Mine to Flotation Process Optimization at Chinalco Toromocho Operation

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ABSTRACT

Minera Chinalco Peru S.A (Chinalco) is currently assessing alternatives to optimize its value chain, from the mine to comminution and flotation circuits, for long-term sustainable results. The aim is to maximize throughput and metal recovery at the Toromocho mining complex in Peru. Hatch Consulting & Technology has been providing technical support throughout the project and identifying opportunities in the comminution and flotation circuits. The project has been conducted in stages, starting with drill and blast optimization in 2017. This was followed by the optimization of the Phase I grinding circuit and the development of a throughput forecast model. Currently, the Phase II grinding circuit optimization is underway along with debottlenecking and optimization study of the Cu bulk flotation circuit to prepare for increased throughput. The project has identified several improvement opportunities, with potential throughput increase of up to 14% in the Phase I grinding circuit. Chinalco is in the process of implementing the recommendations for the Phase I grinding circuit and plans to integrate them with the upcoming recommendations for the Phase II grinding and Cu bulk flotation circuits. This integration will leverage the benefits across the entire production chain. Overall, the Mine-to-Flotation optimization project undertaken by Chinalco is a significant step towards maximizing operational efficiency, metal recovery, and sustainable results at the Toromocho mining complex. By systematically addressing each stage of the value chain and integrating the recommended optimizations, Chinalco aims to establish a robust foundation for long-term success in their mining and processing operations.

INTRODUCTION

Toromocho is an open pit copper mine built, developed, and operated by Minera Chinalco Peru S.A (Chinalco). Located in the Junín Region of central Peru, it is one of the largest copper reserves in Peru and the world, with estimated reserves of 1.52 billion tonnes of ore grading about 0.48% copper. The process plant is situated at an elevation of approximately 4,500 meters above sea level.

Toromocho commenced operating in 2007, and initially encountered challenges in achieving the design production of 5250 tonnes per hour (tph) because the ore hardness was higher than expected. Since then, Chinalco has implemented a series of changes in operational strategies aimed at maximizing production.

Chinalco is currently assessing alternatives to further optimize its value chain, from the mine to comminution and flotation circuits, for long-term sustainable results. The aim is to maximize throughput and metal recovery at the Toromocho operation. Hatch Consulting & Technology has been providing technical support throughout the project and identifying opportunities to improve performance in the comminution and flotation circuits using the existing equipment.

The Mine to Flotation Process Optimization at Chinalco Toromocho operation has been conducted in stages but with an integrated approach. Firstly, drill and blast operations were reviewed in 2017, this was followed by the optimization of the Phase I grinding circuit and the development of a throughput forecast model. Hatch identified opportunities to increase the throughput of the Phase I grinding circuit by up to 14%, while maintaining the final product size (P80 target of 195 µm). Currently, the Phase II grinding circuit optimization is underway along with debottlenecking and optimization of the Cu bulk flotation circuit to prepare the circuit for increased throughput.

The mathematical models, simulations, results, and conclusions developed through the different project stages have been integrated to achieve overall optimization of the Toromocho operation.

Brief Description of the Toromocho Operation

The circuit consists of primary crushing, two SABC grinding circuits followed by two flotation circuits (rougher, cleaner, regrinding, recleaner, and cleaner scavenger), as shown in Figure 1.

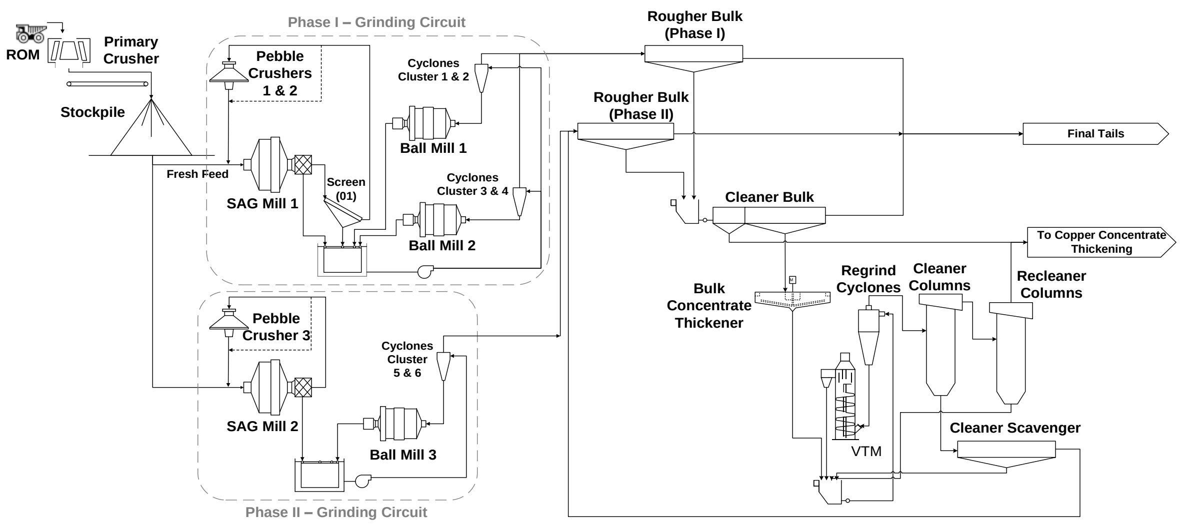

Figure 1 – Toromocho Comminution and Flotation Circuit Flowsheet (Phase I and Phase II)

The Phase I grinding circuit was commissioned first, followed by the Phase II circuit in late 2021. The main comminution equipment is described in

Table 1. The bulk flotation circuit consists of two parallel rougher Phases (I and II) which are fed by the Phase I and II Grinding Circuits respectively. The rougher concentrate from the two phases is combined prior to the cleaning and regrind stages. The flotation circuit is shown in Figure 1 and the main equipment is listed in

Table 1 below.

Table 1 – Main Process Equipment

Equipment		Description	
Crushing	Gyratory Crusher	One 60'' x 113" (745 kW)	
		Phase 1	Phase 2
Grinding	SAG Mill	One 40' x 26' (28 MW)	One 36' x 17' (13.5 MW)
	Ball Mill	Two 28' x 44' (22 MW)	One 28' x 44' (22 MW)
	Pebbles Crusher	Two FLS Raptor XL 1100 (750 kW)	One Metso MP1000 (745 kW)
Flotation	Rougher Bulk	Four lines, each with 7 x 300m³ cells	Two lines, each with 7 x 300m³ cells
	Cleaner Bulk	Two lines, each with 6 x 100m³ flotation cells	
	Regrind Mill	Two VTM METSO 1500WB	
	Regrind Cyclones	One cyclone cluster of 13 x WEIR Cavex 400	
	Cleaner	Four parallel cleaner flotation columns followed by two recleaner flotation columns	
	Cleaner Scavenger	Single line of 6 x 100m³ flotation cells	

METHODOLOGY

The Mine to Flotation Process Optimization project at Toromocho followed a structured methodology consisting of ore characterization, review of drill and blast practices and fragmentation results; a review of comminution and flotation operations; plant audit and survey; mathematical modelling and integrated simulations.

Ore Characterization

The performance of mining and processing operations is influenced by in-situ ore characteristics. Therefore, it is critical to understand these characteristics and how they vary across the deposit to optimize operations.

During the optimization study of the Phase I grinding circuit, there was limited ore characterization data available, hence Hatch used in-house breakage/comminution relationships to convert the available hardness parameters into comminution breakage parameters typically used for SAG mill modelling, namely, the Drop Weight Index (DWi) and JK Axb breakage index. Following this, in

2022, a geometallurgical test work program was conducted including SMC tests® (providing the hardness parameters used in SAG mill modelling) and Bond Work Index (BWi) tests across the different alteration domains within the ore deposit. The results, shown in Table 2, were in line with the breakage parameters estimated from Hatch relationships used in the optimization of the Phase I grinding circuit. Table 2 also shows that the ore was harder than expected from design values, resulting in difficulties with achieving the design throughput.

Table 2 – Summary of Breakage Testwork Results

Type Test	Unit	Design	2014 Samples			2019 Survey	2022 Geomet Testwork
Bond Ball Work Index	BWi (kWh/t)	**12.9**	13.3	14.3	13.2	14.2	14.2
SAG Power Index	SPI (minutes)	**75**	129	120	99	-	-
Drop Weight Index	DWi (kW/m^3)	**6.2***	8.9*	8.5*	7.5*	7.3*	7.0

**Estimated from Hatch in-house relationships.*

Review of Drill and Blast Practices and Fragmentation Results

The Run-of-Mine (ROM) size distribution, and in particular the amount of -10 mm fines, has a significant impact on the performance of comminution circuits (Morrell & Valery, 2001, Valery *et al* 2019; Kanchibotla, Valery and Morrel, 1999). Therefore, optimizing the drill and blast operation and improving the ROM fragmentation are critical steps to maximizing plant throughput and improving downstream energy efficiency. In 2019-2020, Chinalco made significant improvements in the drill and blast operations, resulting in finer ROM fragmentation.

However, recent ROM fragmentation measurements show there is scope to further reduce ROM P80 and fines (-10 mm) and decrease variability by tailoring blast designs to ore characteristics. The ROM fragmentation was measured using image analysis of 27 images of ROM ore in trucks taken during the May 2023 survey which is discussed later. An example of the image analysis (original photo and delineated image using Split Desktop software) is shown in Figure 2 along with the resulting average ROM size distribution and the envelop showing the range and variability.

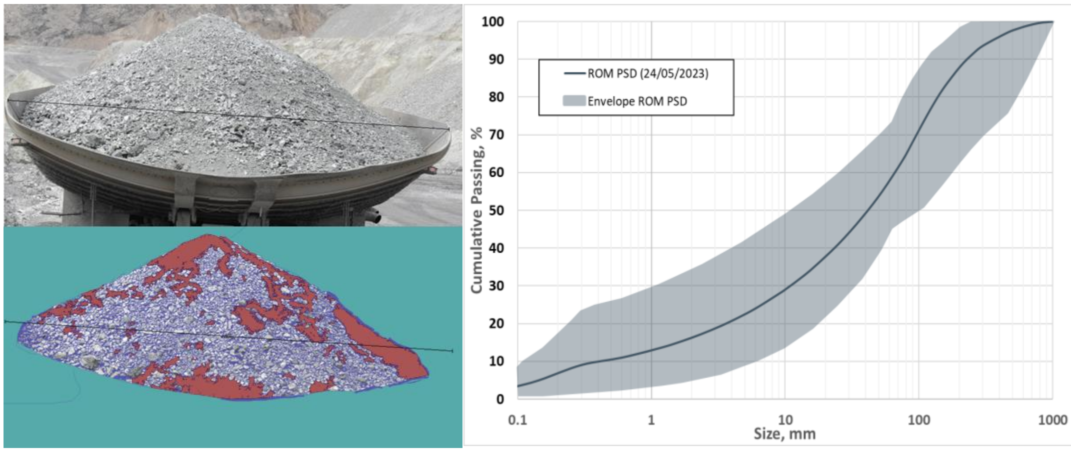

Figure 2 – Audit and Measurement of ROM Fragmentation (May 2023)

Audit and Mine-to-Flotation Survey

The modelling, simulation and optimization of Phase I grinding circuit was conducted using historical operating data and results from surveys conducted previously by Chinalco on the 14th and 22nd of September 2019. However, a full audit and survey supervised by Hatch was conducted in May 2023 for the optimization of the Phase II grinding circuit and the Cu bulk flotation circuit. The results of this recently conducted survey will allow the development and calibration of site-specific mathematical models for each unit operation (blasting, primary crushing, SAG milling, screening, pebble crushing, ball milling and flotation) and this will be integrated with the models and study already carried out of the Phase I grinding circuit.

The audit and survey conducted in May 2023 also included measurement of blast fragmentation and additional rock characterization for the surveyed ores. This will allow comminution performance to be calibrated and linked with the current blasting conditions, rock mass characteristics, and the associated blast fragmentation results.

As part of the survey, crash-stops and grind-outs were also carried out in the SAG and ball mills to gather key information to calibrate the comminution models. Charge measurements were taken, and the condition of the lifters/liners and ball size distributions were reviewed. In the SAG mill, the extent of pegging and peening of the grates, the capacity of the pulp lifters, and the presence of slurry pooling were also investigated. Some examples of activities undertaken during the survey are shown in Figure 3. The feed rate during the survey was about 1,650 tph.

Figure 3 – Sampling activities and equipment inspections during the survey

Mathematical Modelling and Simulations

A site-specific model was developed and calibrated for the Phase I grinding circuit, using a process called model fitting, based on the ore characterisation and 2019 survey data. The resulting JKSimMet model, shown in Figure 4, aligned well with the survey results, and therefore, was used to conduct simulations to evaluate optimization strategies. Site-specific models are currently being developed for the Phase II grinding and bulk flotation circuits based on the survey conducted in May 2023.

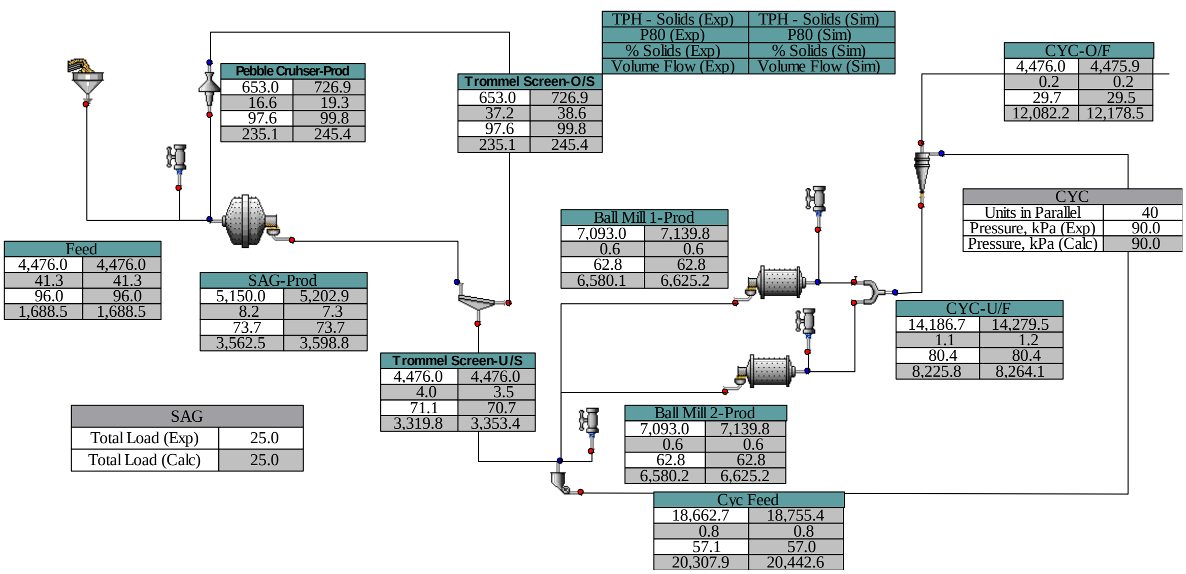

Figure 4 – JKSimMet model flowsheet for Phase I Grinding circuit.

RESULTS AND DISCUSSION

Simulations were conducted for the Phase I grinding circuit to evaluate identified improvement opportunities, as discussed below:

Simulation 1: Increase SAG mill pebble ports size and pulp lifter discharge capacity.

Severe grate pegging was limiting SAG throughput. Installation of larger (80 mm) pebble ports should mitigate this and increase volumetric flowrate of both pebbles and slurry. However, this would likely exceed the discharge capacity of the pulp lifters and cause slurry pooling. Therefore, Hatch provided design concepts to increase the pulp lifter capacity. Simulations indicated that increasing pebble port aperture to 80 mm and improving discharge capacity (with the proposed modifications to pulp lifter design) would increase throughput by almost 10%.

Simulation 2: Simulation 1 + optimized SAG mill ball charge.

The SAG mill feed at Toromocho is reasonably fine (although there is scope to reduce further). Therefore, SAG mill performance could be improved if operated like a large primary ball mill using a higher ball charge and optimizing the lifter/liner design to produce a more cascading charge. Simulations indicate that even a small increase in SAG mill ball charge, from 19% to 20%, would provide an additional 2 – 3 % increase in throughput. Review and optimization of the SAG mill lifters, liners and discharge system was also conducted based on results of Simulations 1 and 2.

Simulation 3: Simulation 2 + reduced both pebble crushers CSS to 11 mm.

The pebble crushers had spare power and capacity, but pebble production was limited due to the grate pegging issues mentioned previously. Implementing the recommended larger pebble ports and operating the pebble crushers with tighter closed-side setting (CSS) would improve utilization of the available pebble crusher power. Toromocho implemented chamber design changes to one of the two pebble crushers to allow reduction of the CCS to 11 mm. Simulations confirmed that operating with a CSS of 11 mm should increase throughput by about 2%. Therefore, both pebble crushers should be operated at a CCS of 11 mm by implementing this same change in the second crusher.

Simulation 4: Simulation 3 + increased ball mill power.

Implementation of all the above recommendations should increase throughput by about 14%. However, the grinding product size would coarsen to about P80 220 μm (target P80 is 195 μm) which could reduce flotation recovery by about 2%. Therefore, coarsening of product size is not desirable.

Simulations indicated that grinding product size may be reduced to P80 199 μm at the higher throughput rate by increasing the ball mill power to 22 MW. This would require installation of a retaining ring to maintain a higher ball charge, and the structural integrity of the mill needs to be evaluated and confirmed for the higher charge level prior to implementation of this recommendation.

Simulation 5: Simulation 4 + wider primary crusher CSS

The impact of operating with a wider primary crusher CSS (to feed both grinding circuits) was also estimated, resulting in approximately in a throughput drop of 1%.

Summary of Results

The simulations indicated the throughput of the Phase I grinding circuit can be increased up to 14% while maintaining the current product grind size (P80 197 µm), as can be seen in Figure 5 which shows the cumulative benefits of all recommendations.

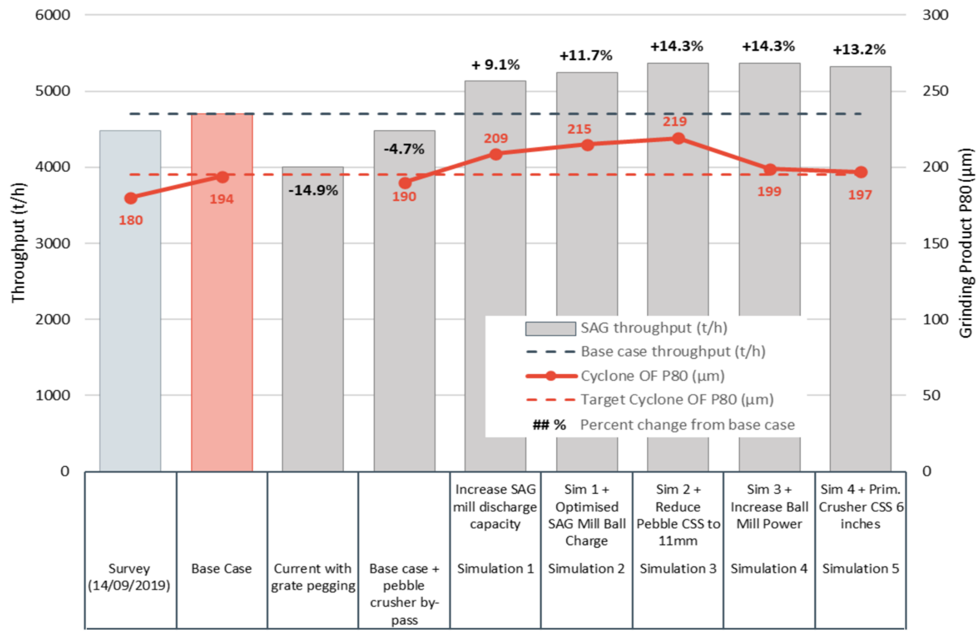

Figure 5 – Simulations Results Summary

The mathematical models developed for the Phase I grinding circuit were also used as the basis for developing a Throughput Forecast Model for the Life-of-Mine (LOM), this model calculates SAG Feed F80 based on a regression model between the proportion of each lithology (alteration domain) in the blend and the SAG mill F80 measured by online image analysis system, furthermore calculates the total circuit specific energy, as well as SAG mill specific energy, based on ore hardness properties and the calculated SAG mill feed F80, using equations derived from the Morrell methodology (Morrell, 2009). The specific energy is then used for a given SAG milling and ball milling power to determine plant throughput, the model predicts throughput quite well on a weekly and monthly basis, with errors of 11% and 3.5 % respectively. This will be updated and extended to include the Phase II grinding circuit when models are completed and using the results of the geometallurgical testing program recently conducted, to improve even more its accuracy.

Mathematical models and simulations for the Phase II grinding and flotation circuits are currently being developed and will be integrated with the existing models for a complete model of Toromocho operations. Updated results will be presented at the conference.

CONCLUSION

The Mine-to-Flotation methodology has identified significant opportunities to maximise the plant throughput around 14% in Phase I grinding circuit without compromising the final product size. Similar results are expected for Phase II grinding circuit.

With respect to the Flotation Circuit (Phase I & II), the study is currently underway, which requires an assessment based on the results of the comminution circuit. The complete project outcomes will be presented at the conference.

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