TAKING CONTROL OF THE MILL FEED: CASE STUDY - PARTIAL SECONDARY CRUSHING MT RAWDON

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CASE STUDY - PARTIAL SECONDARY CRUSHING MT RAWDON

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ABSTRACT

The use of a partial secondary crushing circuit provides a flexible way to optimise existing SAG comminution circuits limited by rock competency or enables optimal processing of an ore through second hand equipment not specifically selected for that ore. This paper details the process involved in designing a partial secondary crushing circuit using the recent installation at Mt Rawdon Gold Mine in Queensland as an example.

By understanding the ore breakage characteristics and by utilising comminution circuit modelling, the benefits of SAG mill feed size manipulation can be readily assessed. Furthermore the paper discusses the features of partial secondary crushing circuits and the pros and cons of various configurations.

The intervention undertaken involved characterising the ore using a new measure of competence, determining power utilisation efficiency, identifying spare capacity and devising a blending strategy to allow a mix of primary and secondary crushed ore to be processed.

Power analysis showed that at Mt Rawdon the capacity could be lifted from 2.2 Mtpa to 3.2 Mtpa by a combination of improved power efficiency from secondary crushing and optimised equipment performance. This necessitated increasing the power available to the SAG mill and reconfiguring the ball mill to a grate-discharge unit to draw full motor power.

Manipulation of the proportion of secondary crushed feed allowed balancing of the duty between the SAG and ball mill. Diverting primary crushed ore to a surge bin ahead of a secondary crusher, and allowing the bin to overflow into a by-pass achieved this.

INTRODUCTION

In Australia, there are several examples of the retrofitting of secondary crushing circuits to reduce feed size and hence increase SAG mill capacity, most notably those of Kidston Gold Mine (MacNevin, 1997) and St Ives Gold Mine (Atasoy, Valery and Skalski, 2001). However circuits treating totally secondary crushed feed are often unstable and are difficult operate. They do not always provide an optimum circuit balance whereby the total installed power is utilised.

The effect of feed size in AG/SAG milling has been studied extensively with an early review presented by Abel (1997), whilst the relationship between changes in feed size and comminution has been covered by a number of authors under the banner of "Mine to Mill" (Morrell and Kojovic, 1999).

The present case study relates to the Mt Rawdon Gold Mine, owned and operated by Equigold NL and located west of Bundaberg in Queensland. The intervention undertaken involved characterising the ore using a new measure of competence, determining power utilisation efficiency, identifying spare capacity and devising a blending strategy to allow a mix of primary and secondary crushed ore to be processed.

MT RAWDON CASE STUDY

Background

The Mt Rawdon comminution circuit was commissioned with Run of Mine ore tipped directly into a 42 x 65 Allis-Chalmers gyratory primary crusher before being conveyed to the crushed ore stockpile.

Mill feed was reclaimed from the stockpile to a SAG mill operating in closed circuit with a discharge screen. Screen undersize flowed into the mill discharge hopper before being pumped for classification in Krebs 250 mm (10-inch) cyclones. Cyclone underflow flowed to the secondary ball mill feed, with a portion processed in a gravity circuit before being recombined to form the ball mill feed. The cyclone overflow gravitated to the first leach tank via a trash screen. Ball mill discharge combined with SAG mill discharge to form the feed to the screen (See Figure 1).

Screen oversize pebbles were conveyed to a recycle crusher, where they were crushed and returned to the SAG mill feed conveyor. A 736 Allis Chalmers pebble crusher (110 kW) performed this duty.

A Process Flow Diagram is presented in Figure 2.

The 8.53 m Ø x 3.92 m EGL (28 x 12.8-ft) SAG mill is fitted with two 1850 kW motors. An operating ball charge in the range of 4 to 10% is used. The mill currently operates at a fixed speed of 72.5% of critical, however it has variable speed capability through the use of the liquid resistance starter. The grates have 20 mm slotted apertures and 50 to 70mm slotted pebble ports. These relieve slurry from the mill onto the discharge screen, which is fitted with 17 mm aperture panels.

The 4.27 Ø m x 12.94 m EGL secondary ball mill is fitted with a 4125 kW motor and operates in overflow configuration. Ball mill discharge slurry gravitates to the feed of the SAG mill discharge screen situated above the mill discharge hopper.

In 2002, the grinding circuit became SAG mill limited by the competency of the mill feed. In consultation with its advisors, Orway Mineral Consultants, Equigold undertook duplicate circuit surveys to provide information in an effort to de-bottle neck the circuit and optimise throughput.

Ore characterisation tests were undertaken on the surveyed feed materials. This involved a suit of tests including UCS, RWI, BWI, Ai and a Media Competency Test (Kjos, 1985). Surviving lumps of rock from the competency test were then subjected to twin pendulum impact testing, using a rig similar to that described by Bond (1951). Ranging in size from 12 to 100 mm, 100 particles were tested, with the energy required to obtain first fracture recorded.

Figure 1 : Mt Rawdon grinding circuit

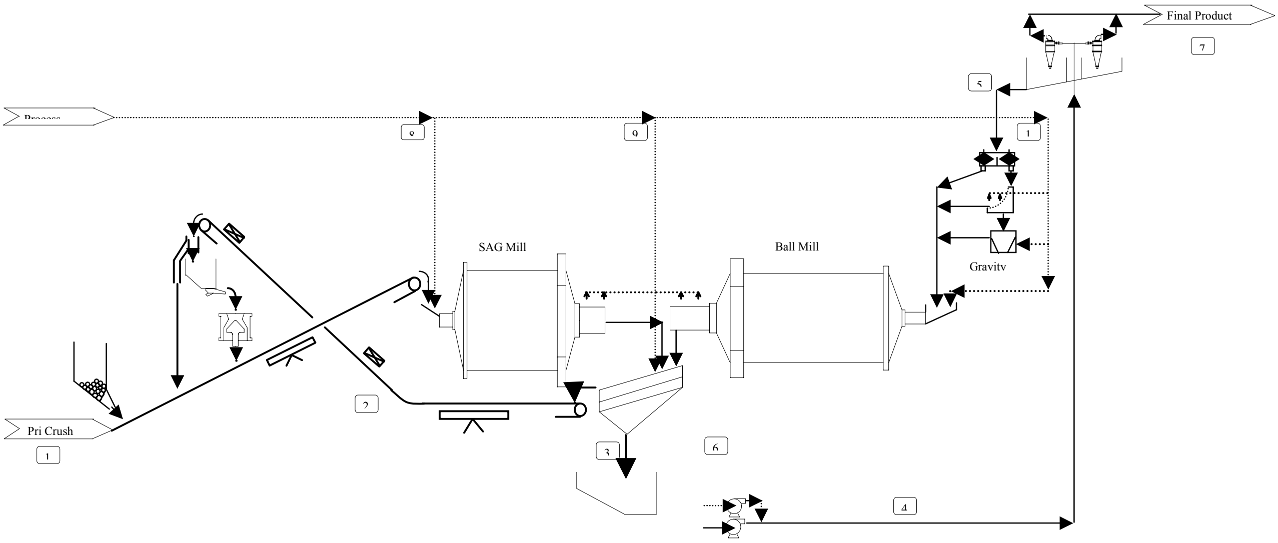

Figure 2 : PFD of Mt Rawdon comminution circuit before optimisation.

Survey Results

Net pinion power was obtained by applying the assumption that energy losses across the motor and drive train were 7.5% of the power measured at the motor input. This accords with industry norms, Table 1.

Table 1: Grinding Circuit Survey Results

	Units	Survey 1	Survey 2
New Feed Rate	tph	271	229
SAG Mill Pinion Power	kW	3348	3316
Ball Mill Pinion Power	kW	2621	2574
Recycle crusher feed rate	tph	77	91
SAG F_{80}	mm	96	80
Ball Mill P_{80}	um	140	124

The measured particle size distributions for the two feeds are shown in Figure 3. It can be seen that the amount of fines varied significantly between surveys. The 80% passing values were 96 and 80 mm respectively for Surveys 1 and 2.

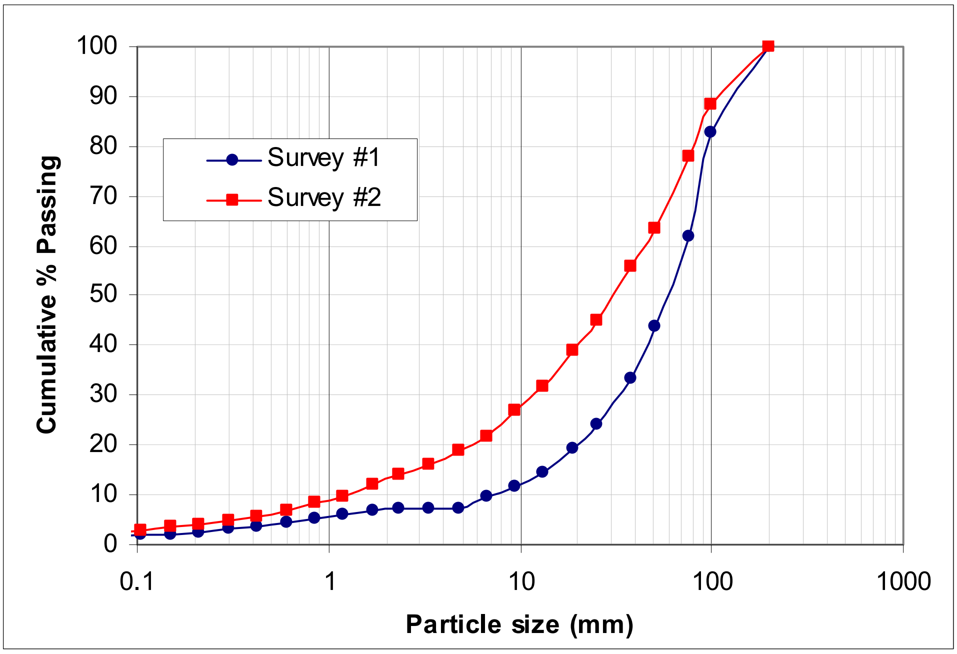

Figure 3: Feed size distributions

Impact Strength of Rock

The energy that must be applied to Mt Rawdon ore to achieve first fracture across a range of sizes is shown in Figure 4.

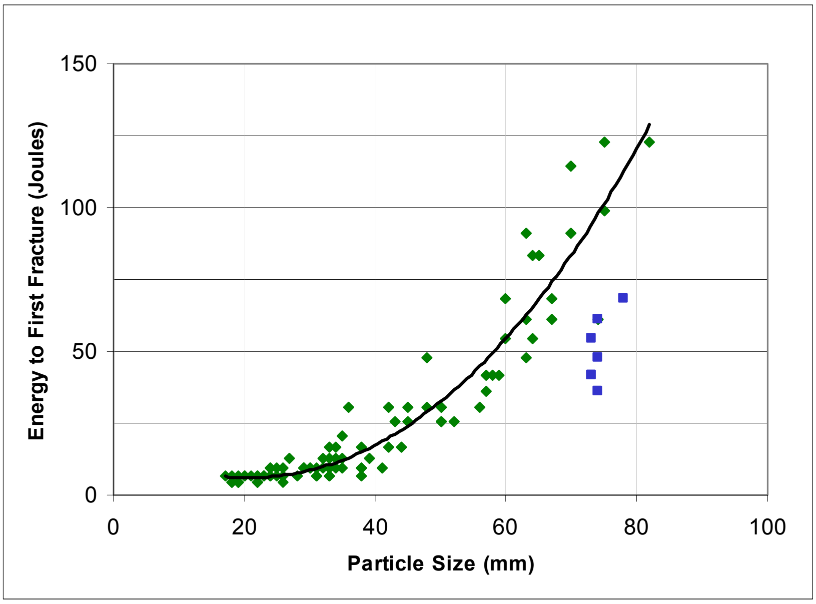

Figure 4: Variation in energy to first fracture with particle diameter (Survey 2 sample)

Ball Mill Work Index

Survey #1	**Survey #2**
18.3 kWh/tonne	20.7 kWh/tonne

Interpretation of Test and Survey Data

The actual specific energy demands derived for the two grinding stages are shown in Table 2, together with a measure of power efficiency, f_{SAG} This compares the actual grinding circuit specific energy to that of the Bond predicted energy for a standardised feed and product size (80% passing 150 mm to 75 µm.), and its use has been described by Siddall, Henderson and Putland (1996). The analysis indicates that the measured inefficiency when milling primary crushed ore is consistent between the two surveys at 1.34 to 1.35. This corresponds to power demands of 49 and 45% in excess of theoretical, at the coarse product sizes generated (P_{80} of 140 and 124 µm). The analysis also reveals that the circuit is limited at the SAG mill, with spare power in the ball mill.

Table 2: Power analysis of survey data

Power Utilisation	Units	Survey 1	Survey 2
SAG Mill Specific Energy	kWh/t	12.4	14.5
Ball Mill Specific Energy	kWh/t	9.7	11.2
Operating Work Index (Wio)	kWh/t	27.1	29.8
f_{SAG}		**1.35**	**1.34**

The amount of pebbles extracted, crushed and recycled is governed by the size of the pebble ports installed. At 30 to 40% of new feed, the current recycle crushing operation is close to optimum.

The circuit product was variable and finer than the target grind size of 80% passing 150 µm.

The impact testing indicates that the breakage energy required to achieve fracture increases linearly with increasing particle mass or volume, (Figure 5). Energetic impacts of >50 Joules are required to break particles in excess of ~55 mm, rising to 100 joules at 75 mm. DEM Modelling of SAG mills (Morrison & Cleary, 2004) suggests that the frequency of 100 Joule impacts is less than 1 per second in an 11m diameter mill. As such, rocks requiring energy to first fracture above 100 joules will only be reduced in size slowly, and thus become severely rate-limiting. Size reduction of such rocks is thought to occur predominately through low energy abrasion and chipping events (Morrell et al, 2001). It should be noted that, in OMC's experience, not all types of rocks produce this behaviour. When observed, it is often diagnostic of a rate-limiting condition, and hence serves as an indicator of the gains available from partial secondary crushing.

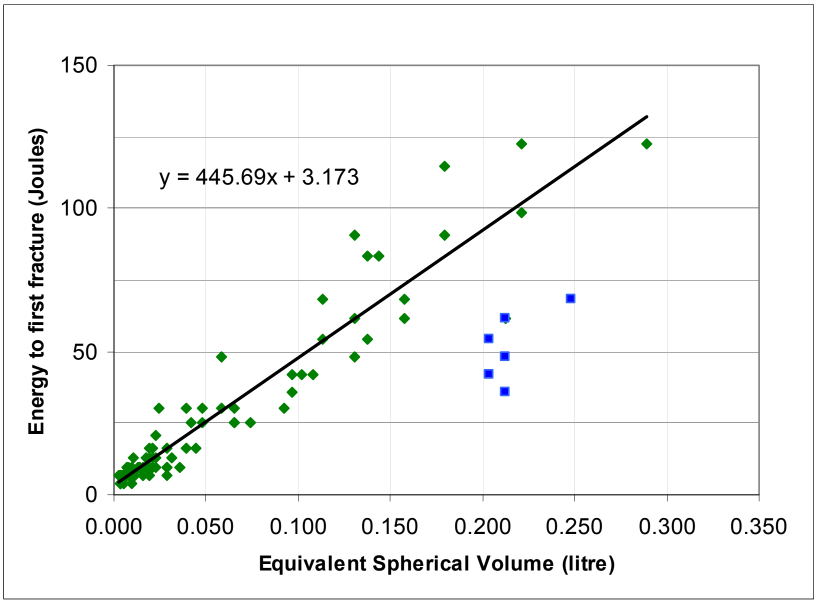

Figure 5: Variation in energy to first fracture with particle volume (Survey 2 sample)

The inference from this observation was that breakage of coarse rocks is limiting the circuit at the SAG mill. In consequence, the ball mill appears starved of feed.

Applying an in-house model of the power that can be drawn by an overflow ball mill showed that the installed ball mill is incapable of drawing the power available from the motor. A higher power draw is possible if the mill is converted to a grate discharge configuration, some 900 kW above the existing maximum power drawn.

Strategies for Increasing Circuit Capacity

From the diagnosis, the following aspects warranted attention:

SAG Power - The available 3.6 MW of SAG mill power restricts the ball charge to 5% when operated at maximum load. If operated with a 15% ball charge, the mill could draw in excess of 5.0 MW. Investigations were therefore undertaken to determine the maximum ball charge that could be structurally sustained by the mill shell and the maximum power that could be delivered through the existing drive train and ring gear.

Ball Mill Power - Conversion of the ball mill to a grate discharge unit should allow full motor power (4.1 MW) to be utilised. Further, a coarser product is obtained from a grate discharge mill as a consequence of the lower slurry level present in the mill.

Grinding Efficiency and Power Utilisation - The circuit was bottlenecked at the SAG mill, with the diagnosis suggesting that high-energy impacts are required to break material coarser than 55 mm. A reduction in the amount of top-end competent material in the feed should reduce the SAG specific energy demand. This could be achieved by introducing secondary crushed ore into the mill feed.

Further modelling showed that treating 100% secondary crushed feed would result in the circuit being ball mill limited, with the SAG mill under-utilised. Furthermore, it would result in very low loads in the SAG mill, exposing the liners to ball impacts. Therefore the use of partial secondary crushed feed best satisfied the requirements of the optimisation. It:

1. decreases inefficiencies, and
2. fully utilises the available installed power

Model Predictions

Using in-house power modelling techniques, the specific energy and power split between the SAG and ball mill was calculated for the case of secondary crushed ore, with results shown in Table 3. Power inefficiency, as measured by f_{SAG}, was estimated at 1.05, and the SAG specific energy was modelled to reduce to 6.0 kWh/t. The technique used has been validated across a range of ores, with an RMS error of 6.0% for the predictions, as illustrated in Figure 6.

Minor optimising strategies for the existing plant were also incorporated, lowering the predicted f_{SAG} to 1.26 for primary crushed ore. These modifications comprised changing to larger cyclones and altering the ball mill to a grate discharge unit.

Using the models derived, it was predicted that 45 to 50% of the feed should be secondary crushed to utilise the available power between the SAG and ball mill. Table 3 shows the balanced power scenario for a 50:50 blend and the maximum capacity estimate for the circuit. A maximum throughput of 420 tph resulted at full and balanced power utilisation, suggesting a sustainable target capacity of +380 tph.

Table 3: Partial secondary crushed feed - model of power utilisation

	Units	Primary Crushed Model (Optimised)	Secondary Crushed Feed Model	Part Secondary Crushed Model (Wt Average)
Proportion of Feed Secondary Crushed	%	0	100	50
Ball Mill Work Index	kWh/t	19.5	19.5	19.5
Net SAG Milling Rate	tph			**420**
SAG Mill Pinion Power	MW			3.85
SAG F_{80}	mm	96	25	50
Final Product	um	150	150	150
Portion of New Feed Pebble Crushed	%	35	15	25
Ball Mill Power – required	MW			3.87
POWER UTILISATION				
SAG Mill Specific Energy F_{80} to T_{80}	kWh/t	12.4	6.0	9.2
Specific Ball Mill Energy	kWh/t	8.6	9.9	9.2
f_{SAG}		**1.26**	**1.05**	**1.15**

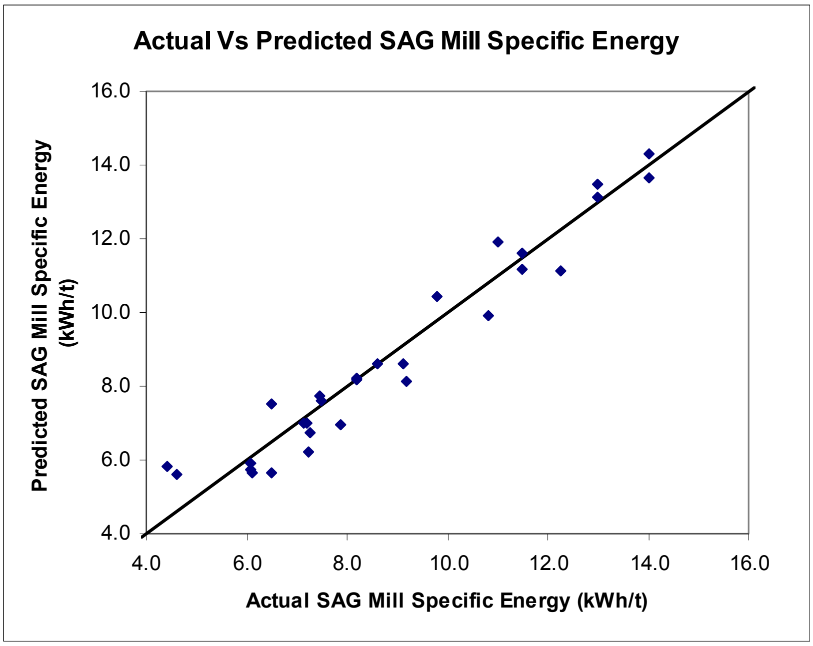

Figure 6: Comparison of actual and predicted SAG specific energy using OMC in-house technique

ENGINEERING DESIGN CONSIDERATIONS

A number of factors must be considered in the design of a secondary or partial secondary crush circuit. This section discusses some of these, such as configuration and location.

Feed Splitting and Feed Bins

Feed splitting to the secondary crushing circuit is readily achieved by use of an overflowing bin. The bin provides the feed to the secondary crusher, whilst the primary crushed material overflowing the bin by-passes the secondary crusher. Varying the rate of discharge from the bin using a reclaim feeder varies the amount of primary crushed material overflowing to the grinding circuit. This provides a large degree of flexibility and thus allows optimisation of the grinding circuit. The split material can be fed to the secondary crusher directly or a further surge bin and feeder can be installed. Use of the single feeder is lower capital but may result in higher operating costs as it does not guarantee choke feeding of the secondary crusher.

The alternative strategy of screening all the primary crushed material into two or more size fractions is not favoured, since the objective is to split the coarse fraction, providing just enough lump media to the mill, whilst crushing the remainder of the tough coarse material. Another problem with this arrangement is that there is no control of the split ratio of crushed to uncrushed ore as this is affected by the variability in the product of the primary crusher.

Crushing and Screening Configurations

A number of screening options are available to achieve a secondary crush, once the feed has been split. These include:

- Open Circuit, no screening (100% feed to secondary crusher)
- Open circuit, scalping screen – The installation of a scalping screen ahead of the secondary crusher to remove fines.
- Open circuit, Intermediate crushing – The primary crushed feed is sized on a double deck screen with the top deck oversize bypassing the crusher, the bottom deck undersize bypassing the crusher and the bottom deck oversize feeding the crusher.
- Closed circuit product screen – The secondary crusher is placed in closed circuit with a product screen.

Table 4 defines selection criteria for partial secondary crushing circuit configurations based on ore competency, secondary crusher reduction ratios and down stream processing.

Table 4: Configuration selection criteria

Configuration	Pros	Cons	Comment
Open circuit, no screening	Low Capital	Requires a fine CSS on the Primary Crusher and operates at a coarse closed side set on the secondary crusher which results in a more intermediate material	Suitable for primary mills with recycle crushers
Open circuit, scalping screen	Medium Capital	Secondary crusher CSS may be restricted by the primary crusher product size	Suitable for primary mills with recycle crushers
Open circuit, Intermediate crushing	Medium capital, Allows operation of finer secondary crusher closed side sets	Not suitable for extremely top end competent ores. The amount of secondary crushed material is influenced by the primary crusher product.	An alternative to the installation of a recycle crusher
Closed circuit product screen	No intermediate critical size generation	High Capital	Suited to primary mills without primary crushers or single stage mills. Provides high degree of control on topsize for extremely high competency ores

Location

The final major consideration is the location of the secondary crushing circuit. It can either be after the primary crusher and before the stockpile or it can be between the stockpile and the grinding circuit. Each circuit has advantages and disadvantages.

Operation as part of the primary crushing circuit is typical. This configuration requires higher capital, as the rate of secondary crushing must match that of the primary crusher, but the availability of the crushing circuit does not affect the grinding circuit. Stockpile segregation is still an operating variable with this circuit, however it is less severe than that of a primary crushed feed circuit. Changes in the amount of secondary crushed feed will have a lag time between the crusher and mills depending on the size of the stockpile.

Installation of the partial secondary crushing circuit off the mill feed conveyor will reduce the capital cost of the installation, as the circuit capacity is only required to match the milling rate. Operation off the mill feed conveyor also allows immediate changes to the mill feed composition. Under these conditions the portion of the feed secondary crushed could be controlled to maintain a consistent feed through the use of an optical monitoring system. This would result in very steady feed to the mill and thus steady production rates. The negative of this configuration is that the lower availability of the crusher will affect mill throughput, as the grinding circuit would be forced to treat primary crushed feed when the crusher is offline. The effect on production would be expected to be similar to that experience when a recycle crushing circuit is taken off line.

IMPLEMENTATION

The Mt Rawdon upgrade involved the installation of a secondary crushing circuit, new cyclones to cope with the increased flow, and modifications to the ball mill. The secondary crushing circuit was installed after the gyratory and before the stockpile. A photograph of the installation is shown in Figure 7 and a Process Flow Diagram is presented in Figure 8.

Figure 7: Secondary crushing arrangement

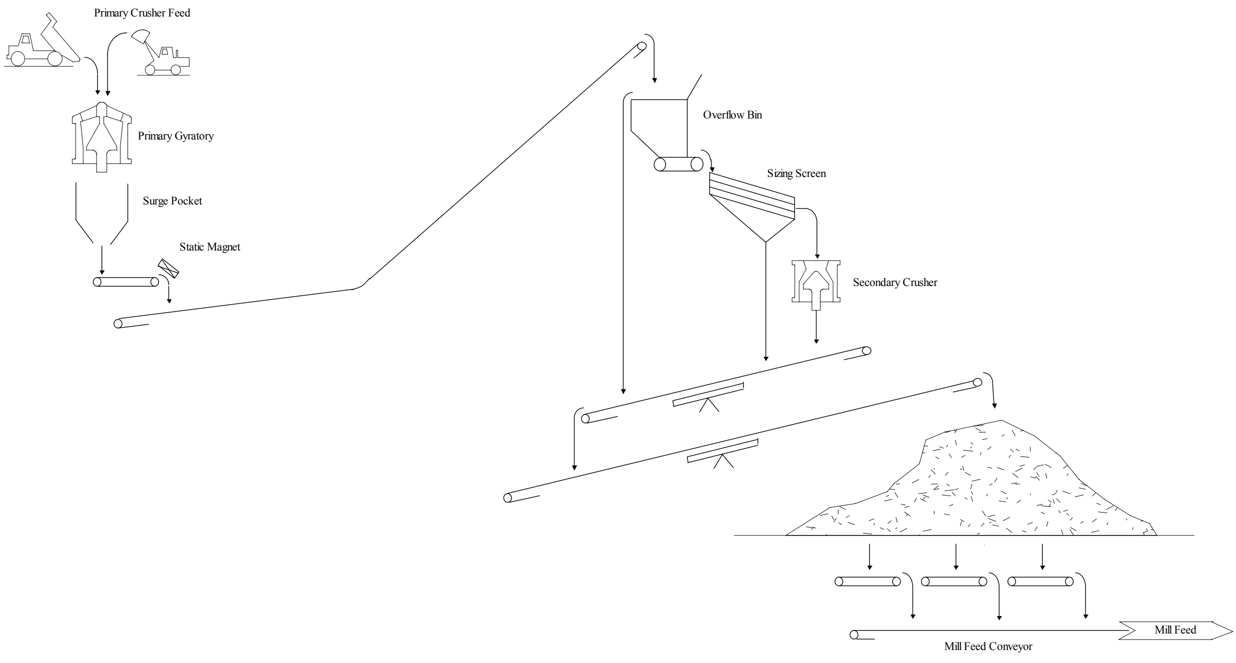

Figure 8: Secondary crushing PFD

The arrangement comprises an open circuit with a surge bin, double deck screen and Jaques El-Jay 65 cone crusher. A vibrating feeder transfers ore from the surge bin to the screen. The feed to the screen is controlled such that a set portion of primary crushed material overflows the surge bin, which then combines with the crushed material to achieve a partially secondary-crushed blend. Material not passing through the 80 and 30 mm aperture decks of the scalping screen is fed to the secondary crusher before being recombined with the screen undersize.

Upgrades were made to both mills. A grate was installed in the discharge end of the ball mill to provide better pulp removal and thus increased the mill power draw by 600 kW. The twin 1850 kW motors on the SAG mill, which were presenting maintenance issues, were replaced with two 2.4 MW motors. The SAG mill drive train now limits the mill power draw at 4.2 MW.

CIRCUIT PERFORMANCE

This upgrade increased the circuit capacity from ~270 tph to in excess of 395 tph, with 50 to 60% of the ore crushed. With an increased ball charge and load, the SAG mill is drawing on average 3.8 MW.

Table 5 compares the design specific energy predictions to the actual circuit performance for Dec.03 and Jan.04, during which time approximately 50% of the ore was primary crushed as per the circuit design. The circuit efficiency is displayed as an operating work index (Wio) and in terms of f_{SAG}. It can be seen that the power split and f_{SAG} are close to the design values.

An average Bond Ball Mill Work Index of 19.5 kWh/t was used for the analysis and design. The ball work index of the ore is know to vary from 18.3 to 20.7 kWh/t and contributes to some of the variation in plant performance. Motor input power from the plant data has had a 92.5% efficiency factor applied to arrive at pinion power, the same factor that was used in the upgrade design.

Figure 9 shows the ramp-up to higher capacity, with the upgrade being done in stages.

Table 5: Power utilisation - design versus actual

		Design Max Capacity	**2 Month Average**
Ball Mill Work Index	kWh/t	19.5	19.5
Milling Rate	**tph**	**420**	**395**
SAG F80	mm	48	48
Final Product	um	150	154
SAG Mill Pinion Power	MW	3.76	3.50
Ball Mill Pinion Power	kW	3.78	3.59
POWER UTILISATION			
Specific Crushing Energy 150 mm to F80	kWh/t	0.26	0.26
SAG Specific Energy	kWh/t	9.2	8.9
Specific Pebble Crushing Energy	kWh/t	0.1	0.1
Ball Mill Specific Energy	kWh/t	9.3	9.1
Total Specific Circuit Energy	**kWh/t**	**18.6**	**18.3**
Operating Work Index (Wio)	**kWh/t**	**23.9**	**23.7**
$\mathbf{f_{SAG}}$		**1.15**	**1.14**

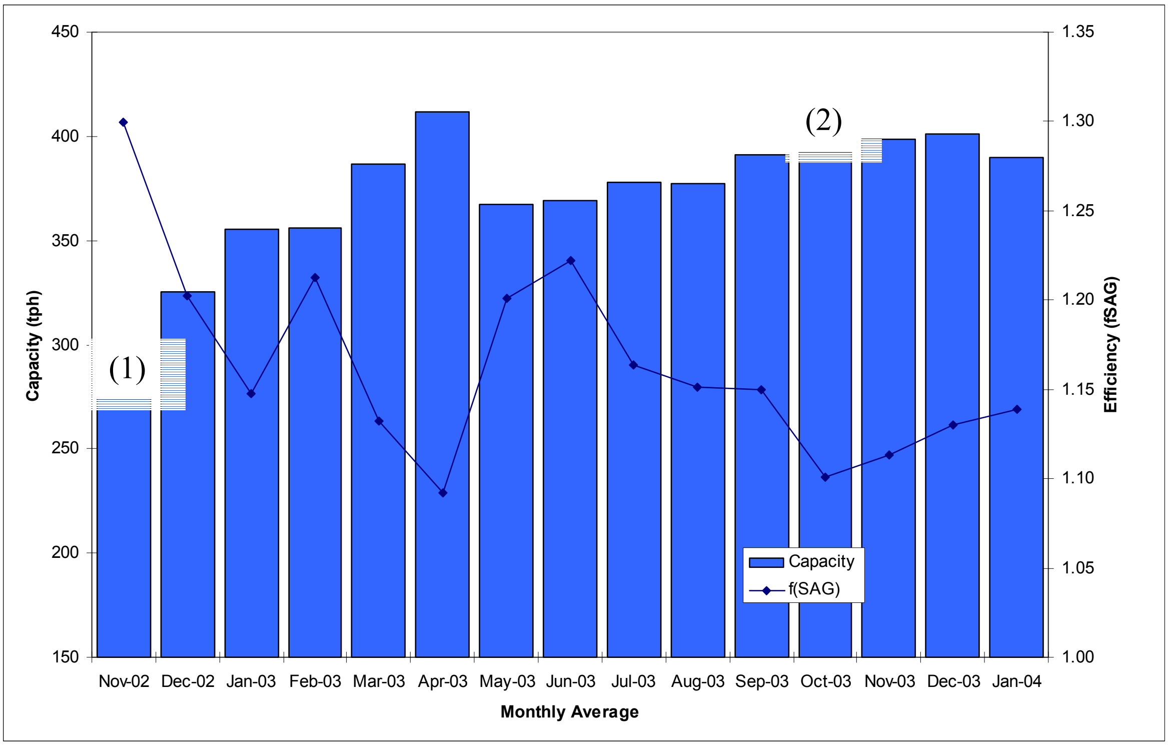

Figure 9: Monthly production data

(1) Installation of the secondary crushing circuit and ball mill modifications
(2) Installation of new SAG mill motors

Overall the optimisation and upgrade resulted in a 45.8 % increase in production. This comprised:

- a 12.5% decrease in the operating work index of the ore being treated;
- generation of 4.6% more power in the SAG mill (2.6% overall);
- utilisation of 37% more power generated in the ball mill (16.2 % overall);
- coarsening of the final product to design value.

CONCLUSIONS

In any optimisation project on a comminution circuit, it is important to identify the factors causing the rate limitation and to understand the full potential of the installed plant equipment. Typically, this is done using ore characterisation testwork, in conjunction with plant survey data.

Identification of rock properties that cause rate limitation is critically important. The method advocated here is to determine the energy required to achieve first fracture. A first order response with increasing mass appears diagnostic of rate-limiting problems, with accompanying SAG power inefficiencies of around 50%.

For a competent ore such as Mt Rawdon, reducing the feed size by partial secondary crushing will reduce the amount of coarse rock, thereby increasing the capacity of the SAG mill. There are many methods of achieving a partial secondary crush, the one favoured here used a simple overflowing bin approach to balancing the split. Location ahead of the stockpile was favoured to de-couple the crusher from the SAG mill feed.

Blending of primary and secondary crushed ore allowed sufficient media to be presented to the mill, whilst lowering the energy demand. It decreased inefficiencies, allowing controlled utilisation and balancing of the grinding energy available.

The validity of the predictions was amply demonstrated in practice, with an increase in capacity approaching 50% achieved for minimal capital outlay. Elimination of power limitations played an important part in the optimisation, allowing the installed mills to reach their full potential.

Finally, by controlling the feed to the SAG mill, partial secondary crushing dampens the wild swings in throughput often experienced by SAG milling circuits which cannot be controlled by recycle crushing. Stable operation will provide higher annual capacity whilst aiding downstream processes such as flotation, which are often negatively affected by changes in throughput and product size from the grinding circuit. In essence, a partial secondary crushing circuit allows control of the feed to the grinding circuit and if installed effectively, it can be used to nullify much of the effect from mining changes, primary crusher performance and stockpile segregation.

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