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Improving copper recovery at Xstrata Copper's Ernest Henry concentrator by changing the grinding chemistry

ABSTRACT

The conversion of a concentrator from one grinding media type to another is a major undertaking in terms of both financial and technical risk, and this risk is further magnified when the current economic climate is considered where cost reductions have gained significance at the expense of metallurgical performance.

The objectives of this paper are twofold: to provide the reader with a strategy for conducting plant trials comparing one grinding media with another, and to confirm observations made at the laboratory and pilot plant scale. That is, when employing an electrochemically inert grinding media in the primary grinding circuit it is possible to change the pulp chemistry of the system and improve the metallurgical response of ore.

This paper tracks the changes in pulp chemistry and metallurgical performance of Xstrata Copper's Ernest Henry copper/gold concentrator as the ball mill was converted from forged steel to high chrome grinding media. The change in metallurgical performance is correlated to the shift in pulp chemistry.

INTRODUCTION

The application of more electrochemically inert grinding media to 'real' ore systems at an industrial level to improve metallurgical performance has not gained universal acceptance. Even when it does become the 'industry standard', for example the PGM mining industry in South Africa, when events like the Global Financial Crisis occur the status quo is challenged based on unit cost of the raw material as mining companies pursue cost reduction strategies to maintain their financial viability. Several examples exist which describe the metallurgical results of converting an operating concentrator from forged steel grinding media to a more electrochemically inert high chrome alloy [1, 2]. This paper provides a description of the work conducted at Xstrata Copper's Ernest Henry Mine in north western Queensland, Australia.

ERNEST HENRY MINE

The Ernest Henry Concentrator treats ore from an iron oxide hosted copper-gold deposit located 35 km north east of Cloncurry, in the Mount Isa-Cloncurry mineral district of north western Queensland, Australia. The ore contains about 1 percent copper, as chalcopyrite, and nominally 5 percent pyrite, within a magnetite-biotite-calcite matrix. Gold is strongly associated with the sulphide minerals (chalcopyrite and pyrite), and has an average head grade of 0.5 grams per tonne.

The ore is trucked from the 'pit' to a single stage gyratory crusher. The crusher product is conveyed to an intermediate stockpile, from where the ore is drawn to feed an 11 MW SAG mill (10.4 m diameter by 5.1 m long), at an annual throughput of 11 million tonnes. The SAG mill discharge is screened, with the screen oversize returned to the SAG mill feed. The SAG mill screen undersize, and the ball mill discharge combine, to feed the ball mill cyclone pack. The cyclone underflow gravity feeds the 5.5 MW ball mill (6.1 m diameter by 8.4 m long), while the cyclone overflow (P80 220 microns) reports to flotation feed.

Rougher flotation occurs in nine by 127 m³ Wemco flotation cells. The rougher concentrate is reground in a 1 MW Vertimill, in closed circuit with cyclones, to produce a cleaner feed P80 of 38 microns. Cleaner flotation is accomplished in three stages using OK50 (first cleaner) and OK16 (second and third cleaner) flotation cells. The rougher tailing and cleaner tailing are combined to form the final tailing, which is pumped to the tailings dam. The final copper concentrate assays nominally 29.2 percent copper, at 92.6 copper recovery and 75 percent gold recovery. The concentrate is trucked to Mount Isa for smelting.

LABORATORY STUDIES

A number of studies employing the Magotteaux Mill[®] were completed on a variety of SAG mill feed samples collected between 2002 and 2006 [3, 5], using the methodology described by Greet and Steinier [6] to determine which high chrome alloy would produce the better metallurgical performance for the Ernest Henry ore.

PULP CHEMISTRY

These studies indicated that the pH of the system remained constant at 10.9 (Table 1), however changing from forged steel to a high chrome alloy resulted in a shift in the

Eh of the mill discharge to more oxidising pulp potentials (*i.e.* an average increase of 110 mV). The dissolved oxygen content of the mill discharge pulp also increased slightly when high chrome grinding media was employed. The EDTA extractable iron values determined for the high chrome alloys were significantly lower than that reported for forged steel. These data suggest that grinding with high chrome would shift the grinding chemistry to more oxidising conditions, with lower levels of grinding media corrosion products present in the system (*i.e.* a reduction in the percentage EDTA extractable iron). These changes in the grinding chemistry should have a positive impact on copper and gold flotation.

Table 1 Pulp chemistry data for the Magotteaux Mill[®] discharge for the SAG mill feed sample ground with forged, 18 and 30 percent chrome media

Media	pH	Eh, mV (SHE)	DO, ppm	EDTA Fe, %	EDTA Cu, %
Forged	10.9	-23	0.0	1.6	0.08
18% Cr	10.9	93	0.4	0.2	0.10
30% Cr	10.9	110	0.6	0.2	0.09

COPPER-GOLD FLOTATION

In terms of flotation, the laboratory copper rougher tests indicated that at 15 percent copper concentrate grade for, the copper recovery was increased from 85.6 percent for the forged steel to 88.8 percent for the 18 percent chrome alloy, an increase of 3.2 percent (Figure 1 and Table 2). The 18 percent chrome alloy also produced a gold recovery increase of 4.7 percent (Table 2).

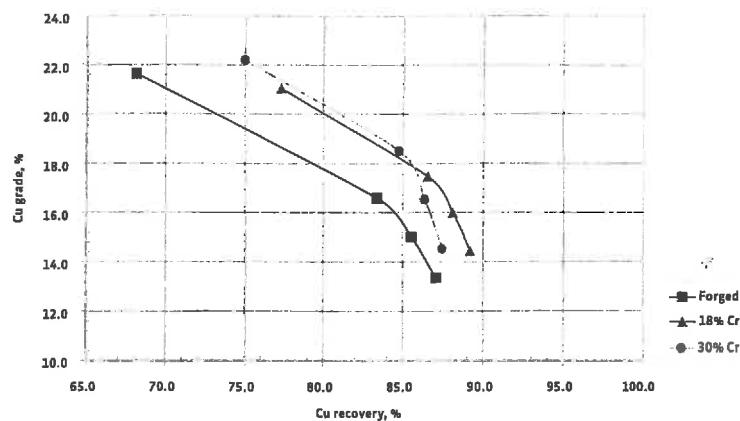


Figure 1 Copper grade/recovery curves for copper rougher flotation tests completed on a sample of SAG mill feed, ground with forged, 18 and 30 percent chrome grinding media.

Table 3 Copper and gold recoveries and diluent grades, at 15 percent copper rougher concentrate grade for copper rougher flotation tests completed on a sample of sag mill feed, ground with forged, 18 and 30 percent chrome grinding media

Test	Recovery, %		Diluent grade			
	Cu	Au	Au, ppm	Mo, ppm	IS, %	NSG, %
Forged	85.6	65.7	5.4	1436	18.3	38.4
18% Cr	88.8	70.4	5.2	1552	14.4	42.3
30% Cr	87.2	65.3	5.5	1528	7.6	49.1

The laboratory test work suggested that the changes in the pulp chemistry were responsible for the marked increase in both the copper and gold metallurgical performance during rougher flotation. Based on these rougher recovery improvements and assuming that cleaner flotation efficiency is 95 percent, the improvement in gross metal value was calculated using the spot price for copper and gold. Hence, if all the recovery gains are achieved for both copper and gold the potential increase in metal value would be US\$ 35,070,000 per annum (Table 3).

Table 4 Improvements in plant recovery and resultant metal value increases based on laboratory data when forged steel media was substituted with 18 percent chrome

Parameter	Copper	Gold
Rougher recovery improvement	3.2	4.7
Plant recovery improvement	3.0	4.5
Metal value increase \$USD ¹	\$24,265,000	\$10,805,000
Total \$USD	\$35,070,000	

PILOT PLANT STUDY

With consistently positive results achieved in the laboratory studies the options available to Ernest Henry Mine metallurgists were to progress to an industrial test or advance to a pilot plant study. As the Ernest Henry circuit consists of a sag mill followed by a single stage ball mill, it was considered too greater risk to the operation to proceed directly to an industrial test, so it was decided to advance the work to pilot plant scale where the technical and financial risks to the operation were minimal. However, a question mark remained over how to feed the pilot plant. After considerable discussion a way forward was agreed to, and the pilot plant was commissioned and operated at the beginning of 2008.

The pilot plant study involved taking ball mill cyclone feed material from the plant to feed the pilot plant, which consisted of two parallel grinding and rougher flotation lines (Figure 2). One grinding circuit was loaded with forged steel grinding media and the other with 18 percent chrome. The products from the two grinding circuits were fed to the flotation banks. In order to minimise any bias introduced by differences in the flotation circuits, a randomised block trial was designed for the pilot plant whereby the feeds to the flotation lines were swapped periodically. Once the pilot plant reached steady state pulp chemical and metallurgical surveys were completed. A total of 65 metallurgical data sets were collected during the operation of the pilot plant.

¹ These calculations assume a plant throughput of 11,000,000 tonnes per annum, at a copper and gold head grade of 1 percent and 0.5 grams per tonne, respectively. The metal spot prices used in these calculations are: \$7,353 (USD) per tonne for copper and \$1,237.90 (USD) per ounce for gold, as of 19 August 2010.

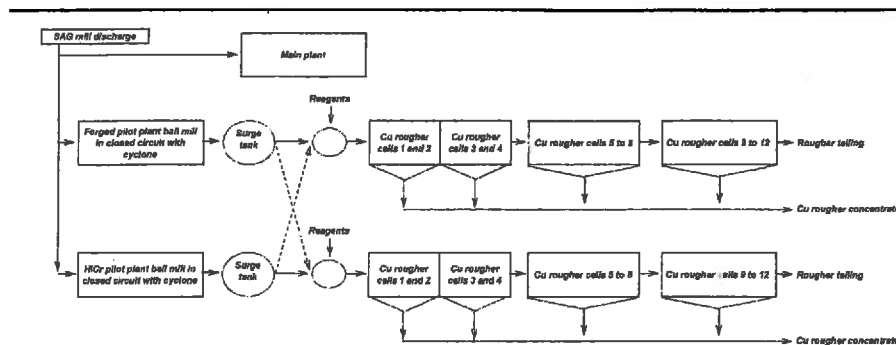


Figure 2 Pilot plant configuration [7].

PULP CHEMISTRY

The pulp chemistry surveys of the forged steel and high chrome lines in the pilot plant clearly demonstrated that ore ground with high chrome grinding media produced a ball mill discharge that was more oxidising than the forged steel case. The average difference in the Eh between the two media types was about 135 mV (Table 4), approximately the same as that observed in the laboratory work completed using the Magotteaux Mill®.

The EDTA extractable iron data provides an excellent indication of the differences in corrosion resistance of the two grinding media types. It is apparent that the circuit employing forged steel grinding media produced higher concentrations of EDTA extractable iron than the line operated with high chrome. For example, the forged line recorded an average EDTA extractable iron concentration of 0.05 percent compared with 0.03 percent for high chrome. This suggested that the addition of high chrome grinding media to the ball mill has effectively reduced media corrosion by about 40 percent of that noted for forged steel.

Table 4 Pulp chemistry data for the pilot plant ball mill discharges for the ball mill cyclone feed samples ground with forged and 18 percent chrome media [7]

Media	Parameters				
	pH	Eh, mV (SHE)	DO, ppm	EDTA Fe, %	EDTA Cu, %
Forged	10.3	-83	0.03	0.05	0.1
18% Cr	10.1	54	0.02	0.03	0.1

COPPER-GOLD FLOTATION

The surveys collected during the pilot plant were mass balanced, and the results analysed using statistical methods [8]. The statistical analysis (*t*-test) of the pilot plant data showed:

- A copper recovery improvement of 2.8 ± 1.8 percent with a confidence percentage greater than 99%;
- A copper rougher concentrate grade increase of 1.3 ± 0.8 percent with a confidence percentage greater than 95 %; and
- A gold recovery improvement of 3.4 ± 2.2 percent with a confidence percentage greater than 99%.

The pilot plant test work suggested that the changes in the pulp chemistry were responsible for the improvement in both the copper and gold metallurgical performance during rougher flotation. Using the lower limits of the recovery improvements from the pilot plant study indicated that the application of high chrome grinding media in the primary ball mill would increase the metal value by US\$ 10,421,000 per annum (Table 5).

Table 5 Improvements in plant recovery and resultant metal value increases based on pilot plant data when forged steel media was substituted with 18 percent chrome

Parameter	Copper	Gold
Rougher recovery improvement	1.0	1.2
Plant recovery improvement	1.0	1.1
Metal value increase \$USD	\$7,684,000	\$2,737,000
Total \$USD	\$10,421,000	

Note: The same assumptions as those used in Table 3 apply

PLANT TRIAL

The pilot plant study produced excellent proof that converting to high chrome grinding media would alter the pulp chemistry to more favourable conditions that would lead to an improved metallurgical performance. Furthermore, improved metallurgical performance would result in a significant increase in revenue. These results provided the mine with the confidence to convert the plant to high chrome grinding media. However, how to convert the plant became a major challenge. The options available were to, either, dump the mill and add a new graded charge of high chrome balls, or top up the mill with high chrome media until the mill was purged of forged steel.

Dumping the mill has the attraction of producing an 'instant' result, whereby the plant data prior to dumping the mill can be compared directly to the data collected immediately after replacing the whole charge. That is, the results are known sooner, and are not complicated by the time delay which is inherent to the purge method. In this case purging the Ernest Henry Mine ball mill would take nominally nine months to replace the charge. During this purge period many parameters can change and impact the result. The decision was taken to dump the mill during the maintenance shutdown in November 2009.

Unfortunately, the decision to dump the mill was complicated by the fact that the ball mill did not have an inspection hatch. So, a method to unload the 340 tonnes of steel in the mill was required. Many options were considered ranging from using a high suction vacuum cleaner to the use of a magnet. Unfortunately, all required an extended plant shutdown to achieve the desired goal, and were rejected. Eventually a scoop (Figure 3) arrangement [9] was manufactured and used successfully to unload the mill during the planned 72 hour shutdown.

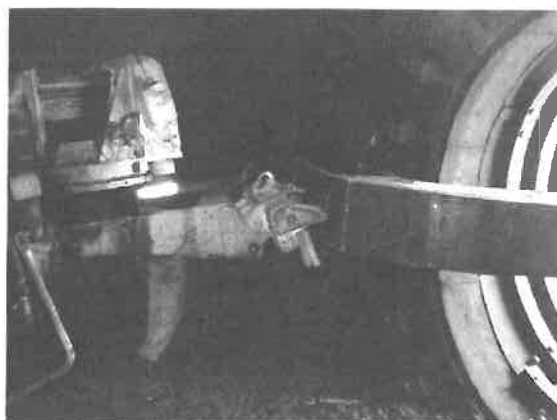


Figure 3 Installation of the 'scoop' to unload the ball mill at Ernest Henry Mine.

PLANT TRIAL DESIGN

The design of grinding media trials in a single stage ball mill is challenging. As it is not possible to conduct a randomised block on/off trial, it is necessary to collect a comprehensive data set before and after the media charge in the mill is replaced. A sampling campaign was developed whereby the following data were collected from the plant for three months before and three months after the mill charge was replaced:

- The pulp chemistry of the grinding and rougher flotation circuits;
- Down-the-bank surveys of the rougher circuit;
- Flotation tests of the cyclone overflow;
- Weekly size-by-size data for the rougher and final tailing; and
- The daily shift mass balanced data.

In addition to these data, wear and reagent consumption data were also collected.

Initially the plant was to be converted to high chrome grinding media during the August 2009 plant shutdown. However, because the mine plan indicated that only low grade ore (less than 0.3 percent copper) was to be mined starting August 2009 for nominally 12 months so that the benches in the pit could be cut back to gain access to high grade ore, the trial was postponed until the November shutdown. Therefore, the trial is being completed in two parts: the low grade ore phase; and the high grade ore phase. It is anticipated that the mine will start producing high grade ore during the third quarter of 2010.

PULP CHEMISTRY

Pulp chemical surveys of the low grade ore while the plant was operating on forged steel were completed during October and early November 2009. These data were compared with pulp chemical data collected during the second half of November once the plant had converted to high chrome grinding media.

Table 6 contains the average pulp chemical data collected before (forged steel) and after (high chrome) the November plant shutdown when the ball mill was converted. These data suggest that there was a subtle shift in the Eh of the ball mill discharge of

around 25 mV, however the dissolved oxygen content of the pulp increased from an average value of 0.6 ppm up to an average of 1.9 ppm. The EDTA extractable iron was reduced by about 60 percent from 0.64 percent when the plant was operated with forged steel grinding media to 0.27 percent once converted to high chrome (Figure 6). The data suggests that the change in grinding media from forged steel to high chrome resulted in a significant decrease in the corrosion rate of the media, which shifted the pulp chemistry to more oxidising values.

Table 6 Average pulp chemistry data for the plant ball mill discharges ground with forged and 18 percent chrome media

Media	Parameters				
	pH	Eh, mV (SHE)	DO, ppm	EDTA Fe, %	EDTA Cu, %
Forged	11.5	75	0.6	0.64	0.66
18% Cr	11.2	98	1.9	0.27	0.26

COPPER-GOLD METALLURGY

Statistical analysis of the shift data for low grade (less than 0.3 percent copper) ore treated before (forged steel) and after (high chrome) the shutdown in November 2009 revealed that the change in media type had resulted in improved recoveries. That is:

- The copper recovery had increased by 2.4 ± 0.8 percent, with greater than 99 percent confidence; and
- No statistical difference in gold recovery was observed between forged steel and high chrome grinding media. More data is being collected and further analysis is underway.

The copper concentrate grade was statistically the same.

COPPER DISTRIBUTION BY SIZE IN THE FINAL TAILING

Figure 7 contains the average final tailing copper distribution for forged steel and high chrome grinding media when the plant was treating low grade ore. An inspection of these data indicates that the losses of copper in the finer size fractions (<38 microns) to the final tailing were significantly lower (by 6.3 percent) when grinding with high chrome grinding media compared to forged steel. This would suggest that the improvement in copper recovery observed with the change from forged steel to high chrome grinding media was probably achieved through an increase in the recovery of fine (liberated) chalcopyrite particles.

Using the lower limits of the recovery improvements from the low grade ore plant study indicated that the application of high chrome grinding media in the primary ball mill would increase the potential metal value by US\$ 12,941,000 per annum (Table 7).

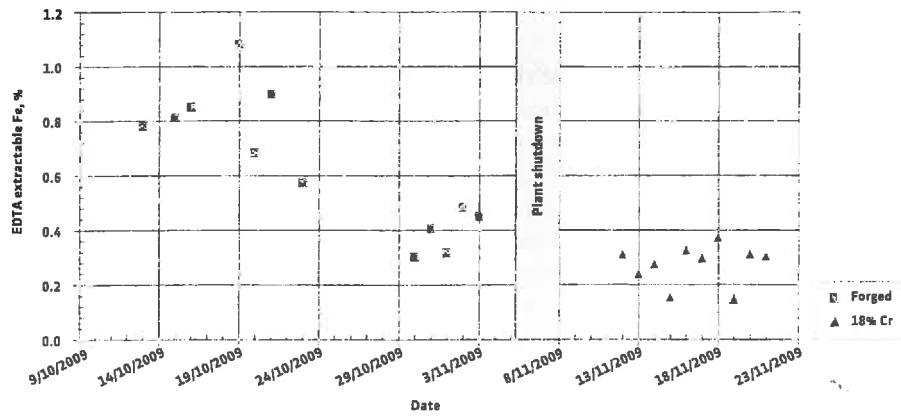


Figure 4 The percentage of EDTA extractable iron in the ball mill discharge before (forged steel) and after (high chrome) the shutdown in November 2009.

Table 7 Improvements in plant recovery and resultant revenue increases based on pilot plant data when forged steel media was substituted with 18 percent chrome

Parameter	Copper	Gold
Plant recovery improvement	2.4	Nil
Plant recovery improvement – lower limit	1.6	Nil
Metal value increase \$USD	\$12,941,000	
Total \$USD	\$12,941,000	

Note: The same assumptions as those used in Table 3 apply

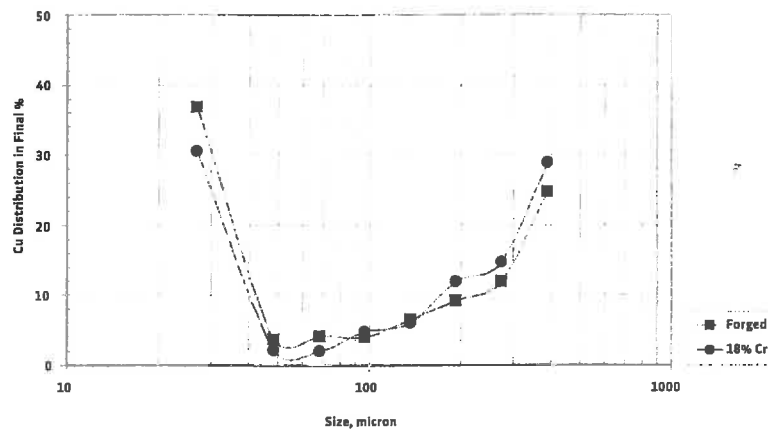


Figure 5 The average final tailing copper distribution for forged steel and high chrome grinding media when the plant was treating low grade ore.

CONCLUSIONS

The paper provides an account of the metallurgical test work completed at Xstrata Copper's Ernest Henry Mine in north western Queensland, in Australia. The work completed extended over a number of years, and included laboratory studies using the Magotteaux Mill®, pilot plant and eventually a full plant trial.

Broadly, laboratory results indicated that an 18 percent chrome alloy would produce the optimum pulp chemical conditions for the best copper/gold metallurgy. The change from forged steel to 18 percent chrome grinding media produced:

- A shift in the ball mill discharge Eh 110 mV, to more oxidising pulp potentials;
- A subtle increase in the dissolved oxygen content of the pulp; and
- A reduction in the percentage of EDTA extractable iron.

These pulp chemical changes suggest that a change in grinding media was effective in altering the grinding chemistry. Further, the laboratory study showed that the change to a more inert grinding media would have a positive impact on copper/gold flotation performance.

In April 2008 a pilot plant trial was conducted, whereby ball mill cyclone feed material was tested using forged steel and 18 percent chrome grinding media. The data collected from the pilot plant indicated that a change from forged steel to high chrome grinding media resulted in the following pulp chemical changes:

- A shift in the ball mill discharge Eh of 135 mV, to more oxidising pulp potentials;
- An increase in the dissolved oxygen content of the pulp; and
- A reduction in the percentage of EDTA extractable iron.

The change in media type resulted in statistically significant improvements in copper and gold recovery (2.8 ± 1.8 percent and 3.2 ± 2.2 percent, respectively).

In November 2009, the mine elected to dump their ball mill and load it with a graded charge of 18 percent chrome balls, the pulp chemistry of the system was measured, and the shift data collected. Unfortunately, the mine was treating low grade (less than 0.3 percent copper) ore at the time, so this analysis is restricted to this ore only. The plant pulp chemical data shows that the conversion from forged steel to 18 percent chrome grinding media resulted in:

- A shift in the ball mill discharge Eh of 25 mV, to more oxidising pulp potentials;
- An increase in the dissolved oxygen content of the pulp; and
- A reduction in the percentage of EDTA extractable iron.

The pulp chemical changes were smaller than those observed in the laboratory and pilot plant studies, and may be related to the ore type tested. Notwithstanding this variation, the change in media type resulted in statistically significant improvement in copper recoveries (2.4 ± 0.8 percent). Additional data is being collected to determine if gold recovery has changed. Further, the improvement in copper recovery may be attributed to improved fine particle recovery.

The next step in the Ernest Henry plant trial is to test high grade ore. It is anticipated that this will occur from the third quarter of 2010.

The work demonstrates that using a robust laboratory schedule such as the Magotteaux Mill® can be used effectively to predict plant performance.

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