 x 6.0

* two secondary and one tertiary ball mills

Note: Adapted from

¹ Watson (2010) and Griffith & Libby (2006)

² Mills et al. (2009)

³ Ahumada (2012) and Villanueva & Soto (2014)

⁴ Osisko (2008)

⁵ Feasibility Study, December 2008

ANALYSIS

All of the projects that experienced throughput issues were treating competent ore. Some completed pilot plant trials to determine SAG mill specific energy requirements.

The Copper Mountain project was preceded by the Similco project treating ore from similar locations (Pits 2 and 3), albeit higher grade. The design and operating data are summarised in Table 3.

Table 3 –Similco and Copper Mountain design parameters and equipment data.

Parameter	Unit	Similco 1972	Similco 1975	Copper Mountain 2007
Throughput	kt/d	13.6	18.8 ¹	35.0
Cu	%	1.08	1.08	0.35
Breakage properties				
A x b		na	na	na
ta		na	na	na
RWi	kWh/t	na	na	20
BWi	kWh/t	na	na	22.3
Circuit type		SS SAG ²	SAB ³	SABC
Target P80	Mm	na	0.10 - 0.12	0.15
AG/SAG mill				
Number	#	3	3	1
Diameter	M	9.75	9.75	10.4
EGL	M	4.27	4.27	5.0
Power	MW	2 x 3	2 x 3	2 x 6.4
Grate size	Mm	19	19	32 and 55
Ball top size	Mm	100	100	na
Ball charge	%	6	6	15
Specific energy	kWh/t	na	20.5	8.0
Ball mills				
Number	#	-	2	2
Diameter	M	-	5	7.3
EGL	M	-	7.9	12.1
Power	MW	-	3.7	12.8
Specific energy	kWh/t	-	9.2	16.0

Note: Adapted from Marks et al. (2011).

¹ Average throughput between 1983 and 1992

² Design AG mill with pebble crusher converted to single staged SAG mill without crushing

³ The circuit throughput was limited by the SAG mill, so in 1983 a pebble crusher was installed

The following quoted information was sourced from Barrett (1979, 1983) and McPherson (1977).

Previous operations at the Copper Mountain deposit (as also known as Similkameen) were undertaken by Similco, beginning operation in 1975. The initial Similco operations selected three single stage AG mills with pebble crushers. The ore was identified to be variable, “containing bands of hornfels with Bond work indices ranging from 22.8 to 30.3. It was estimated that a rod mill - ball mill combination would consume 16-17 kWh/ ton [short].” Shortly after the commencement of operations, it became clear that the single stage AG mills could not achieve the desired throughput and they were ultimately converted to single stage SAG mills, with ball addition levels of between 7% and 8%, and a power consumption of “about 24 kWh/ton.” The addition of steel to the mills resulted in operational issues with the pebble crushers and these were bypassed and eventually removed.

“ According to MacPherson (1977) “The Similkameen plant in British Columbia ... has been grinding a tough copper ore in single stage semi-autogenous mills to produce a product containing 60% - 200 mesh, which can be sent directly to flotation . This ore was stated to have a Bond Work Index of 23 and very high steel consumption when ground in rod and ball mills. The work in the 450-mm mill indicated an Autogenous Work Index of 45, which is one of the highest obtained in any work to date.”

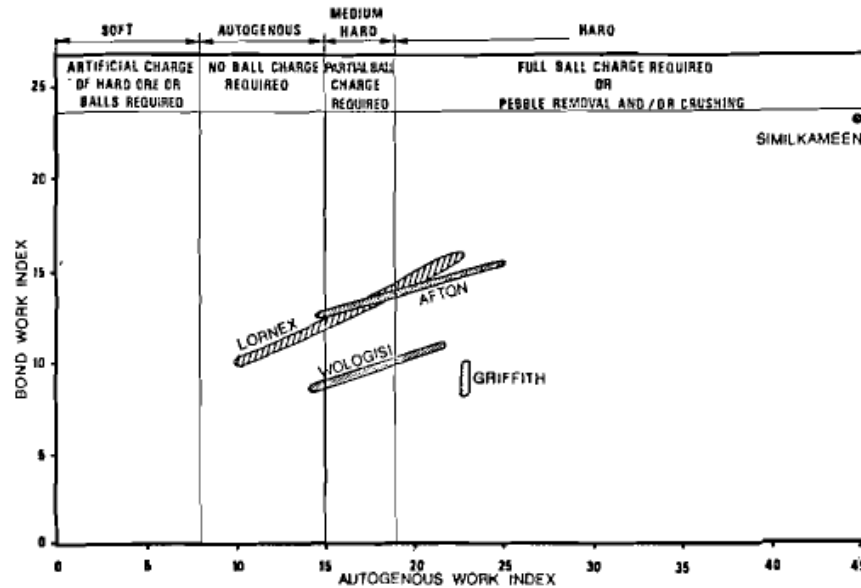


Figure 6 – Bond Work Index vs. Autogenous Work Index and classification of ore types based on autogenous grinding characteristics. Reprinted from MacPherson (1977).

“Expansion of the plant to treat 22.0 skt/d ... was accomplished by installing two ball mills in closed circuit with cyclones to regrind a coarser product from the semi-autogenous circuits.” Operational data indicate that the SAG specific energy was in the region of 20.5 kWh/t and the total specific energy, at 28 kWh/t, was similar to that observed in the previous single stage SAG mill operation. The post expansion SAG mills were running in closed circuit with spiral classifiers and had a fine transfer size to the ball mill.

The throughput issues encountered by the new Copper Mountain operation were very similar to those encountered by the previous Similco operation. SAG competency testing undertaken during the Copper Mountain project design phase also indicated that the amenability of the ore to SAG milling was low (A x b of 22.9 and 20.1) and confirmed that the previous operational difficulties were due to the inherent properties of the ore. The design SAG mill specific energy of 8 kWh/t is very low when compared with benchmark data for other projects (Figure 7). These benchmarks indicate SAG mill specific energy of 12 kWh/t would have been more appropriate. The benchmark data was in the public domain in 2005, well before the construction of the Copper Mountain project.

Similar indications of competency, based on pilot plant and test work data and historical operations were available for the other recent projects listed above.

All of the operations struggled to achieve design throughput during the early periods of mill operation and all required the installation of secondary crushing circuits prior to SAG mill feed to achieve design throughput. Based on the reported competency of the ores at all of these projects, these outcomes should have been anticipated. Figure 8 indicates the design and actual SAG specific energies for the cohort of projects and that these mill designs generally fell short when benchmarked against most other projects treating competent ore.

Malartic had an installed SAG specific energy of 7.8 kWh/t for an average A x b of 38.2. The design Malartic ore characteristics are similar in competency to the Cadia Project ore. The Cadia Project's 40 x 20 ft, 20 MW SAG mill treated approximately 48 kt/d, operating under similar conditions. Cadia operates (in SABC mode) with a SAG mill specific energy of around 8.5 to 9 kWh/t. The Malartic SAG mill is 38ft x 21ft EGL 26 000 hp (19.4 MW) and based on the throughput recorded in early production, the SAG mill was operating with an ECS of about 10.8 kWh/t. This is higher than Cadia and higher than the authors would have predicted based on an A x b of 38.2.

Andacollo was designed for an A x b of 30 and 55 kt/d. The operation approached the design throughput with the aid of higher intensity blasting and secondary crushing. "During the fourth quarter, mill throughput was below plan ... blasting modifications have been implemented to reduce the material size to the SAG mill. In addition, some ore is being pre-crushed using the supergene (leaching plant) crusher." ("Teck Reports Unaudited", 2011). The methods used to size the SAG mill proved to underestimate the required specific energy for primary crushed ore.

The available specific energy for Esperanza, based on a design of 97 kt/d, 94% availability and a 22.4 MW mill, was less than 5 kWh/t. This compares to an expected SAG mill specific energy of over 8 kWh/t based on the data in Table 7. However, insufficient information is available in the public domain to fully elaborate on the methods used by Esperanza to achieve 87 kt/d. A combination of blast design and secondary crushing is believed to have enable throughput to be improved from initial lower throughputs.

Pilot plant trials were run for Mt Milligan in 1990. These trials resulted in SAG mill specific energies ranging from 9.3 to 9.7 kWh/t (reported in the Mt Milligan Feasibility Study in 2009). These results were achieved in SABC mode with a pebble production of 60% of new feed. However, the project only installed a 22 MW SAG mill for a feed rate of 60 000 t/d, equating to a maximum SAG mill specific energy of approximately 8 kWh/t.

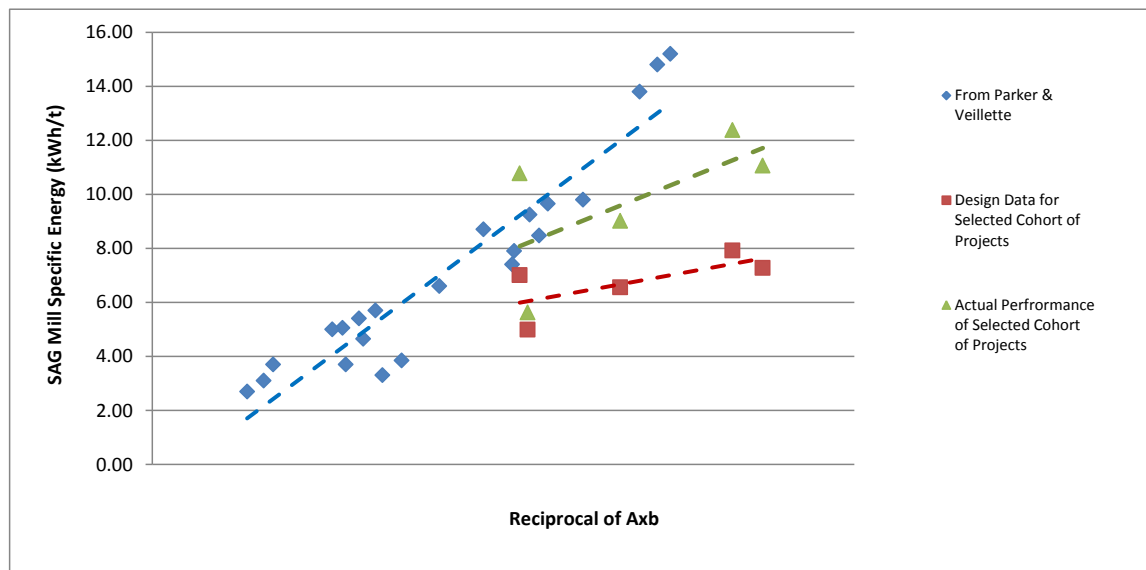


Figure 8 – Comparison of A x b of data adapted from Veillette & Parker (2005) (blue diamonds), design basis for cohort for projects discussed above (red squares) and actual plant performance for cohort in SABC mode (green triangles)

Whilst there is very little pilot plant data available in the public domain for the above projects, pilot plants were conducted for some of these projects. These data would have been used to support the determination of SAG mill specific energy for the respective projects. The authors postulate that some of the errors made in the case of the historical projects (Cadia, Sossego and Pheonix) when scaling pilot plant data to full size mills are still impacting on projects, particularly for competent ore treatment.

CONCLUSIONS AND RECOMMENDATIONS

The current scepticism within financial circles of the ability of consulting and engineering firms to predict SAG mill throughput, as evinced by the Scotia Bank articles referred to above, should not be considered as a lack of sophistication of the available testing methods or the maturity of SAG milling technology. Rather it reflects issues in properly apply the available techniques for prudent SAG mill design when processing competent ores, including benchmarking of performance.

As stated in Lane (2010), in some cases poorly compiled JKSimMet models have been used to support the data provided by other sources. The issues relating to JKSimMet modelling of competent ores have been previously discussed by Bailey et al. (2009). There are several SAG mill specific design tests available to determine the amenability of an ore to SAG milling and the resultant SAG mill specific energy. Recent projects that have failed to achieve design throughput have typically failed to take sufficient heed of the indications of ore competency in the test work data or analysis of the data.

If $A \times b$ values are below, say, 40 or DWI values are above 6.5, due consideration should be given to the inherent competency of the rock and benchmark data relating ore competency to SAG mill specific throughput. The scale-up of pilot plant mill specific energy to large scale operation requires careful consideration of the pilot mill discharge function and associated breakage rates external to the mill in SABC mode. As a minimum, careful benchmarking of design outcomes against available data in the public domain is strongly recommended.

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