OPTIMISATION AND CONTINUOUS IMPROVEMENT OF ANTAMINA COMMINUTION CIRCUIT

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ABSTRACT

Compañía Minera Antamina is a polymetallic mining complex that produces copper and zinc concentrates as primary products and molybdenum and lead/bismuth/silver concentrates as by-products. In 2007, Metso Process Technology and Innovation (PTI) was contracted to increase SAG mill throughput by integrating and optimising blast fragmentation, crushing and grinding for the harder M4/M4A (CuZn) ores. Following the implementation of recommendations provided by Metso PTI, the SAG mill throughput increased from 2750tph to reach an average of 3600tph for the remainder of 2007. Due to continued application of mine to mill integration and optimisation philosophy, by 2010, the concentrator consistently exceeded the target of 4400tph while processing harder CuZn ores.

KEYWORDS

Antamina, SAG, blasting, crushing, grinding, optimisation, simulation, comminution

INTRODUCTION

Antamina, a polymetallic mining complex that produces copper and zinc concentrates as primary products and molybdenum and lead/bismuth/silver concentrates as by-products, represents one of the main complexes of the Peruvian mining industry. It is situated in the central Peruvian Andes around 4,300 meters above sea level.

The project, which commenced operation in 2001, had worked on initiatives which achieved the design capacity of 70,000tpd after five months of operation with the copper ore (M1/M2). There were several issues associated with the copper/zinc ores (M4/M4A), which limited the throughput for these ores types to just half of the M1/M2 throughputs (i.e., 2,000-2,500tph vs. 4,000-5,000tph respectively). Achieving similar throughputs for both ore types became a challenge for Antamina, and in 2007 Antamina contracted Metso Process Technology & Innovation (PTI) for the implementation of a Mine to Mill project.

Ore classification at Antamina considers six principal ore types which are processed based on grinding and flotation requirements. One of these ore types includes sub categories, M4 and M4A, which are blended together prior to processing in order to get the most stable grades for the downstream separation. This paper describes the work carried out by Antamina and Metso PTI with the objective to increase the throughput exclusively for the copper/zinc ore types (M4/M4A).

Metso PTI started the project in early 2007 and continued until the end of 2009. Work conducted during this period included: comprehensive review of existing operations at the mine and in the comminution circuits, characterisation of ore sources into domains of similar blasting/fragmentation properties, measurement of blast design implementation and resulting fragmentation, measurement of vibration and definition of main constraints, monitoring of blasted material movements using passive radio-frequency transponders or SmartTag^{TM} system, review of current operating practices of the primary crusher, the SAG and Ball mills grinding circuits, a comprehensive analysis of historical data, modeling of current drill and blasting, crushing and milling operations, and mine to mill simulations of optimum operating strategies which were finally put into practice in combination with other initiatives led by Antamina personnel.

Metso PTI methodology is based on mechanistic and forward analysis that involves the following practices:

a) Characterisation and delineation of blast domains based on rock structure and strength. The measurement techniques that have been developed over many years present results that represent the conditions in which the mines operate in a production environment. The techniques are practical and statistically representative requiring only a few other tests to validate the results and confirm the correlation (e.g., Drop Weight and SMC tests). They are inexpensive and can be easily carried out by mine personnel.
b) Establish process constraints such as wall stability, damage and control in the pit and in the tailings dam, presence of water, ore dilution, muckpile characteristics, size of mining equipment, size and installed power of crushing and milling equipment and other process bottlenecks.
c) Definition of the key downstream requirements and development of drilling/blasting strategies for each domain to suit the defined downstream requirements (milling of ore or waste).
d) Use of proven software tools, predictive models and simulations in conjunction with the experience and collaboration of mine and plant personnel to establish optimum operating and control strategies to maximise overall profit from the blast to the mill.
e) Implementation and monitoring of the defined integrated operating strategies (suitable blast designs for each ore domain followed by respective optimal crushing and grinding strategies) and establishment of standards, quality assurance and control mechanisms.
f) Analysis and management of comprehensive data and results.
g) Long term implementation and maintenance of benefits.

The steps above are focused on the development of an integrated mining and milling optimisation strategy to increase profitability of the operation. Part of this strategy is to increase plant throughput with little or no capital investment. By optimising rock breakage and fragmentation from blasting through crushing and grinding the following benefits could be achieved:

- Increased excavation and loading efficiencies;
- Reduced ROM topsize allowing the primary crusher to achieve greater throughput while operating at a smaller gap to produce mill feed with a finer topsize;
- Reduced SAG mill feed topsize and increased proportion of fines (-10mm material) to increase mill throughput with existing installed power;
- Minimal adverse impacts such as dilution or ore loss, structural damage or environmental nuisance.

This paper summarises the work performed by Antamina and Metso PTI and includes recommendations of changes in blasting, crushing and grinding operation and also control in order to improve mill performance during the treatment of M4/M4A ores.

ROCK CHARACTERISATION

Metso PTI Process Integration & Optimisation methodology involves rock characterisation in terms of its strength and structure. One of the objectives of rock characterisation is to determine domains within the orebody that will generate similar blast fragmentation. By understanding what domains exist, the mine can establish standard blast patterns for each of the different domains that will generate similar fragmentation distributions. This may require either an increase in blasting energy (e.g., powder factor or explosive weight per tonne of rock) or perhaps a decrease in energy – depending on the rock properties.

Measurement of Rock Strength & Structure

Fracture Frequency (FF) and Rock Quality Designation (RQD) give a good indication of the rock mass structure, which in turn will drive the proportion of coarse material in the blast fragmentation. Fines generation in the blast is mainly related to rock strength as well as explosive/rock interaction.

The Point Load test provides an Is50 index for rock strength classification that is well known and widely used in the industry, mainly by geotechnical personnel. It is commonly used as a quick and simple method to predict Unconfined Compressive Strength (UCS).

Antamina categorises their ore into material classifications or *ore types*: copper-only (M1, M2, and M2A), copper-zinc (M3, M4, M4A) and bornite (M5, M6) depending on the Cu, Zn and Bi assays. However, this ore type classification is based on assays alone and does not necessarily reflect any distinct rock type or lithological variation.

Much higher mill tonnages experienced for M1 compared with M4/M4A material are due to differences in the SAG mill feed size distribution. Figure 1 shows a range of M4A SAG feed size distributions compared with an M1 feed size distribution.

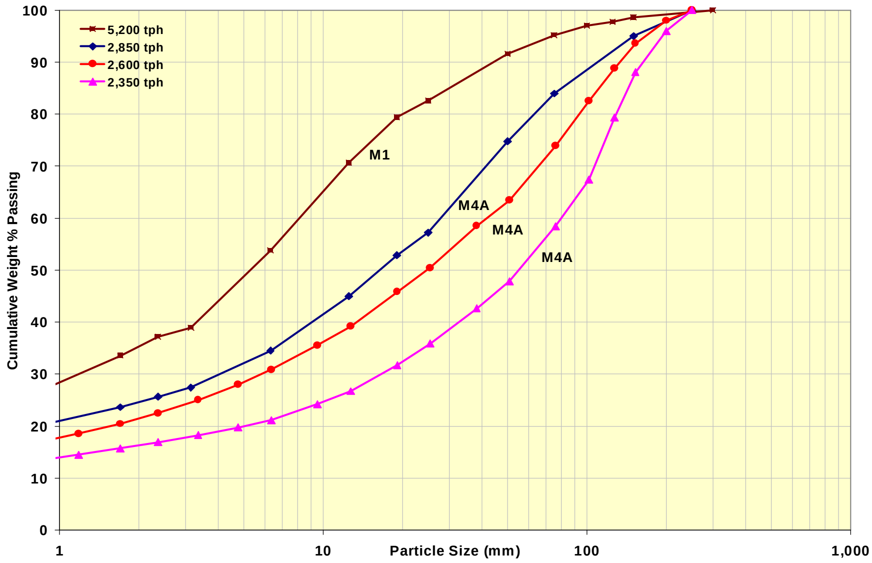


Figure 1 – Comparison of SAG mill feed size & throughputs

It is clear that the M1 material fragments very finely in the blast – producing about 70% minus 10mm and an 80% passing size (P80) of 20 to 25mm after crushing, and is processed at 5,200tph. In contrast, the M4A material blasts much coarser – after crushing it has a P80 of 50 to 150mm – and represents a typical SAG mill feed. This material is processed between 2,350 and 2,850tph.

<u>Rock Strength – Point Load Index</u>

Based on the Point Load Index (PLI) Is50 value, the Unconfined Compressive Strength (UCS) was estimated. The results, presented in Figure 2, show that all ore types and survey samples exhibited a wide range of rock strengths from below 50MPa to more than 250MPa. The wide range of strengths indicates that each ore type is not consistent in rock properties; most likely due to a variety of rock types and structures.

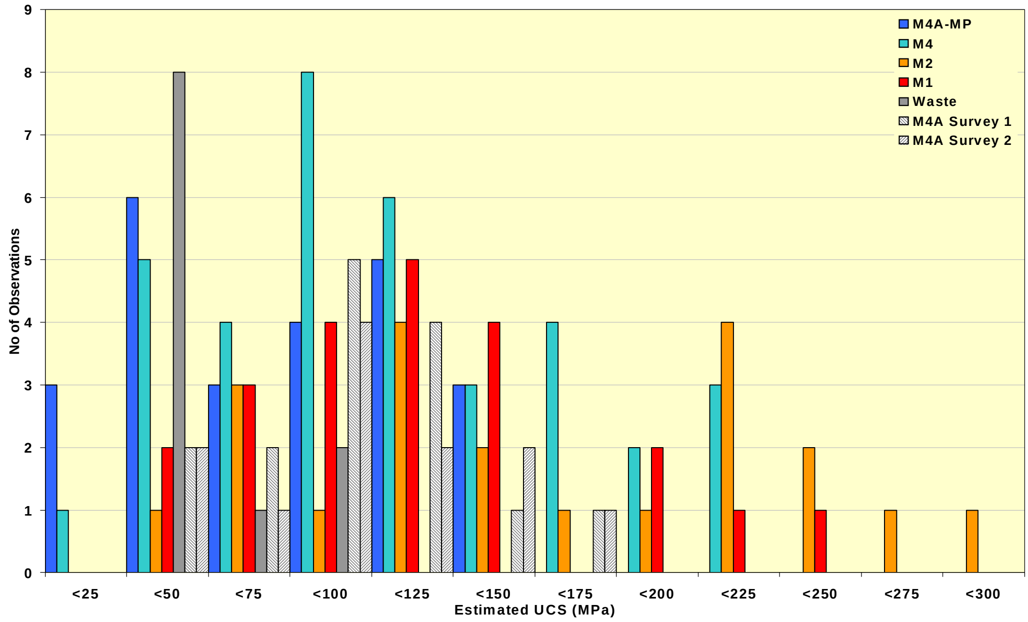


Figure 2 – Summary of estimated UCS from Point Load Index measurements (Jan 2007)

Metallurgical Hardness Testing

A summary of the Bond Ball Mill Work Index (BWi) results since 2002 is shown in Table 1. These results appear to be quite consistent with M1 reporting a BWi of around 10kWh/t (relatively soft) and M4/M4A between 12 and 14kWh/t (moderate). It appears that the variability in hardness between ore types is lessened when the material is below 3mm and suitable to be processed by ball mills.

From a SAG mill's perspective, the UCS and BWi results indicate a wide variability in rock hardness with both M1 and M4A ore types exhibiting soft and hard behaviour. However, once reduced to ball mill feed size; the materials have similar properties with M1 exhibiting a slightly lower energy requirement compared with M4A.

With a constant blast pattern used for all these ore types, it would be expected that the variable rock properties would respond differently and result in a finer and coarser fragmentation which finally results in a range of mill throughputs.

Overall, the M1 material fragments very well whereas M4/M4A ore types do not fragment as well and result in lower mill production. However, the variable production figures indicate that fragmentation is never consistent – a consequence of not adjusting the blast pattern to suit the rock conditions. By identifying the rock strength and structure associated with each rock type, and adjusting the blast design accordingly, it is expected that the variability would be reduced and making it easier to predict.

Table 1 – Summary of Bond Ball Work Index by ore type

Ore type	Date	BWi(kWh/t)	S.G
M1	Feb 2002	10.0	3.10
M1	Aug 2002	9.5	2.90
M1	Oct 2002	9.6	3.00
M1	Feb 2006	10.3	3.40
M1 intrusive	Feb 2006	9.5	2.80

M3	Jan 2002	10.5	3.71
M3	Jan 2003	12.1	3.64
M4	Jan 2002	12.1	3.59
M4	Nov 2002	11.3	3.30
M4	Feb 2003	10.5	3.60
M4A	Mar 2002	12.7	3.30
M4A	Feb 2003	12.6	3.30
M4A	May 2003	11.8	3.20
M4A	Feb 2006	13.1	3.54
M4A	Feb 2006	13.8	3.39

Blasting Domain Definitions

It was recommended that Antamina initiate a drill core-testing program measuring both rock strength and structure based on PLI and RQD. In core sections of known ore types, samples of different rock types should be logged for RQD and then tested for PLI. Very quickly, Antamina could generate an updated database of rock strength and structure for rock types associated with M1 and M4A (the two main ore types requiring domain definition). Table 2 lists possible rock types to be tested for M1 and M4A.

Table 2 – Rock Types to be characterised (Based on 2007 mill feed)

Ore Type	Rock Type
M1	Café Endoskarn
M1	Rosa Endoskarn
M1	Café Verde Exoskarn
M1	Intrusive
M4A	Verde Exoskarn
M4A	Café Verde Exoskarn
M4A	Café Endoskarn

When designing a blast pattern, it was recommended to estimate the amount of Endoskarn and Exoskarn in the blast and set the burden and spacing according to a tighter pattern for Exoskarn and wider pattern for Endoskarn. Metso PTI recommended that Antamina design the blast pattern for the most difficult rock conditions encountered –i.e., presence of M4A material, Exoskarn rock type or high Blastability Index– whatever the measurement used. Rather than design the blast for the average rock conditions or for the softest material, blasts should be designed to adequately fragment the most challenging material. This will ensure a minimum quality of fragmentation (and mill throughput) is maintained.

REVIEW OF BLASTING PRACTICES

Metso PTI carried out an audit of Blast 3-SP-4283-08 detonated on January 10th 2007. The blast polygon was a mix of ore (domains M4, M4A, M1 and M2) and waste. The copper zinc ore (M4, M4A) from this blast was monitored very closely with passive radio frequency transponders (SmartTags™) placed both in the stemming of some of the blast holes and on the surface of the muckpile after the blast to track this particular ore "parcel" from blast to the mill. The SmartTags™ were detected using an antenna placed over the primary crusher product conveyor and another over the SAG mill feed belt. The following data was collected as a part of the blast audit:

- Blasthole locations (design & actual)

- Explosive loading
- Measurement of velocity of detonation (VOD) and far-field vibration
- Fragmentation images for size analysis
- Samples for Point Load Testing

As a part of the audit carried out on Blast 3-SP-4283-08, Metso PTI reviewed ‘as designed’ and ‘as drilled’ drill hole parameters to determine accuracy of the design implementation. The parameters included burden, spacing, blasthole length and stemming length. Figure 3 overlaps the location of the designed versus the ‘as drilled’ hole patterns, which generally matched very well.

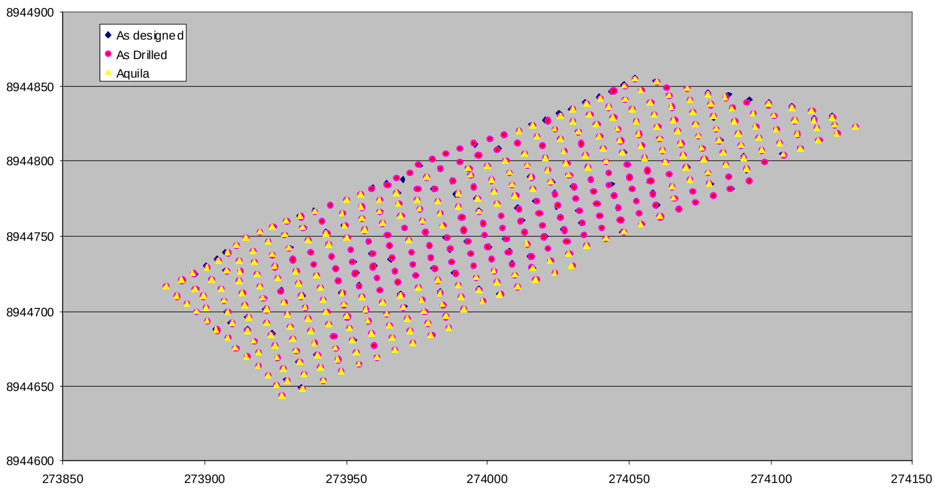


Figure 3 – Design and actual drill hole locations

Estimates of ROM or blast fragmentation distributions were made using image analysis software. Digital photographs were taken of muckpile, shovel working face (digline) and haul truck beds while dumping at the primary crusher. An example of the image delineation used to determine the particle size distribution is presented in Figure 4.

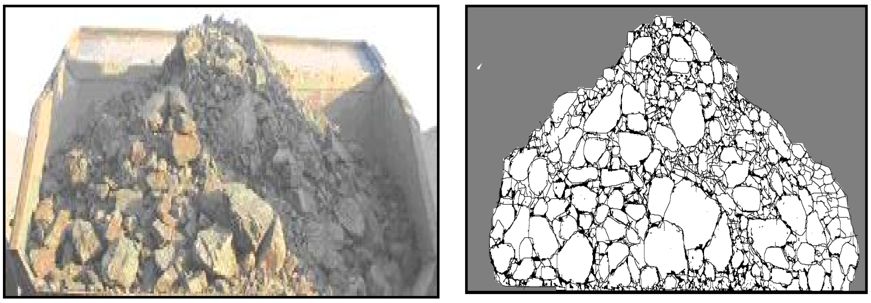


Figure 4 – of Truck bed image and resulting particle delineation

Blast fragmentation modelling has been used to identify the key parameters affecting fragmentation. Each of these parameters has a natural variation (e.g., rock strength) and error (e.g., hole position) associated with it. Therefore, a stochastic approach is taken in modelling blast fragmentation and these variables are input with a mean and standard deviation. This modelling approach uses Monte Carlo sampling followed by model simulation giving envelopes of ROM size distributions.

Figure 5 shows the impact of variations in blast design parameters (explosive, rock, drill pattern, stemming length, and subdrill) on the fragmentation of Blast 3-SP-4283-08. The envelope of ROM ore size distributions is shown by the lower 95% confidence level, the upper 95% confidence level and the mean. Based on the variation in design parameters measured in the audited blast, it is expected that significant variations in blast fragmentation are common at Antamina. For these simulations, the 80% passing size varied from 157 to 476mm.

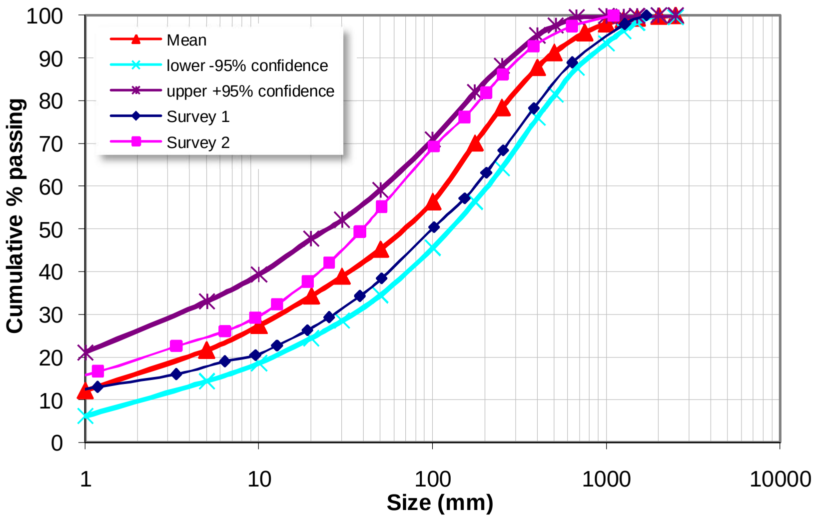


Figure 5 – Stochastic fragmentation modelling

The fragmentation model was calibrated for a range of ore types (i.e., M1, M2 and M4). It appeared that fragmentation in the M4 domain is much coarser than M1 and M2. Based on the SAG mill feed surveys conducted, the variations in cumulative percent passing at 25mm size in M1 and M4/M4A are 70 to 80% and 35 to 60%, respectively. Figure 6 shows typical ROM fragmentation curves for M1, M2 and M4/M4A ores.

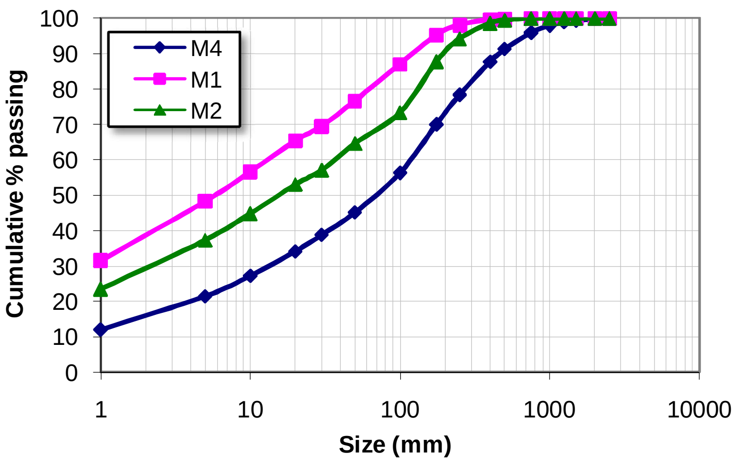


Figure 6 – Blast fragmentation modelling of different ore types

The blast fragmentation model was used to predict the ROM fragmentation size. Two additional blast designs were reviewed for the M4/M4A domain using a new powder factor design. The fragmentation model estimates a reduction in ROM P80 from 401 to 129mm. The results showed that the blast design with the smaller blasthole diameter generates the finest fragmentation. The explosive energy distribution was better with this design. Thus, Metso PTI recommended a blast design with 251mm drill holes.

SMARTTAG™ MATERIAL TRACKING

In any PIO project, it is crucial that the material being fed to the mill during a plant survey is the same material that has been characterised in the mine. Metso PTI has developed an ore block tracking system named SmartTag™ that allows parcels of ore to be tracked, from the mine, through the crusher and finally into the grinding mills. The SmartTags™ are built around robust passive radio frequency transponders. Not having an internal power source, they can remain in stockpiles and ROM pads for extended periods of time.

Figure 7 shows a typical SmartTag™ installation. The tag passes under the antenna along with the ore where it is energised by an electromagnetic field. The tag then transmits its unique ID back to the antenna where it is stored along with a time stamp in the recording device or Tag Reader. For permanent installations, a wireless communications link or direct network connection can be used to transmit the tag information back to a central database.

Tags can be placed in the stemming column of blastholes and a high percentage will survive the detonation. Alternately, they can be placed on the muckpile surface post-detonation. The tags are small enough to pass through a primary crusher and be detected on the product conveyor belt. They can then be detected on the SAG mill feed belt before being destroyed in the mill. SmartTags™ offer an inexpensive and versatile tool for material tracking and can provide information on blast movement during detonation, dilution or ore loss, stockpile inventories and blending practices.

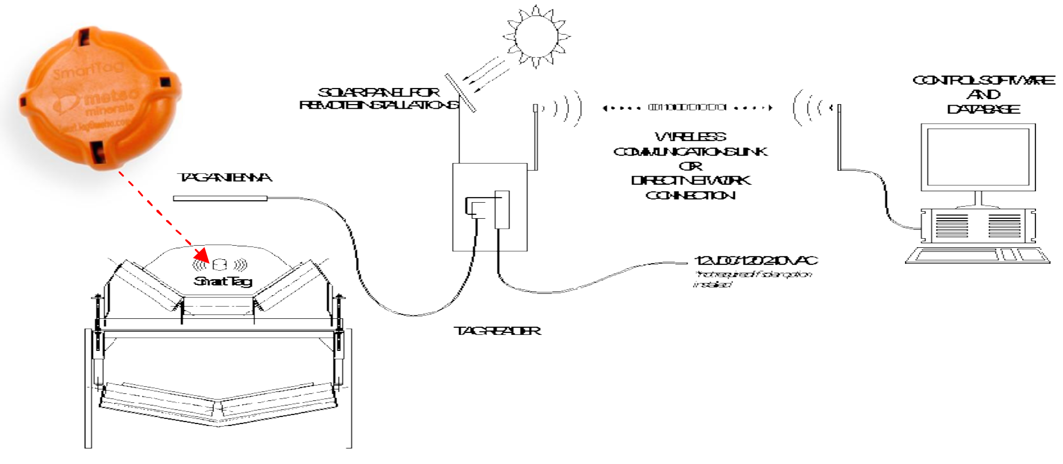
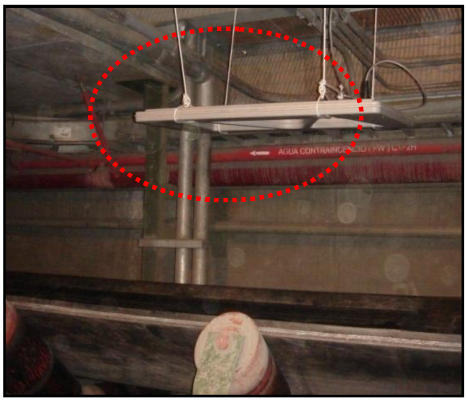


Figure 7 – Elements of SmartTag™ installation

By locating antennas at critical points in the process flow ahead of the milling circuit, SmartTags™ can be detected a number of times and provide valuable information on material movements. In particular, they provide a means to link the spatial information associated with the mine to the time-based or temporal information of the concentrator. Two antennas were installed at Antamina – one on the primary crusher product belt and another on the SAG mill feed belt – as shown in Figure 8a and b.

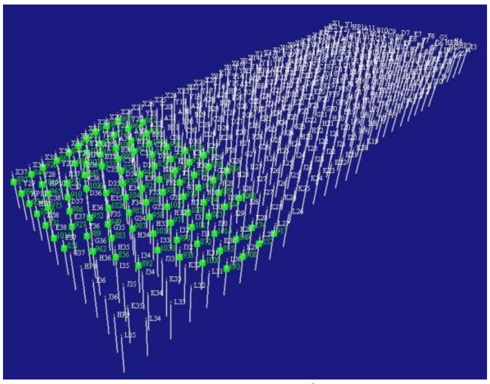
(a) Primary crusher product.



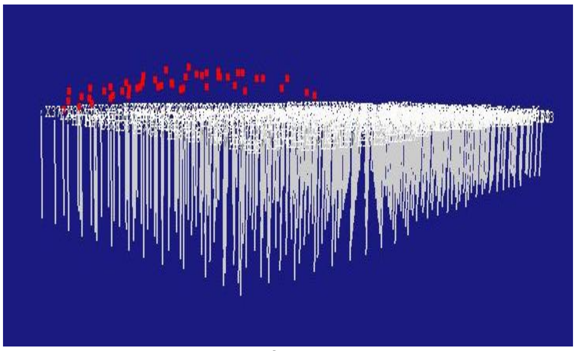
(b) SAG mill feed

Figure 8 – SmartTag ™ temporary installation

For audited blast 3-SP-4283-08 discussed previously, 101 SmartTags™ were placed in the stemming of the blast holes, with a further 48 on the muckpile surface post-detonation. Figure 9 illustrates the tag distribution in each case.



(a) stemming columns of blast holes



(b) muckpile surface post detonation

Figure 9 – SmartTag ™ locations

Figure 9a shows that all the blastholes that were tagged were in the southwest portion of the blast. The southeast corner was known to be in waste and was not tagged. The x,y,z locations of all tags placed on the muckpile surface post-detonation were picked up by a surveyor. The audited blast was quite confined with the material throw inwards. As a result the muckpile heave was measured to be a few metres as shown in Figure 9b.

The SmartTag™ detection times are presented at the bottom of Figure 10, with blue icons representing tags that passed through quickly (<2hrs) and red icons representing tags that passed through slowly (>32hrs). In the first cluster of blue icons, it appears that the coarse ore pile height was low for an extended period. This also corresponded with an increase in the SAG feed size F80 (mm) as measured by the on-line image analysis system and a decrease in mill tonnage. January 16th recorded periods where the tag residence time was long. It is hypothesised that the tags that had detection times greater than 32 hours were placed on the pile at high stockpile levels and were consequently carried to the outer perimeter increasing residence time.

Knowledge of shovel locations over time – combined with the SmartTag™ detection times enables material movements during a blast to be estimated. From these movements, the potential for ore loss and dilution can be quantified. This is particularly important at Antamina where the polygons of different ore types and waste can be very small – perhaps only tens of metres squared. Using the tag detection times at the primary crusher, the dispatch records were used to determine which truck was dumping in addition to the shovel location when that truck was filled.

The audited blast was quite confined where the material was thrown internally and this was reflected in the resulting tag movement vectors. The length of the vector also reflected the distance the tags moved during the blast (and possibly during clean-up and excavation). This movement averaged 25m indicating that some of the material moved in excess of 25m. While some of this may be due to the tags rolling down the free face as they are exposed during excavation, it is estimated that the tags experienced at least 15m of movement in the direction of the free face. Based on the SmartTag™ results from the audited blast, there was evidence of significant dilution and ore loss.

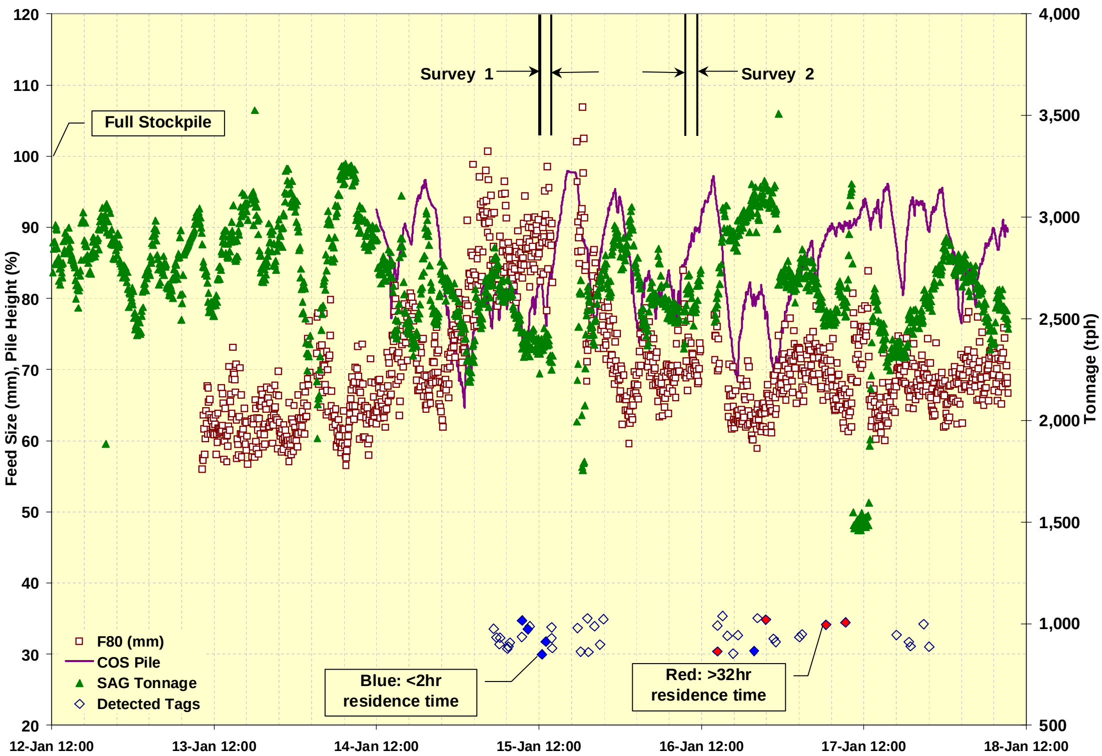


Figure 10 – SmartTag™ detection times with coarse ore stockpile conditions

PRIMARY CRUSHER OPERATION

Operation of the primary crusher is very important in optimising mill feed size for maximum throughput. While it has already been stated that the majority of the fines in the feed are generated in the 'crushing' zone during the blast, the top size of the mill feed is dictated by the crusher setting and operation. Maximising the ***average*** power draw of a primary crusher will result in a finer product. In addition, choke feeding of a primary crusher results in multiple breakage events as the material passes down the chamber rather than only a few events for a non-choked crusher. The ROM topsize and crusher gap have the following interdependence, which will affect "Mine-to-Mill" optimisation:

- Crusher throughput for a given CSS is largely controlled by the largest rocks in the ROM.
- Reducing the top size of ROM ore allows the crusher to operate at the same throughput (and same power draw) with a smaller CSS.
- Finer ROM allows the CSS to be reduced and results in the production of a finer crusher product.
- Finer ROM and smaller CSS allows better choke feeding in the crusher, which produces finer feed to the SAG mills and also increases the life of the crusher mantle and concaves.
- For a given crusher CSS, variations in the crusher product P80 will result from differences in ore hardness as well as variations in the blast fragmentation.

Primary Crusher Product Sample

In order to evaluate the performance of the primary crusher, a sample of the product material was collected from the conveyor belt on January 15th following the Metso PTI methodology. At the same time, trucks dumping into the crusher were photographed for image analysis of the crusher feed material. These data were used to develop a primary crusher model for the simulation study investigating the impact of ROM ore size and crusher setting on mill throughput. The ROM and crusher product size distributions are provided in Figure 11. **Figure 11**

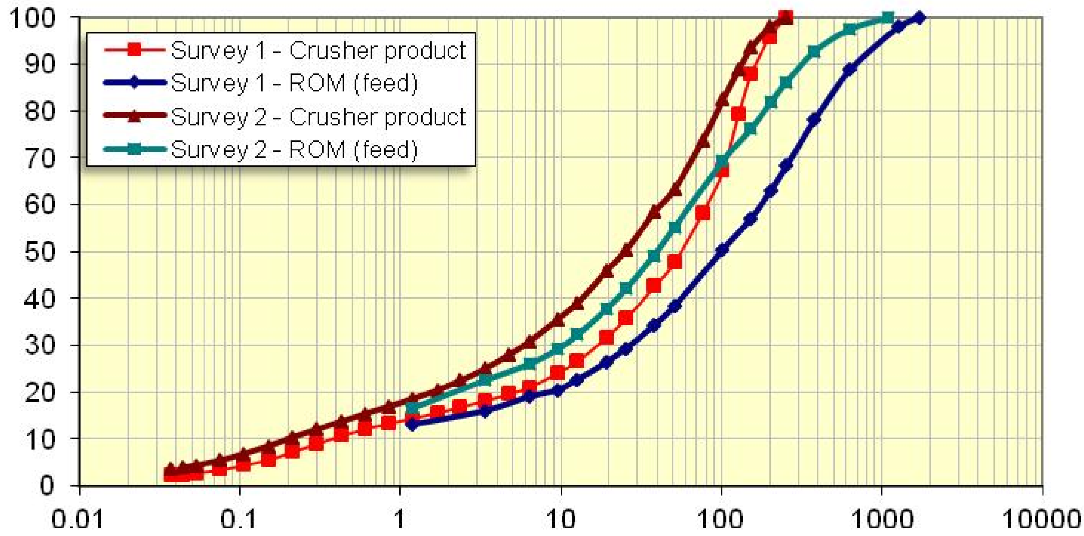


Figure 11 – ROM and crusher product size distribution

Using a tighter setting did not produce a higher power draw and therefore there was more capacity available in the primary crusher to operate at a tighter setting (4.5 to 5 inches) without negatively affecting the throughput.

GRINDING CIRCUIT

In January 2007, two complete grinding circuit surveys were performed followed by a SAG mill crash stop and grind-out. After stopping the mill, a SAG mill feed sample was also collected from Conveyor 1. Figure 12 shows the circuit and sampling points of the grinding circuit.

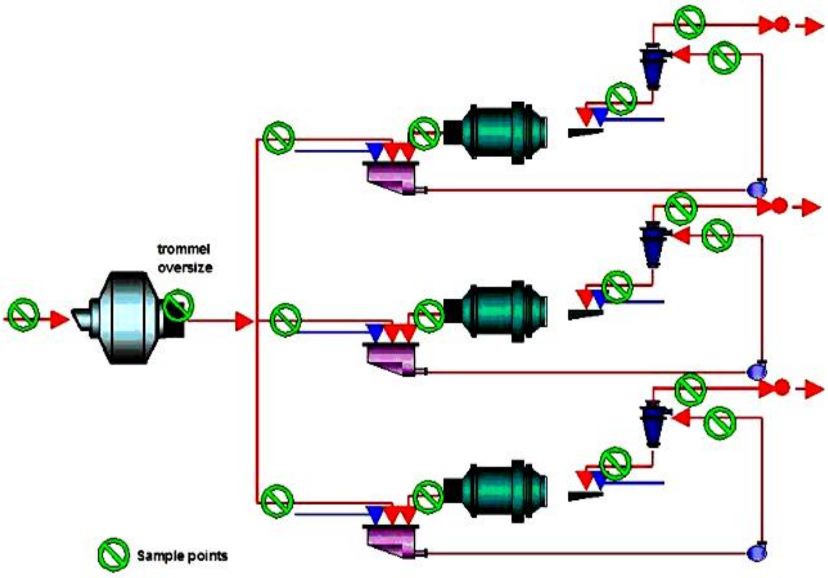


Figure 12 – Flow sheet and sampling points of the milling circuit

Due to lower throughputs when processing M4/M4A ores, only two of the three ball mills are operated when treating these ores. For instance, during the first survey, ball mill 2 was not operating and during the second survey, ball mill 1 was not operating. The summary of the surveys conditions are presented in Table 3.

Table 3 – Summary of SAG mill survey conditions

Variable	Survey 1	Survey 2
Power, MW	14.8	15.6
Bearing Pressure, kPa	5347	5386
F80, mm	89.7	79.5
Throughput, tph	2366	2617
Total charge, %	23	23

Mass Balancing

Mass balancing showed that the survey data were of good quality and consistent. Table 4 summarises the key stream tonnages, percent solids and P80 values for both surveys.

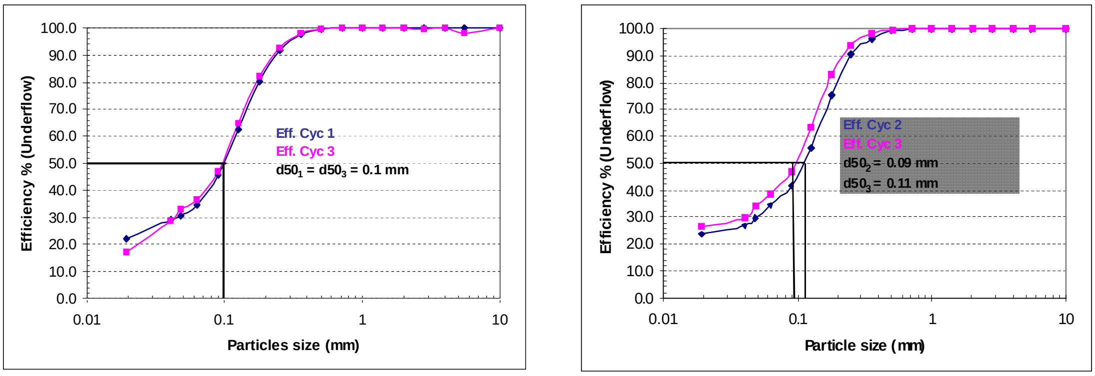
The cyclone feed density was lower for Survey 1 compared to Survey 2 (60% vs. 65%). All the ball mill circuits had relatively low circulating loads of approximately 230%.

Table 4 – Grinding circuit survey – balanced results for Survey 1 and Survey 2

Stream	Mass Balance results Survey 1			Mass Balance results Survey 2		
	Solids (tph)	% solids	P80 (mm)	Solids(tph)	% solids	P80 (mm)
Fresh Feed	2363	96.69	121.5	2617	95.0	92.99
SAG discharge	2363	70.88	1.12	2617	69.7	1.47
trommel oversize	45.78	92.31	30.18	62.9	95.7	30.72
BM 1 product	2482	69.85	0.321	3131	77.5	0.454
BM 3 product	2342	68.68	0.296	3079	75.5	0.335
cyclone 1 feed	3602	59.46	0.454	4462	65.1	0.651
cyclone 1 o/f	1120	38.42	0.124	1332	42.9	0.13
cyclone 1 u/f	2482	78.98	0.736	3131	83.5	1.234
cyclone 3 feed	3585	60.67	0.351	4364	64.9	0.409
cyclone 3 o/f	1242	41.95	0.113	1286	43.3	0.116
cyclone 3 u/f	2342	79.47	0.484	3079	82.1	0.555
SAG disch. BM1	1120	74.59	2.112	1332	72.4	1.984
SAG disch. BM3	1242	67.85	0.619	1286	67.0	1.058

Based on the mass balanced results, the cyclone efficiency curves were plotted. It was observed in Figure 13a that the sharpness of classification for Survey 1 was relatively high and fraction of fines by-passing to the underflow was relatively low (<20%). This can be explained by a favourable cyclone feed density of around 60%.

Figure **13**b shows the cyclone efficiency curves for Survey 2. The cyclone feed density was higher, therefore, the cyclone efficiency was slightly lower and the amount of fines by-passing to the underflow had increased to at least 25%.



(a) Survey 1 (b) Survey 2

Figure 13 – Cyclone efficiency curves

Model Fitting

Following data balancing, mathematical models of all the process units were calibrated in *JKSimMet*. The purpose was to model the grinding circuit and primary crusher as they were operating at the time of the surveys.

Feed Size Effect on SAG Mills

SAG mill feed is supplied from the primary crusher, and the product from the primary crusher is influenced by the size distribution achieved from blasting. Significant effort has been spent at a number of operations to relate SAG mill throughput to SAG mill feed size. Particularly for the Antamina case, a correlation was obtained, derived from measurements and data analysis, indicating that finer M4/M4A topsize and F80 mill feed gives higher SAG mill throughput as presented in Figure 14.

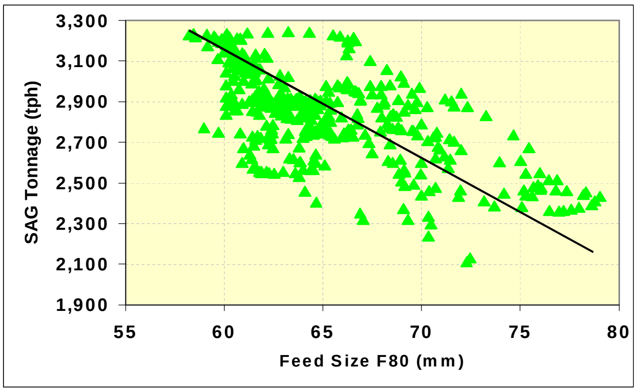


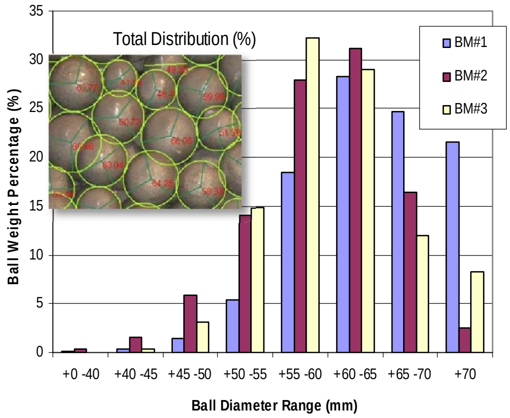
Figure 14 – Antamina SAG feed size F80 vs. throughput

Reduction at the coarse end of the feed size distribution to the SAG mill is only part of the optimisation effort. In operations such as Antamina, increasing the amount of fines (-10mm) should increase the SAG mill throughput proportionally. Such material is smaller than the mill discharge grates and trommel screen apertures and can be considered as 'free grind'.

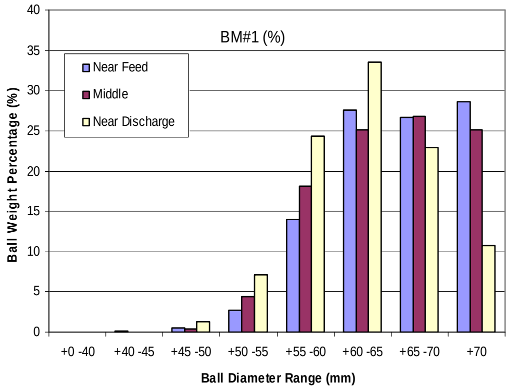
Ball Mill Media Size

Photographs along the mill axis of the three mills were taken for image analysis to determine the size distribution of grinding media within the mills. Antamina was trialling different ball make-up sizes in each mill: a different combination of 2½ and 3 inch balls are added to the three ball mills.

Figure 15a shows the ball size distribution results from the photos of the surface of the ball charge in the three ball mills. Less than 5% of balls were found to be smaller than 50mm.



(a) In three ball mills



(b) Along ball mill 1

Figure 15 – Ball Size Distribution

The analysis of the ball size distribution along the mill axis was also carried out to determine if larger balls tend to concentrate at the feed end and smaller balls towards the mill discharge. This effect may be observed in Figure **15b** for ball mill 1 where the proportion of large balls at the mill discharge is lower than near the feed or middle of the mill. For the other two ball mills this effect was not observed and therefore segregation along the mill axis could not be proven definitively.

"MINE TO MILL" SIMULATIONS

Models for blasting, crushing and grinding operations were developed based on data collected on-site and results of the samplings during trials. These models can be combined to simulate the overall "Mine-to-Mill" Process Integration & Optimisation. Inputs to these models include rock properties (UCS, RQD), blast design parameters (burden, spacing, stemming column, explosive type, etc.), primary crusher setting, SAG mill operating conditions (ball size, ball charge, total charge, grate size, mill speed, etc.) and ball mill circuit conditions (ball size, ball charge, mill speed, cyclone geometry, pressure, etc.)

These simulations quantify the possible throughput increases. When changes indicate higher tonnage, it is quite likely that combining two or more of these conditions will give an even higher increase in plant throughput. Conditions such as different blast designs, primary crusher setting, SAG mill grate design (worn vs. new), SAG mill ball charge level were considered in the simulation study.

ROM Size Distribution Simulations

The results of the simulations of the different ROM size distribution are presented in Table 5. The Base Case followed the conditions of the audited blast while the D2 blast design and a 5 inch CSS on the primary crusher resulted in a 12% increase in tonnage which translates to 2,750tph of the same material. The effect of blast fragmentation variability was demonstrated as the coarser end of the 95% envelope of ROM size reduced mill throughput by 10% and the finer end increased throughput by 22% or 3,000tph.

Table 5 – Simulations of different ROM size distribution

Operating Condition	Base Case	D2 Mean	Coarser ROM	Finer ROM
Run of Mine P80 (mm)	401	266	521	209
Primary Crusher CSS (inch)	5	5	5	5
SAG Feed Rate (tph)	2,450	2,750	2,200	3,000
SAG Feed F80 (mm)	119	99	120	92.8
SAG Feed % -10mm	27.7	38	22.8	41.1
Scats Rate (tph)	99.6	96	91.6	101.6
No. of Cyclones	8	9	7	9
Cyclone O/F % solids	33.5	39	34	52
Cyclone O/F P80 (μm)	125	139	119	165
Tonnage Increase (%)	**–**	**12.2**	**-10.2**	**22.4**

SAG Mill Operating Condition Simulations

Simulations were carried out to investigate the impact of changing grate open area and SAG mill ball charge level. The simulations indicated that –as the grates wear– the scats rate increases marginally and the mill tonnage increases by 4%. Due to additional ball mill capacity being available under low tonnage conditions (i.e., M4A material), the option of increasing the trommel screen aperture and sending coarser material to the ball mills should be considered. Due to the fineness of the M1 (high tonnage) SAG mill feed, this should have little impact on the ball mill circuits.

At the time of the grinding circuit survey, the SAG mill was operating with a 13.5% volumetric ball charge. A simulation of 15% ball charge level was done to estimate the impact on mill throughput. This result indicated that mill throughput could increase by 5% as a result of the greater ball load. While changes in feed size and material hardness may reduce the benefit of an increased ball charge, it was recommended that Antamina trial a 15% ball load during M4/M4A campaigns.

CONTINUOUS IMPROVEMENT AFTER FIRST STUDY

Implementation of the recommendations made by Metso PTI during the 2007 study resulted in an increase in SAG mill throughput from 2750tph up to an average of 3600tph. Following this, Compañía Minera Antamina and Metso PTI entered into a technical services support contract for 2008-09, to implement continuous improvement projects to further improve the mine and mill efficiencies. As a part of this contract two projects were conducted in 2008: 1) Mine to Mill Blast Fragmentation and 2) Blast Damage and Wall Control.

The main objective of the “Mine to Mill Blast Fragmentation” project was to improve blast fragmentation in M4/M4A ore blasts in order to increase the SAG mill throughput even further. Three high intensity blasts were conducted in M4/M4A ore and the ore was campaigned through the plant to assess the SAG mill performance. These high intensity blasts produced finer ROM fragmentation and feed to the SAG mill. The SAG feed F80 was reduced to around 50-60mm compared to 100-120mm previously and fines (-10mm) percentage was increased from 25% to 45%. Primary crusher power peaks were reduced significantly during these campaigns. SAG mill throughput averaged 4100tph for the three blasts and throughput above 4500tph was achieved for several hours during these trials.

A full plant survey was conducted during the third trial in December 2008, and used to update site specific blasting, crushing and grinding models as pebble crushers were installed in the meantime. Modelling and simulations indicated that modified blast designs and proper utilisation of pebble crushers can increase the SAG mill throughput up to 4500tph for the softer ore and 4250tph for the harder ore. Simulation results shown in **Figure 16** indicate that blast design changes increased the mill throughput by 25% (14% from the first design change and 11% from the second design change). Simulations also show that pebble crushers with larger grates can potentially increase the throughput by 11% and the increase in ball load would contribute about 4%. M4/M4a ores have become softer compared to the 2006 base case. Where the ore is very soft, ore hardness has contributed to 11% increase whereas for relatively harder ore, its contribution is only 4%.

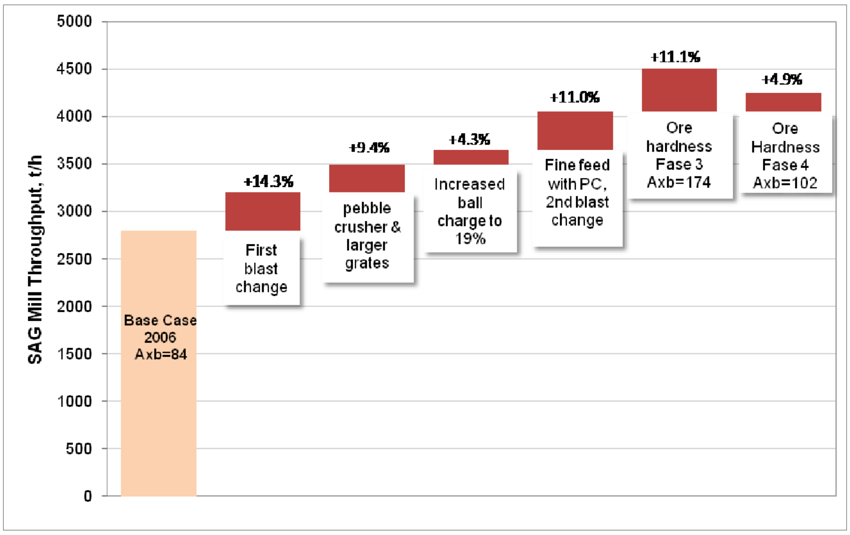


Figure 16 – Simulated effect of blast and plant changes on SAG mill throughput

Based on the results achieved in the project, Metso PTI concluded that Antamina can consistently achieve SAG mill throughput above 4000tph in M4/M4a ores by implementing the mine to mill process integration and optimisation philosophy.

CONCLUSIONS

Compañía Minera Antamina engaged Metso Process Technology and Innovation (PTI) to provide technical assistance for implementation of continuous improvement projects. The main objective of the support contract was to increase the SAG mill throughput by improving blast fragmentation and comminution for the harder M4/M4A (CuZn) ores. This project started in 2007 and proceeded through a continuous improvement contract to completion in 2009. The project consisted of a complete review and optimisation of existing operations, including:

- Characterisation of ore sources into domains of similar blasting/fragmentation properties;
- Measurement of blast design implementation and resulting fragmentation; measurement of vibration and definition of main constraints;
- Monitoring of blasted material movements using passive radio-frequency transponders or SmartTag^{TM} system;
- Review of current operating practices of the primary crusher and grinding circuits (SAG and Ball mills);
- Modeling of current drill and blasting, crushing and milling operations;

- Simulations of optimum operating strategies from the mine to mill;
- Implementation of recommendations and operating strategies.

The production budget in 2007 was 2750tph for the harder CuZn ores. After the implementation of changes recommended by Metso PTI during the first phase of the project the production increased to 3600tph on average for the remainder of 2007. By continued application of the mine to mill integration and optimisation philosophy, the concentrator exceeded its target of 4400tph for harder CuZn ores by 2010.

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