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DEGRUSSA MILLING CIRCUIT - CRITICAL ISSUES, MODIFICATIONS AND RESULTS

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DEGRUSSA MILLING CIRCUIT - CRITICAL ISSUES, MODIFICATIONS AND RESULTS

ABSTRACT

Sandfire Resources' (Sandfire) DeGrussa copper comminution circuit has been designed to produce, by today's standards, a very fine primary grind size of 45 microns. The grinding circuit is comprised of two stages of milling – primary and secondary, to process 1.5Mt per annum (187tph) of primary sulphide ore. The primary grinding circuit consists of a 7.30m x 3.35m variable speed SAG mill in closed circuit with 500mm cyclones designed to deliver a 180µm transfer size, the secondary grinding circuit consists of a 4.7m x 7.5m ball mill in closed circuit with 250mm cyclones to provide a 45µm product to flotation.

Initially the primary mill was commissioned as an autogenous grinding mill (AG mill) at lower than designed throughput (~150tph) and to achieve the design capacity of 187tph steel grinding media was added. Even with the steel addition, high pebble generation with finer transfer size (<100µm) and excessively fine flotation feed have remained an issue. The over-ground sulfides in the flotation feed led to issues in maintaining mineral selectivity and optimised copper recovery.

Several process and operational changes were carried out to reduce the circulation of critical size material and generation of ultra-fines, however stable throughput rates could not be maintained at the design rate of 187tph. Besides the process issues, the variable speed drive (Slip Energy Recovery - SER) limited the available power to the system to ensure the driveline was not over loaded, and the mill vibration at higher mill speeds limited the upper operating range to 74% critical speed. Further to these issues it became difficult to maintain a high ball charge in the SAG mill, to maintain throughput, due to concern over damaging the grates and shell liners (pushing the mill to the design boundaries)[1].

This paper discusses the journey from discovery through comminution design and into commissioning of the DeGrussa concentrator, the difficulties faced in achieving design throughput rates, maintaining a consistent throughput rate and the inability to achieve design flotation feed particle size distribution while transitioning from partial open pit ore (transitional) treatment to solely underground ore (primary sulphide) treatment. The paper also focuses on the need to run a high ball charge in the primary mill and the damage to the lining system due to this elevated ball charge. The paper also outlines the modelling and simulation work carried out to debottleneck the primary mill. The detailed process modelling identified the presence of elevated proportions of critical size material in ore feed and highlighted the need to include a pebble crusher and primary classifying screen to overcome the problems. Post pebble crusher operational results are also discussed due to the system having been commissioned in February 2015.

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KEYWORDS

SAG mill, Grate discharge ball mill, Pebble crusher, Charge motion and Material transport.

MILLING CIRCUIT DEVELOPMENT

The DeGrussa project was fast tracked due to the high grade of the resource and the quantity of copper in the ground, first drill hole into the orebody to commissioning the processing plant took just 40 months. To achieve the schedule a high level prefeasibility study (PFS) was completed; different layouts and options were considered and locked-in before the definitive feasibly study (FS).

The brief for designing the milling circuit was to work with known comminution parameters and design a flow sheet that would have an annual capacity of 1.5Mtpa at a primary grind of 45µm, efficient use of capital, easy to operate, low maintenance and energy efficient. At the time it was also important the designed system could be easily upgraded if the initial mining rate could be increased and/or additional sources of ore were found in the future. The flow sheets considered for the project were:

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[1] SAG2015 paper#LETAD- Sandfire Resources

- Single crush stage followed by SAG and ball mills (SAB)
- Secondary crush stages followed by SAG and ball mills (SAB)
- Tertiary crush stages followed by primary and secondary ball mills.

It was identified early that the waste material was significantly harder than the ore and the mining department estimated that a maximum of 15% dilution of ore could be expected and the circuits were modelled on this basis.

Table 1: Comminution parameters used for the development of the DeGrussa Milling Circuit

	UNITS	85TH PERCENTILE	HARD DILUTION
CWI	kWh/t	8	-
RWI	kWh/t	19.2	9.2
BWI	kWh/t	14.0	18.3
AI		0.342	0.1127
A		64.4	56.6
B		0.86	0.51
A X B		55.1	28.9
TA		0.35	0.28
SG		3.79	2.66

Different options were proposed at the request of Sandfire (Table 2) by Orway Mineral Consultants (OMC), based on their proprietary power modelling techniques, the results indicated that all the options were viable however Sandfire distinguished that:

- The lowest cost system considered was the two stage crush followed by a SAG and a ball mill (Option 2) due to the combination of reduced diameter mills and one additional crushing step
- The simplest system that had the least equipment was a jaw crusher followed by a SAG and a ball mill option (Option 1)
- The easiest to maintain was also the jaw crusher followed by a SAG and a ball mill (Option 1)
- The most energy efficient system was three stage crushing followed by ball milling (Option 3)
- The easiest system to upgrade was a jaw crusher followed by a SAG and a ball mill (Option 1).

Table 2: Summary of different grinding circuit options for DeGrussa

	OPTION 1	OPTION 2	OPTION 3
THROUGHPUT (DTPH)	187	187	187
CRUSHING	Single Stage	Two Stage	Three Stage
1ST STAGE	Jaw Crusher (110kW)	Jaw Crusher (110kW)	Jaw Crusher (110kW)
2ND STAGE	N/A	Cone Crusher (90kW)	Cone Crusher (132kW)
3RD STAGE	N/A	N/A	Cone Crusher (110kW)
F80	124mm	74mm	11mm
GRINDING	SAB	SAB	BM's
P80	45um	45um	45um
PRIMARY MILL	SAG	SAG	Ball
PRIMARY CLASSIFICATION	N/A	N/A	N/A
DIAMETER	6.1m	5.5m	4.7m
EGL	3.9m	3.7m	7.8m
OPERATING PINION POWER	1920 kW	1440 kW	2400 kW
INSTALLED POWER	2500 kW	1900 kW	2800 kW
SECONDARY MILL	Ball	Ball	Ball
DIAMETER	5.2m	5.5m	4.7m
EGL	8.8m	8.3m	7.8m
OPERATING PINION POWER	3165 kW	3450 kW	2220 kW
INSTALLED POWER	3750 kW	4050 kW	2800 kW
SPECIFIC ENERGY	27.2 kWh/t	26.1 kWh/t	24.7 kWh/t

Option 1, a jaw crusher followed by a SAG mill and a ball mill was considered the best combination of capital cost, operating cost, ease of operation and easiest to upgrade in the future. To maximise the upgrade capacity in the future the decision to increase the diameter of the SAG mill and reduce the size of the ball mill was taken, so that if more throughput was required an identical sized ball mill could be fitted in the circuit with minimum downtime. For this to be feasible the SAG mill needed to do more work so a primary classification stage was required. The simulated results are provided in Table 3.

Table 3: Comparison of open circuit SAG in a SAB circuit to closed circuit SAG in a SAB circuit

	OPTION 1	OPTION 4
THROUGHPUT	187	187
CRUSHING	Single Stage	Single Stage
1ST STAGE	Jaw Crusher (110kW)	Jaw Crusher (110kW)
F80	124mm	124mm
P80	45um	45um
PRIMARY MILL	SAG	SAG
PRIMARY CLASSIFICATION	N/A	Cyclones
DIAMETER	6.1m	7.3m
EGL	3.9m	3.4m
OPERATING PINION POWER	1920 kW	2525 kW
INSTALLED POWER	2500 kW	3400 kW
SECONDARY MILL	Ball	Ball
DIAMETER	5.2m	4.7m
EGL	8.8m	7.5m
OPERATING PINION POWER	3165 kW	2200 kW
INSTALLED POWER	3750 kW	2600kW
SPECIFIC ENERGY	27.2 kWh/t	25.3 kWh/t

Option 4 was considered the most appropriate solution for Sandfire's needs; it gave the throughput required, had two single stage milling circuits, was easy to maintain, was as energy efficient as the most efficient milling system originally proposed (three stage crush followed by ball milling) and was upgradable by at least 33% without major interruptions to the operation of the milling circuit. The flow sheet selected is shown in Figure 1.

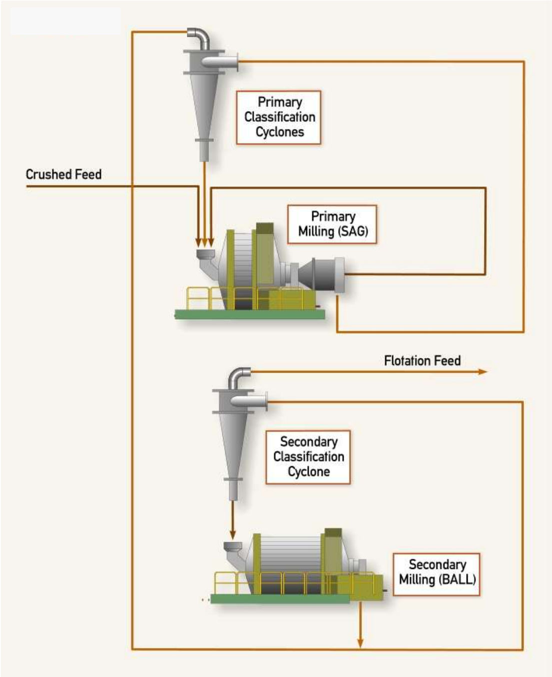

Figure 1: Selected Milling flow sheet for DeGrussa copper mine

Outotec was selected as the preferred supplier and in the contract forming process Outotec offered their Turbo Pulp Lifter (TPL) system for both the SAG and ball mills and guaranteed that the system would result in a net 10% specific energy saving over a traditional pulp system.

COMMISSIONING

Commissioning of the DeGrussa process plant commenced in September 2012. The process plant was commissioned on a significant proportion of open pit material (material that it was never expected to treat). As part of the modelling process Outotec recommended that the SAG mill be operated initially in autogenous mode and the ball mill be operated at 2MW (75% of full load) with 35-40mm balls, reduced from 50-60mm in the original traditional overflow ball mill modelling.

The original grates in the SAG mill were designed with 25mm slots and an open area of 8.9% including the radial slots between the grate plates which had an effective slot opening of 35mm. Within a few days of start-up, the milling circuit achieved 150tph in AG mode with the ball mill (at 2MW) grinding the feed to the flotation plant having an 80% passing (P80) of approximately 25µm.

The primary mill circuit had some issues in this mode primarily due to:

- the amount of pebbles that were produced (~70tph for a system designed for less than 10tph) were overloading the recycle conveyors creating housekeeping issues
- the primary cyclone overflow was too fine with a P80 of 45µm (design was a P80 of 180µm)
- the AG discharge particle size distribution was too fine.

The decision was made to add balls to the mill in an attempt to achieve nameplate throughput, reduce the pebble recycle rate, coarsen the SAG mill discharge and subsequent primary cyclone overflow.

A moderate graded ball charge of 8% with maximum 100mm balls was added to the primary mill which improved the throughput to the design expectation however it did not significantly reduce the tonnage of pebbles or coarsen the discharge of the SAG mill or primary cyclone overflow. The problem was diagnosed as the primary classification circuit not operating correctly, a risk identified in the original review by S. Morrell. During November/December 2012 the milling circuit was operated without the ball mill in an attempt to achieve a primary grind of 45µm with the SAG mill only. The process and operating data collected from the plant during commissioning are given in Table 4.

Table 4: Comparison of design and commissioning data

PARAMETER	UNITS	DESIGN		SURVEYS		
		INSTALL	FUTURE	SEP 2012	DEC 2012	OCT 2013
DWI	KWH/M³	7.9	7.9	8.3	6.6	5.2
AXB		47.6	47.6	33.8	54.4	68.8
BWI	KWH/T	14.5	14.5	18.2	13.2	13.9
SG	T/M³	3.8	3.8	2.8	3.6	3.6
THROUGHPUT	DTPH	187	287	150	187	202
PEBBLE RATE	DTPH	4	-	>70	70	19
FEED 80% PASSING	MM	115	115	90	58	77
SAG PRODUCT 80% PASSING	MM	180	700	54	77	169
SAG MILL						
SPEED	%NC	72	72	72	70	63
BALL LOAD	%	10	9	0	8	11.2
TOTAL LOAD	%	25	25	32	26.6	21.2
SPECIFIC ENERGY	KWH/T	13.7	8.5	14.6	14.0	10.5
POWER @ PINION	KW	2560	2450	2185	2616	2122
MOTOR RATING	KW	3400	3400	3400	3400	3400
BALL MILL						
PRODUCT 80% PASSING	UM	45	45	32	BALL MILL BYPASSED	49
BALL LOAD	%	28	32	16		14
SPECIFIC ENERGY	KWH/T	11.5	16.7	10.8		6.7
POWER @ PINION	KW	2159	4793	1615		1362
MOTOR RATING	KW	2600	5200	2600		2600
TOTAL CIRCUIT						
SPECIFIC ENERGY	KWH/T	25.2	25.2	25.3	14.0	17.3
POWER @ PINION	KW	4719	7243	3800	2616	3485

The results of the full grinding survey conducted in October 2013 were compared to the design parameters and previous surveys. Summary of observations from this grinding survey compared to the original design indicated that:

- the primary mill feed 80% passing was significantly finer than the design value of 115mm
- the pebble generation was significantly higher compared to the design expectation
- the ball charge was increased to crush the pebbles and control pebble generation
- the SAG speed was limited to protect liners from damage.

At this stage of operation, based on preliminary analysis and modelling, Dr Sanjeeva Latchireddi of Energy Efficient Milling Solutions (EEMS), had recommended a pebble crushing circuit be installed to overcome the existing issues and adequately control the SAG mill with different ore types. This recommendation was contradictory to the established rational as stated in JKMRC's Mineral Comminution book (NappierMunn et.al) "*As the action of a recycle crusher is to remove rocks from the mill which are important as grinding media for fine particles, operating with a fine classifier as well can* *produce a build-up of sand-like material. This may lead to a drop in throughput and hence nullifies the advantage given by a recycle crusher."*

In line with the above statement and suggestions from other comminution experts, the pebble crusher recommendation was not considered at this point and put on hold.

To lower the pebble flowrate from the SAG mill, Sandfire elected to blank off the radial slots of the spare set of grates to reduce the top size and the open area of the grates. This reduced the open area from 8.9% to 6.9% and resulted in the pebble production rate being reduced to a manageable level, however the transfer size to the ball mill showed no improvement.

At this point the milling circuit was operating at the design throughput rates on a blend of open pit ore, however as the amount of underground ore in the feed blend increased, the required SAG ball charge also increased to 11% and the throughput rate dropped to 190 - 200tph. Concurrently the operations team retrofitted flat bottom cyclones and increased the density of the feed to the cyclones in an attempt to increase transfer size to the ball mill circuit. These modifications helped to increase the transfer size marginally to 100 - 120 microns as shown in Figure 2. However pump blockages became an issue as the recirculating load on the primary mill reduced.

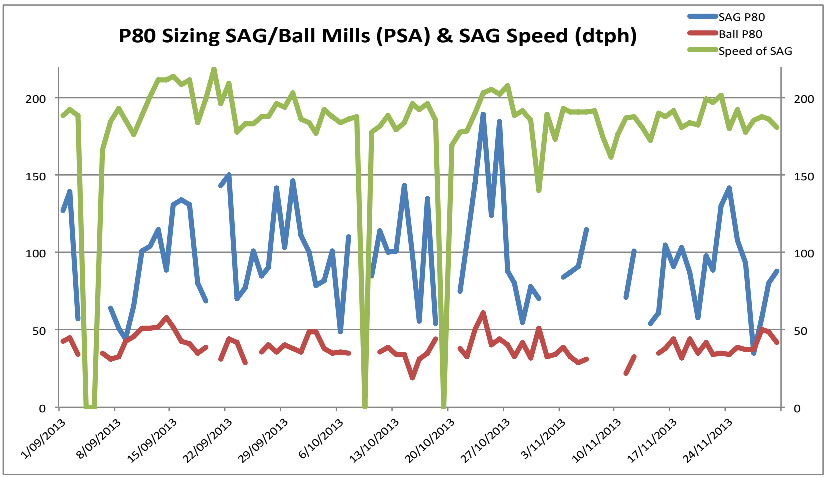

Figure 2: Product size of SAG and ball mill circuits

UNDERGROUND MINE ORE

From July 2013 the milling circuit was operating with the design ore and was operating at the design throughput rate however, this was done at the expense of mill lining life. To achieve the desired throughput rate the mill was operated with a high ball charge reducing the life of the grates from the expected 13 weeks to 6 - 7 weeks. This impacted run time and put more pressure on the instantaneous throughput rate creating a less than desirable operating regime (Figure 3 and Figure 4). At this time both rubber and Hardox plate grates were designed and installed to extend the life of the grates.

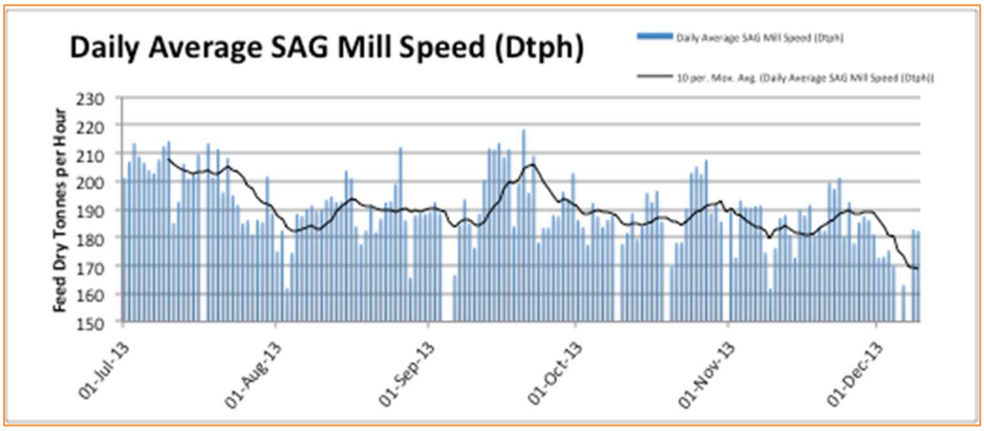

Figure 3: Daily average performance of the SAG mill

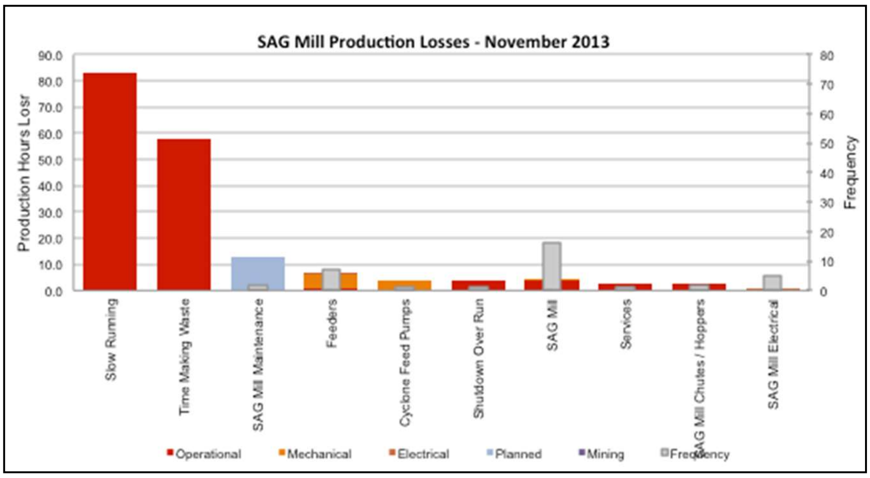

Figure 4: Loss of the SAG mill production hours

MILLING IMPROVEMENT MEETING

A milling improvement workshop was held in late 2013 with a group of milling specialists ranging from milling modelling professionals to mill commissioning engineers intended to understand the problems that Sandfire were experiencing.

The agenda of this meeting was:

- Improve the instantaneous capacity to +200tph (~10%) by unlocking the SAG mill.
- Stop the premature failing of the grates and peening of the shell.
- Improve mill availability.
- Reduce the SAG mill overgrinding.
- Reduce operating costs.

The meeting resulted in two contrasting approaches of how to rectify the issues, a traditional power based modelling approach and a holistic process modelling methodology.

The traditional power based modelling recommendations were to:

- reduce the load on the SAG mill by feeding forward a portion of the SAG mill discharge to the ball mill circuit. The belief that there was a significant amount of ineffective steel in the SAG mill circuit and moving this to the ball mill would reduce the load on the SAG mill
- operate the SAG mill at a fixed feed rate, with a target ball charge of 12% and a mill total volume of 26%. The SAG mill speed should be used to control the mill load and should allow normal SAG operation at speeds as low as 65% critical speed. This would also

minimise liner damage caused by large balls directly impacting the shell liners. Increased mill speeds could be used to control high a SAG mill charge volume
- decrease the pebbles production rate below 30tph by reducing the grate size and open area by either installing new grates or installing blanking sandwich plates on the existing grates.

The holistic process modelling recommendation by EEMS was to pebble port the SAG mill to allow the discharge of the critical size material from the mill and crush these pebbles outside of the mill because;

- from analysis of the pebbles it was evident that and the charge in the mill had a lot of critical size material present due to the finer than expected feed size distribution, up to 250% more 12 - 30mm material, compared to the original design
- an external crusher was considerably more efficient crushing this material than a SAG mill
- the critical size material was hard, the reason for having to operate the SAG mill in an adverse way to maintain throughput (high ball charge low total charge to keep these particles from accumulating)
- the finer product from the SAG mill circuit was due to the quantity of pebble size material inside the mill causing charge slip and resulted in more of a cascading action opposed to a cateracting action.

MODELLING AND SIMULATION OF GRINDING CIRCUIT

After the milling meeting held in late 2013, modelling studies were carried out by the respective experts and their findings are summarised in this section.

TRADITIONAL POWER MODELLING

The outcome from the traditional power modelling provided throughputs for different scenarios – open circuit SAG, correct transfer size and with pebble crusher, these are presented in Table 5.

Table 5: Traditional power based modelling results

PARAMETERS	UNIT	PLANT DATA 7/4 – 16/4	OPEN CIRCUIT SAG	CORRECT TRANSFER SIZE	PEBBLE CRUSHER
CALCULATED BWI	kWh/t	11.3	11.3	11.3	11.3
CALCULATED A X B		68.4	68.4	68.4	68.4
FEED SIZE	mm	70	70	70	70
PRODUCT SIZE P80	um	46	46	46	46
PEBBLE RATE	%feed	2	2	2	15
PEBBLE RECYCLE	%feed	Nil	Nil	nil	15
CRUSHER FEED SIZE	mm	-	-	-	40
CRUSHER PRODUCT SIZE	mm	-	-	-	10
SAG SPECFIC ENERGY	kWh/t	13.2	7.0	11.3	11.1
BALL SPECIFIC ENERGY	kWh/t	7.7	13.9	9.5	9.3
TOTAL SPECIFIC ENERGY	kWh/t	20.9	20.9	20.9	20.4
ESTIMATED THROUGHPUT	tph	226	425	264	269
SAG POWER	kW	2,893	2,893	2,893	2,893
BALL POWER	kW	1,742	5,896	2,516	2,516
CIRCUIT CONSTRAINT		SAG Mill	Ball Mill	Balance	Ball Mill
ESTIMATED PRODUCT SIZE	um	-	134	-	-

Based on the recommendations, the following modifications were made to the grinding circuit:

- the diversion of some of the SAG discharge to the ball mill circuit as shown in Figure 5
- rubber grates with 18mm apertures were installed in the SAG mill to minimise pebble flow rate
- 125mm grinding balls were added to the SAG mill to crush the pebbles.

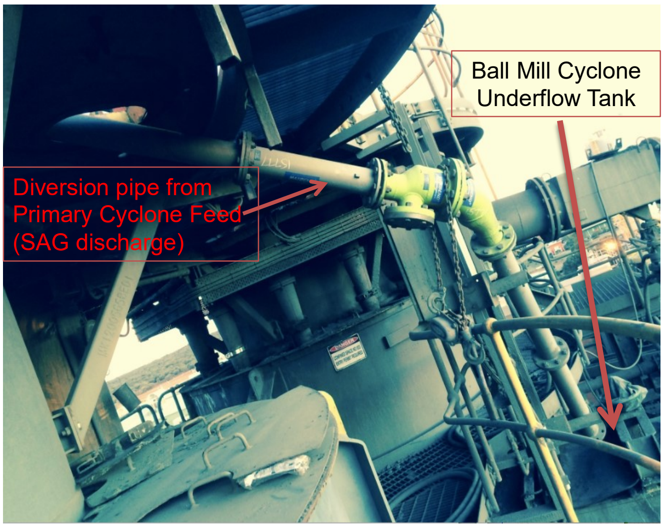

Figure 5: Diversion of the SAG discharge (primary cyclone feed) to the ball mill

In addition to modifications made to the grinding circuit as recommended, the SAG mill ball charge was increased to 12% and this, combined with the 18mm rubber grates, helped in reducing the generation of pebbles. However the partial diversion of the SAG mill discharge to the ball mill resulted in the ball mill requiring a higher ball charge and larger grinding media. Although the circuit throughput increased to approximately 200tph, the specific energy (SE) increased to 24kWh/t ie the efficiency of the circuit was reduced.

Another problem created by operating the circuit in this manner was the requirement to unload the SAG mill at times to maintain throughput (7,000 tpm or 6% of the mill feed). This needed to be managed as the pebbles could not be simply discarded as it would lead to 5% copper recovery loss and hence the pebbles were stored on the ROM pad. Average operating data from July to November 2014 is illustrated in Table 6.

Table 6: Average operational data of July-November 2014 DeGrussa grinding circuit

PARAMETERS	UNIT		JULY – NOV 2014 AVERAGE DATA
THROUGHPUT	tph		194
PRODUCT SIZE P80	um		45
SAG POWER	kW		2,677
SAG BALL CHARGE	%		12
BALL POWER	kW		1,978
SAG SPECFIC ENERGY			13.8
BALL SPECFIC ENERGY			10.2
TOTAL SPECIFIC ENERGY			24.0

Implementing the above changes did not reduce the wear on shell liners, consumption of balls or overgrinding but instead added the following problems:

- frequent blockages of the SAG mill discharge hopper and pump
- increased ball charge level in the ball mill
- increased wear, pegging of the ball mill grates, and pebble issues in the ball mill.

HOLISTIC PROCESS MODELLING

The holistic approach used by EEMS, where the optimisation of energy transfer mechanisms ie charge motion, material transport and particle breakage are individually investigated and integrated to maximise milling efficiency in both grate discharge SAG and ball mills. The results of these simulations demonstrated, using EEMS' proprietary and state of the art simulation tools that:

- capacity can be improved for operations seeking higher throughputs without the requirement for additional infrastructure (saving CAPEX)
- energy savings can be achieved by increasing energy transfer efficiency in grinding, a traditionally a low efficiency process (saving OPEX).

The results shown in Table 7, obtained from holistic process modelling, suggested that the pebble crusher would increase the grinding efficiency of the SAG mill. A classification screen in place of primary cyclones on the SAG mill would help in providing constant transfer size to the ball mill circuit and reduce overgrinding in the SAG mill (-10µm) that were not conducive for downstream processing.

Table 7: Holistic process modelling results of DeGrussa milling circuit

PARAMETERS	UNIT	DESIGN	OCT 2013 SURVEY	PEBBLE CRUSHER	PEBBLE CRUSHER + PRIMARY SCREEN
DWI	kWh/m^3	7.9	5.21	5.21	5.21
MIA	kWh/t		12	12	12
MIH	kWh/t		8.45	8.45	8.45
MIC	kWh/t		4.35	4.35	4.35
AXB		47.6	68.8	68.8	68.8
TA			0.5	0.5	.5
BWI	kWh/t	14.5	13.9	13.9	13.9
FEED SIZE	mm	115	77	77	77
PRODUCT SIZE P80	um	45	49	51	54
PEBBLE RATE	%feed	2	9	7	5
PEBBLE RECYCLE	%feed	2	9	7	5
CRUSHER FEED SIZE	mm			35	35
CRUSHER PRODUCT SIZE	mm			10	10
SAG SPECFIC ENERGY		14.7	11.3	10.3	10.0
BALL SPECIFIC ENERGY		12.4	7.2	6.9	8.6
TOTAL SPECIFIC ENERGY		27.1	18.5	17.2	18.6
THROUGHPUT		187	202	210	210
SAG POWER		2,750	2,282	2,170	2,110
BALL POWER		2,321	1,464	1,450	1,810
FINES (%<10UM)			53	52	43

The following recommendations were suggested to improve circuit throughput and reduce metal losses in finer size fractions. The recommendations are listed below in the order of implementation:

1. install a suitable pebble crusher in the SAG mill circuit to treat up to 100tph of pebbles. A pebble crusher would provide the following benefits:
    - higher throughput of up to 280tph without need of a second ball mill
    - lower ball consumption (due to a lower ball charge of 5%)
    - improve wear life of shell liners, grates and pulp lifters.
2. modify the SAG grates to port the SAG mill
3. modify the shell lifter profile to induce high energy impacts and improve wear life
4. install a suitable classifying screen (vibrating screen or DSM screen) in place of the SAG cyclones for the following reasons:
    - to reduce the circulating loads
    - to reduce fines generation (10µm) in the SAG mill
    - to reduce metal losses in fines (10µm) of the flotation circuit
    - to provide an increase in the SAG mill capacity (>250-tph).

PEBBLE CRUSHER AND SCREEN PROJECT

As the "quick and easy" fixes had been completed to no appreciable improvement the decision was made to commit to installing a pebble crusher in the DeGrussa milling circuit and the revised circuit is shown in Figure 6.

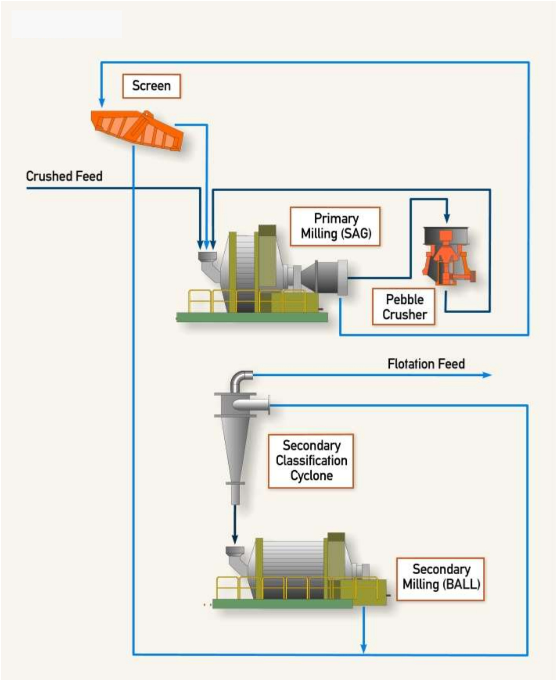

Figure 6: Revised DeGrussa milling flow sheet

After reviewing and understanding the recommendations, additional works were required over and above the installation of a pebble crusher and screen. The additional works required were:

- to upgrade the pebble transfer chute of the SAG mill discharge
- to improve the pumping system and high wear piping of the SAG mill discharge pumps
- to install a suitable magnetic separator and metal detector over the pebble crusher feed conveyor to protect the pebble crusher
- to install an upgraded pebble conveying system
- to redesign the grates suitable for the pebble crusher installation.

Over the course of eight months all of the above items were upgraded and since March 2015 the circuit has been in operation. The operational data collected in different operational scenarios are shown in Table 8. The performance of the circuit during the subsequent four months illustrates the advantage of pebble crushing will not be nullified in a single stage SAG milling circuit with a fine classifier when the system is fully optimized.

Table 8: Comparison of operating data to modelling data

PARAMETERS	UNIT	PRE DATA JULY – NOV 2014	MODEL PREDICTION WITH PEBBLE CRUSHER	POST DATA WITH PEBBLE CRUSHER OFF	POST DATA WITH PEBBLE CRUSHER ON	JUNE 2015 AVERAGE DATA
THROUGHPUT	tph	194	250	180	245	236
PRODUCT SIZE P80	um	45	45	45	47	45
SAG POWER	kW	2,677	2290	2,350	2,254	2,416
SAG BALL CHARGE	%	12	5	5	5	5
BALL POWER	kW	1,978	2183	1,700	1,700	1,690
PEBBLE CRUSHER POWER	kW	N/A	70	N/A	60	41
SAG SPECFIC ENERGY		13.8	9.2	13.0	9.2	10.3
BALL SPECFIC ENERGY		10.2	8.7	9.4	6.9	7.2
PEBBLE CRUSHER SPECIFIC ENERGY		N/A	0.3	N/A	0.3	0.3
TOTAL SPECIFIC ENERGY		24.0	18.2	22.4	16.4	17.8

From Table 8 the following can be concluded:

- the pebble crusher made a significant difference to the specific energy requirement and thus allows the ball charge in both the SAG and ball mills to be reduced to 5% and 16% respectively
- the primary screen not only helped in reducing the recirculating load to the SAG mill, it also helped in minimising overgrinding
- the post pebble crusher operating data confirms the predictive capability of a holistic process modelling approach and ability to identify the critical issues.

Since the milling circuit changes have been made the following benefits have been observed:

- a significant increase in throughput and the SAG mill been debottlenecked
- a significant reduction in specific energy of the system
- a significant decrease in SAG mill ball charge (from 12% to 5%) and ball mill ball charge (21-16%)
- the ball consumption in the SAG mill has reduced by over 25%
- the operational blockages and pump wear reduced.

LESSONS LEARNED - INTERESTING OBSERVATIONS

- The successful performance of the circuit since February 2015, demonstrates that the benefits of pebble crushing will not be nullified in single stage AG/SAG milling circuits operating in closed circuit with fine classification (2mm screen), if the process is fully optimized.
- The milling circuit feed size distribution being finer (akin to a partial secondary crush feed) a pebble crusher is more critical to have in the circuit particularly if the comminution parameters between waste and ore are significantly different. If Sandfire had installed a secondary crush circuit initially the SAG mill would have not allowed any upside on throughput and would be very difficult to rectify.
- Pushing load, ball charge and power to get throughput reduces the efficiency of the grinding circuit such that the throughput reduces and more damage to the mill lining results. It is apparent from this work that it is more important to achieve a highly efficient operating condition irrespective of power draw to achieve maximum throughput, which is contrary to traditional thinking.
- Although grate discharge ball mills are more efficient than overflow ball mills, their application is highly restricted. Hesitation exists to install grate discharge ball mills due to lack of adequate, accurate modelling expertise. The modelling techniques based on Bond work index, population balance models and perfect mixing models have been developed and optimized for overflow discharge ball mills and hence cannot be applied directly to grate discharge ball mills.
- Bond work index method has a limitation; the method significantly overestimates the energy requirement for fine grinding applications. New modelling methodology developed for grate discharge balls mills has successfully predicted the performance of Sandfire's grate discharge ball mill producing a product of 45 microns from a transfer size of 650 µm at 7.2 kWh/t, and is a testament for their application to the fine grinding area.
- Milling is a holistic challenge, for too long Sandfire (and the industry?) has been placing its trust in power based modelling. Sandfire has found that for its ore type traditional modelling techniques have not been able to resolve the problems.
- Holistic process modelling which takes particle breakage, material flow and charge motion into consideration has identified the problem and provided solutions for these problems. This begs the question; will this type of modelling show areas of improvement for any mill, even the ones that are thought to be performing well?
- Since the commissioning of the milling improvement projects the flotation feed has become more stable and the milling circuit is generating an improved particle size distribution (40% less -10µm material is being generated) that improves flotation performance. The recovery of the flotation circuit has improved in the order of 3% and although this coincides with the installation of a flotation column in the cleaning circuit, it is believed that a portion of the recovery uplift is attributable to the improved performance of the milling circuit.

FUTURE WORK

As Sandfire has had significant success in these endeavours the plan going forward is to:

- adjust the profile of the feed and shell lifters to attain better impacts at lower mill speeds, as the upper mill speed has been limited to 74% critical
- install a screen or upgrade secondary cyclones in the ball mill circuit to further improve the overall milling efficiency.

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