A RAPID SAG MILL GRINDABILITY AND MILL SIZING ANALYSIS PROGRAM

ABSTRACT

Engineering feasibility studies have become a significant cost in the mining industry, particularly when a full stage gate approach is used. A portion of this cost is also a function of the time taken to complete the studies and this can be significant as large studies can take years to complete.

Starkey & Associates Inc. completed a feasibility level grinding study in six weeks on mid-scale gold project. This paper will describe the testwork campaign and the steps taken to facilitate a rapid analysis turnaround. The program included a site visit, sample selection, SAGDesign testing on ten composite samples and a final mill sizing analysis. It is estimated that a comparable comminution program of this detail completed using other mill design technologies would require three to six months to complete.

As a result of this work, S&A recommended the selection of a 24 ft diameter by 14 ft EGL single stage SAG mill (4.6 MW installed power) to produce 3,000 mtpd. The circuit was to be expanded in later mine life through the addition of an 18 ft diameter by 29.5 ft ball mill (also 4.6 MW installed power) in order to double the throughput.

KEYWORDS

Feasibility Study, Grindability Testing, SAGDesign, Turnaround Time

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Introduction

Starkey & Associates Inc. (S&A) was contracted by a gold exploration firm (the client) to conduct a feasibility level grinding study for one of their underground and open pit gold deposits in Ontario, Canada. The client specified a need for a rapid turnaround of their engineering reporting, specifically the determination of the optimal SAG mill dimensions and installed power requirement, in order to meet the constraints of their larger reporting schedule. Ball mill sizing was less critical as it would not significantly impact the general layout of the plant or the dimensions of the surrounding structure. As a result, S&A designed a test work and reporting procedure which focused on delivering the highest quality SAG grindability results in the shortest period of time.

The full program was executed in six weeks from preliminary work to final reporting. This was possible thanks to the global test quality control conducted on SAGDesign tests which allowed work to be conducted at several labs simultaneously, ongoing client involvement and the highly focused grinding circuit design process used by S&A.

Methodology

In order to expedite the design process, the engineering program focused on sourcing high quality information in order to minimize re-work at later stages. This necessitated heavy involvement by S&A at all stages of the project including providing recommendations on initial sampling. The program was divided into four primary phases:

Phase 1: Preliminary Planning

This stage of the program focused on selecting the appropriate core samples to be taken in order to achieve a complete understanding of the general ore hardness properties of the deposit. Test volume was reduced to a recommended minimum of ten high quality composites taken from zones representing chronological period of mine production. Advance planning of the sampling campaign, including reference to specific downhole intervals, allowed for on-site personnel to confirm the availability of core prior to the site visit. Some high grade intervals were determined to have already been consumed by metallurgical testing, however, the majority of samples could be taken as requested from available half cut or whole core. This process took approximately three days from S&A project kickoff.

The preliminary planning process also identified that the target final grind size, a key process variable for any grinding circuit, had not yet been determined and would not be available until well into the project.

Phase 2: Sampling

Samples were taken as part of a site visit under the supervision of S&A personnel with the assistance of the client's geologists. The expertise of the site geologists was critical to the timely execution of this stage. Typical sampling programs take roughly two to four high quality composite samples per person per day (each consisting of core from multiple drill holes). In this case, S&A was able to delegate a significant portion of the work thanks to the competency of the field geologists and took 7 samples per person per day, taking all 10 samples in 1.5 days. It is estimated that had the preliminary planning not taken place, the sampling program would have taken a minimum of five days.

It was at this time that a significant dyke of waste material was observed intersecting with ore zones. After discussion with the site staff, it was determined that the dyke was exceptionally hard relative to the ore zones as evidenced by the cutting rate of the core saw. This dyke was clearly distinguishable on even cursory visual inspection with clearly defined contacts and was present in large widths. As a result, the dyke material was tested separately from the composites as an 11th sample. The test indicated that the waste dyke required 60% more SAG grinding energy to reach a D_{80} of 1.7 mm than the hardest tested ore in the deposit and will have a significant impact on throughput if it is fed to the SAG mill.

The core boxes were sorted by the client geologists before S&A's arrival on site. Each SAGDesign sample was a composite of up to 5 drill holes in the same zone. As SAGDesign tests each require at least 15 kg of ore, the length of core required per row of core in the boxes was calculated using the approximate ore specific gravity to give ~20 kg total. This resulted in 7 to 40 cm of core per row being selected. (Note that if the length of the pieces was calculated to be 4 cm or less, longer pieces were selected every other row from the core box to account for variability). Table 1, below, shows the selection of the length of core from each row to create the composite samples.

Table 1: Composite Sample Selection

			Interval			
Zone	**Comp.**	**Hole**	**Start**	**End**	**Length**	**Inch/row**
Open Pit	1	1A	98.6	129.7	31.1	4.5
	1	1B	89.7	137.9	48.3	4.5
	1	1C	187.5	227.5	40.0	4.5
Open Pit	2	2A	95.0	141.9	46.9	4.0
	2	2B	128.1	150.0	21.9	4.0
	2	2C	44.8	81.1	36.3	4.0
Open Pit Dyke	2 Dyke	Dyke A	83.8	92.5	8.7	15.0
UG	3	3A	325.0	362.5	37.5	3.5
	3	3B	312.5	346.9	34.4	3.5
	3	3C	359.0	389.7	30.8	3.5
UG	4	4A	238.2	276.5	38.3	4.0
	4	4B	344.1	370.6	26.5	4.0
	4	4C	367.6	400.0	32.4	4.0
UG	5	5A	345.0	370.0	25.0	4.0
	5	5B	295.0	315.9	20.9	4.0
	5	5C	375.0	402.5	27.5	4.0
UG	6	6A	327.8	350.0	22.2	5.0
	6	6B	410.3	423.1	12.8	5.0
	6	6C	467.6	491.2	23.5	5.0
	6	6D	386.1	402.8	16.7	5.0
UG	7	7A	232.4	261.8	29.4	3.0
	7	7B	307.7	326.9	19.2	3.0
	7	7C	311.3	373.5	62.2	3.0
UG	8	8A	529.4	544.1	14.7	8.0
	8	8B	614.3	628.6	14.3	8.0
	8	8C	551.7	565.5	13.8	8.0
	8	8D	500.0	508.8	8.8	8.0
	8	8E	503.4	517.2	13.8	8.0
UG HARD	9	9A	240.0	256.7	16.7	3.0
	9	9B	345.2	358.1	12.9	3.0
	9	9C	357.1	373.8	16.7	3.0
	9	9D	123.1	165.4	42.3	3.0
	9	9E	79.4	97.1	17.6	3.0
Y 1-5	10	10A	447.1	461.8	14.7	8.0
	10	10B	312.5	325.0	12.5	8.0
	10	10C	325.0	345.0	20.0	8.0

Phase 3: Testing

Each of the 11 samples was sent to one of three SAGDesign labs. Reproducibility studies conducted on S&A "blank" ore standards as well as on duplicate test samples in the same lab have confirmed that the SAGDesign test result is consistent within a maximum of 4.6% relative standard deviation (Brissette, Mihajlovic, & Sanuri, 2014), regardless of which lab tests the sample. As a result, tests can be conducted in parallel in order to expedite the testing process without the need for labs to invest capital in new testing equipment in order to accommodate a single expedited project. The samples were divided between the three selected labs as follows in Table 2. The SAGDesign test outputs three results: an ore specific gravity, the SAG grinding energy from an F_{80} of 152.4 mm to a P_{80} of 1.7 mm (W_{SDT}) and a Bond Ball Work Index Test conducted on SAG ground ore (S_d-BWI). The validation program identified that the Ball Mill Work Index Tests at Lab 2 was anomalous. Upon further investigation, the test mill was found to use a non-standard grinding ball gradation and so those two values were excluded from use in the design analysis.

Table 2: Lab Test Results

Zone	Composite Sample No.	SG Solids	W_{SDT} (kWh/t)	S_d-BWI (kWh/t)	Lab
Open Pit	1	2.77	7.59	19.21	1
Open Pit	2	2.74	7.85	19.46	1
UG	3	2.74	7.21	19.90	1
UG	4	2.77	7.92	18.58	1
UG	5	2.75	8.15	*23.65*	2*
UG	6	2.77	10.60	19.24	3
UG	7	2.75	6.58	19.55	3
UG	8	2.74	7.02	19.60	3
UG Hard	9	2.80	8.41	19.36	3
Yr 1-5	10	2.75	10.25	*24.10*	2*
Overall Average		2.76	8.16	20.27	
Open Pit Average		2.76	7.72	19.34	
Underground Avg.		2.75	7.91	20.09	
Design Point (~80th)		2.76	9.37	19.56	

**S_d-BWI results from Lab 2 were anomalous and therefore not used*

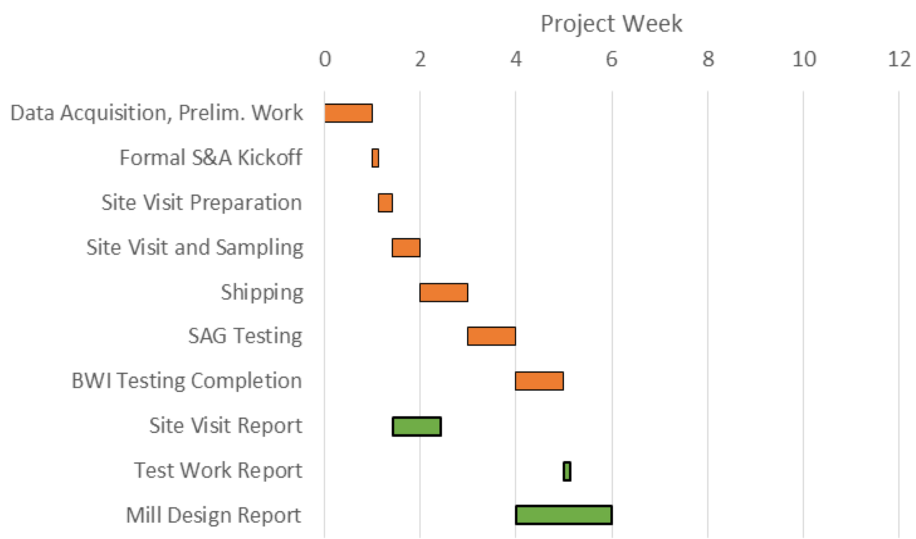
In general, a single SAGDesign test can be completed in three 8 hour working days by a single technician, divided roughly into one day for material preparation, and one day for SAG testing, one day for ball mill testing. However, when multiple samples are completed in series by two technicians this can be reduced to 1 day per test as all three activities can occur simultaneously. This is a significant increase in productivity per technician. In this case, this was not possible at all labs due to technician scheduling. When a single technician was available, priority was given to the SAG grinding portion of the SAGDesign test and once completed, the sample was set aside for continuation later. This allowed for useable SAG grinding data to be output halfway through a given test program, rather than after the completion of all samples. Furthermore, as the final grind size was not available at the beginning of the testing phase, focusing on the SAG portion of the tests allowed for progress to be made until the final grind size was determined mid-way through the phase. After the completion of liberation and flotation studies by a third party, the closing screen of the Bond Ball Work Index Tests was selected as 106 microns to produce a final P_{80} of 75 microns.

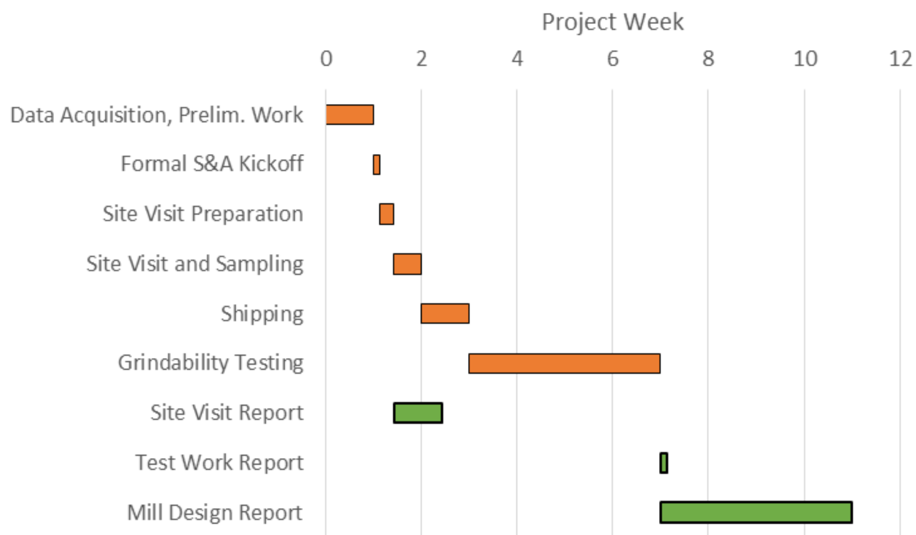
Phase 4: Reporting

Formal reporting began concurrently with the site visit with the issue of the sampling campaign outline/site visit report, and was updated in intervals corresponding to the completion of each phase. Beyond streamlining the project critical path, this had the added benefit of allowing for direct and immediate feedback from the client to comment on and guide S&A work. Furthermore, due to the nature of the SAGDesign test, information regarding the SAG specific grinding energy can be output prior to the completion of the test as a whole. This allowed for the SAG mill diameter (a critical design variable for the clients infrastructure engineering as it determined ceiling height) to be determined with confidence early in the design process.

Completion of the final mill sizing reporting was finalized on September 15, 2014, six weeks from project kickoff. A conventional program with similar sample quantity is estimated to take a minimum of 10 weeks, however most other test methodologies require significantly larger volumes of test work for feasibility level studies, and consequently take 12 to 24 weeks.

Comparative Gantt charts showing both the S&A methodology and a more conventional analysis program are shown below in Figure 1. Both charts are plotted on the same timescale for direct comparison with engineering reports shown in green.





Figures 1 and 2: Comparative Gantt Charts for S&A Expedited Program (upper) Vs. S&A Standard Comminution Analysis (lower)

The mill design report ultimately selected a 24 ft. diameter by 14 ft. EGL single stage SAG mill (4.6 MW installed power) to produce 3,000 mtpd. The circuit was to be expanded in later mine life through the addition of an 18 ft. diameter by 29.5 ft. ball mill in order to double the throughput.

Discussion

Based on S&A's experience in this project, S&A has determined several key factors which contributed to the success of this rapid comminution analysis program. They are as follows:

1. *Clearly establish project goals in advance of work*

In this case, the client was specifically concerned about the diameter of the SAG mill and the program was customized to output this deliverable as early as possible. This allowed the client to remove the grindability study from their feasibility study critical path.

2. *Minimize rework through careful planning*

Over the course of this project, the engineering analysis was developed over the entire project in order to complete the final reporting more quickly when the full suite of data was available. This can increase the risk of rework if input variables change over the course of the project. In order to mitigate this risk, S&A maintained close contact with the client and their other retained engineering firms in order identify the confidence level associated with each of the input variables. Variables with a high degree of uncertainty, such as the final grind size, were not formally incorporated into the analysis until the final reporting.

3. *Conduct tests in parallel when possible*

Testing consumes a large portion of the time associated with a comminution project. Comminution testing tends to be labour intensive, requiring a large amount of material handling and screening time which limits the speed at which it can be completed. When completion time is critical, testing can and should be divided among a number of laboratories so long as sufficient QA/QC data is provided to ensure that all labs will generate comparable results.

4. *Prioritize data generation*

The most critical project data should be output as early in the project as possible. Due to the nature of the SAGDesign test, S&A was able to prioritize the generation of the SAG specific energy data without compromising the quality of the results.

5. *Be flexible when selecting samples*

While on site, the sampling plan had to be amended to work with what core samples were available in large enough quantities. Being able to work with what was given was critical in making the time spent on site valuable.

6. *Minimize cost by using SVT where applicable*

As was done for the dyke sample, a SAG Variability Test (SVT) can be conducted in addition to or instead of SAGDesign tests. An SVT is an abbreviated version of the SAGDesign test which was developed from the SAGDesign database and returns SAG grindability data in kWh/t. An SVT is less expensive and faster than a full SAGDesign test. The results of the SVT on the dyke sample showed that the material was very hard and would slow production if it were introduced into the grinding circuit.

7. *Involve client geologists*

Involving the client geologists allowed for quick and efficient sample selection, saving the project time and money, as the geologists had preselected core boxes before S&A's arrival on site.

Conclusions

S&A has demonstrated that a feasibility level grinding design can be completed over a time period as short as six weeks. A conventional grinding design program conducted by S&A is estimated to take a minimum of three months. A program of comparable accuracy completed with alternative grinding mill design technologies is estimated to take three to six months. The rapid turnaround of this project was accomplished through careful planning of sampling and test work with direct involvement from the client. The SAGDesign test also facilitated the scheduling of the SAG mill sizing by allowing the SAG specific energy to be measured early in the project prior to the completion of all the grinding tests.

As a result of this work, S&A recommended the selection of a 24 ft diameter by 14 ft EGL single stage SAG mill (4.6 MW installed power) to produce 3,000 mtpd. The circuit was to be expanded in later mine life through the addition of an 18 ft diameter by 29.5 ft ball mill (also 4.6 MW installed power) in order to double the throughput.

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