Converting of Lubambe Copper Mine Ball Mill from Grate Discharge to an Overflow

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The Lubambe milling circuit utilises a primary semi-autogenous mill and a secondary ball mill in closed circuit. Milling circuit was commissioned in 2012 with a grate discharge arrangement in the ball mill. High mill balls consumption mad it necessary to explore alternatives to reduce the consumption. An overflow was successfully implemented and dramatically reduced the ball consumption to levels of below 300 g/t from 1100 g/t. The paper reviews the operational experience of the ball mill with particular focus on discharge conversion.

INTRODUCTION

Lubambe Mines Operations

Lubambe Copper Mine is located within the Greater Konkola Area of the Zambia Copperbelt and consists of a large-scale mining license covering an area of approximately 240 square kilometers. The mine is a modern, world-class facility with fully mechanized underground operations. Lubambe Copper Mine is owned by EMR Capital of Australia (80%) and ZCCM – Investments Holdings (20%). The mine has two ore sources: the South and East ore bodies.

The secondary mill was commissioned in October 2012. The mill started with a grate discharge configuration with an open area of around 8%. The grinding media consumption since then was exceptionally high. Initially, it was in excess of 2400 g/t for high-chrome balls. This was far too high if compared with secondary mills operating in the region. According to the mill balls supplier, Magotteaux, the expected wear rate for secondary mills is less than 500 g/t. The design volumetric ball charge (filling degree) was 35% and unfortunately this was not achieved due to media breakage and spalling. The grate discharge was designed with the need to reduce sliming of oxides, which was not even experienced after conversion of the mill to an overflow.

Mineralogy

The Lubambe concentrator treats a mixed ore of sulphide and oxide copper with a ratio of 15% to 23% oxide. The Lubambe mineralisation is predominantly chalcocite with minor bornite and chalcopyrite, which are sulphide copper minerals. Malachite, pseudomalachite and azurite (oxide copper) are also present. Feldspar is the major gangue mineral, which comprises 60 to 70%.

PROCESS SUMMARY

Grinding Plant Process Flow

The milling circuit (Figure 1) comprises a 4.4 MW, 5.75 m × 8.65 m variable speed primary semi-autogenous (SAG) mill and a 6.2 MW, 5.7 m × 8.65 m ball mill. Ore is fed into the primary mill by means of vibrating feeders underneath the plant stock pile. There are eight feeders installed, with capacity of 16 5t per feeder. The design mill feed rate is 331dtph.

The SAG mill discharges onto a double-deck vibrating screen with top deck size panels of 21 mm × 21 mm and the bottom deck is fitted with 8 mm × 8 mm panels. Over-size material from both decks collects in a chute and is recycled back into the SAG mill by pebble-recycled conveyors. Vibro screen −8 mm product discharges into the sump and is pumped to a cluster of cyclones at a pressure of 0.85 to 0.95 bar. Cyclone overflow is the feed to flotation and underflow is the feed to the ball mill, which is in closed circuit with the cyclones. The ball mill has a discharge trommel screen of 15 mm aperture with −15 mm feeds to the common sump and pumped to the cyclones. The +15 mm fraction is combined with SAG pebbles to the feeder belt. Cyclone overflow target grind range is 94 to 95% passing 75 µm.

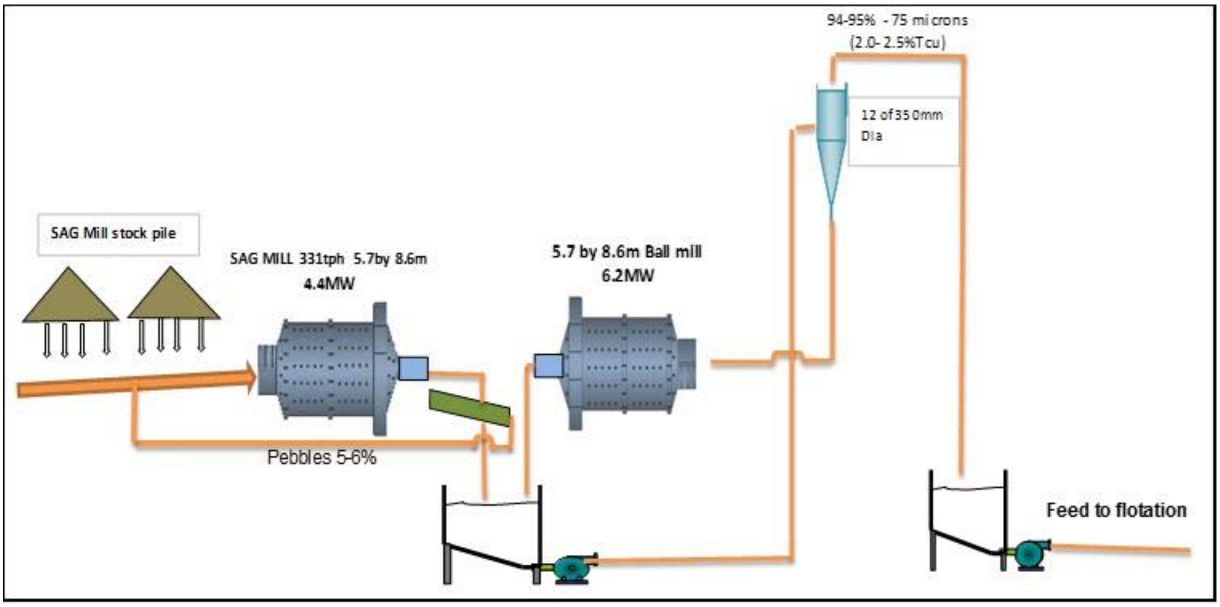


Figure 1: Lubambe milling plant circuit.

The secondary mill design criteria are shown in Table I.

Table I: Design specifications for Lubambe grinding circuit.

Mill feed size, F_{100}	µm	850
Mill feed size, F_{80}	µm	212
Target mill circuit product size, P_{80}	µm	60
Specific energy	kWh/t	14.67
Ball charge	%v/v	31
Power at pinion	kW	4853
Maximum ball charge	%v/v	35
Installed power	kW	6200
Ball mill drive speed, % of critical	%	75
Ball mill diameter, inside shell	m	5.7
Ball mill effective grinding length, EGL	m	8.654
Mill discharge arrangement	–	grate
Mill grate aperture	mm	15 mm slots

BALL MILL OPERATIONS

Mill Ball Size and Load

Designed maximum ball loading is 35%. At commissioning, the mill was charged with 10 mm, 30 mm and 40 mm diameter high-chrome steel balls as the initial charge, with a total ball tonnage of 240 t. Expected media consumption was less than 500 g/t of ore treated. The initial ball charge level was 25%.

After running for three weeks, it was observed that the mill was discharging small balls due to breaking. During the same period, the mill load and power draw dropped from 240 t to 90 t and from 3500 kW to 1100 kW. There was also a drop in grind from the then target of 85% to 70%, thus affecting plant recovery.

Investigations were conducted into the cause of the media breakage and propose possible solutions. On 2 November 2012, Lubambe mine process team and mill balls supplier Magotteaux conducted a mill inspection and it was evident that the balls were breaking as shown in figure 3. After the mill inspection, the ball level was found to be 8%, against the target of 25%. Figure 2 shows that the ball level was low and most of the space was occupied by slurry instead of steel balls, even after grinding out the mill for 35 min.

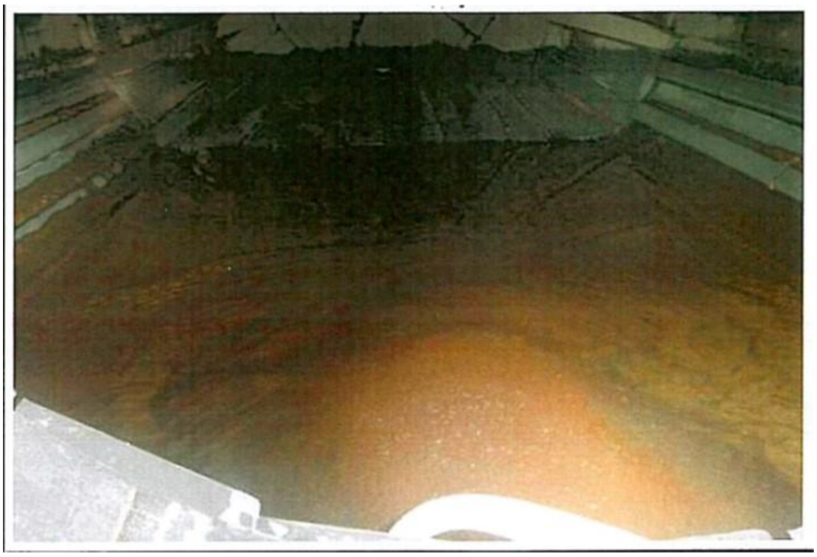


Figure 2: Slurry pool in the mill after grinding out for 35 minutes.

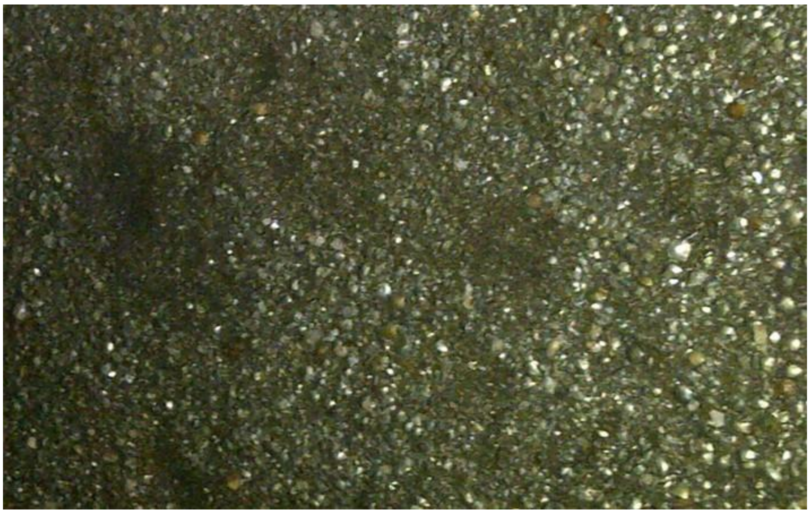


Figure 3: Pieces of broken balls inside the mill.

FACTORS INFLUENCING GRINDING MEDIA WEAR RATE

Ball Quality

The four main aspects affecting grinding quality are:

- Hardness;
- microstructure;
- chemical composition;
- soundness (refers to inclusion, shrinkages and blowholes).

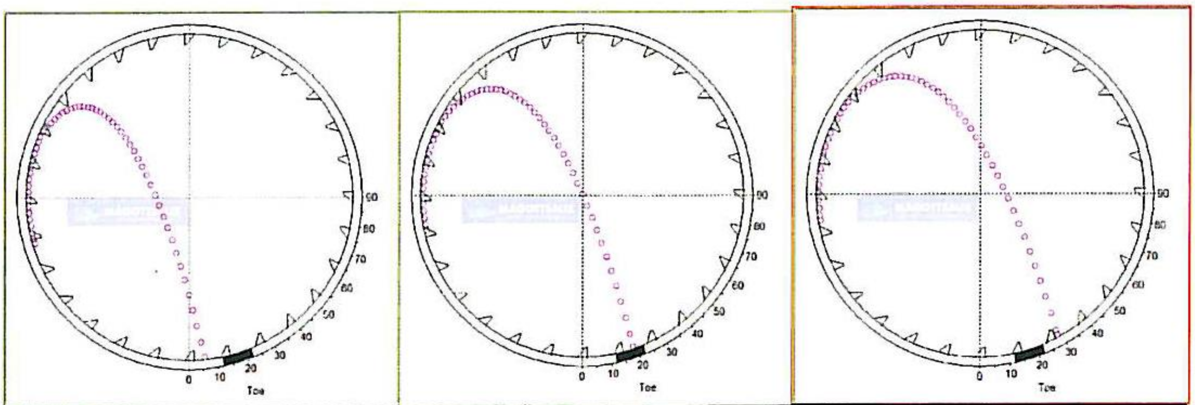
Total quality assurance tests of the balls were carried out to ensure that they were supplied as per required standard and specification were within expected range.

Impacts

Total filling degree

For a given mill speed and liner profile, when the mill rotates, the grinding media are projected into the charge or the toe of the charge or to the shell liners. This is dependent on the mill total filling degree (Figure 4). If the grinding media is projected to the shell, this results in ball breakage, irrespective of the grinding media quality. For secondary milling, grinding media must fall onto the charge or onto the toe of the charge for efficient milling and optimum ball wear. Breakage can be expected should the grinding media fall on the shell.

From the inspection conducted, it was evident that trajectories of the balls were on the shell and the balls were breaking due to high impacts. See figure 5 which is showing ball trajectory at attack angle of less than 10^{o}.



Trajectories: **Into charge**	Trajectories: **At toe of charge**	Trajectories: **On the shell**
- Very low impacts - secondary ball mills	- Medium impacts - SAG & ROM mills	- High impacts - AG mills

Figure 4: Mill balls trajectories.

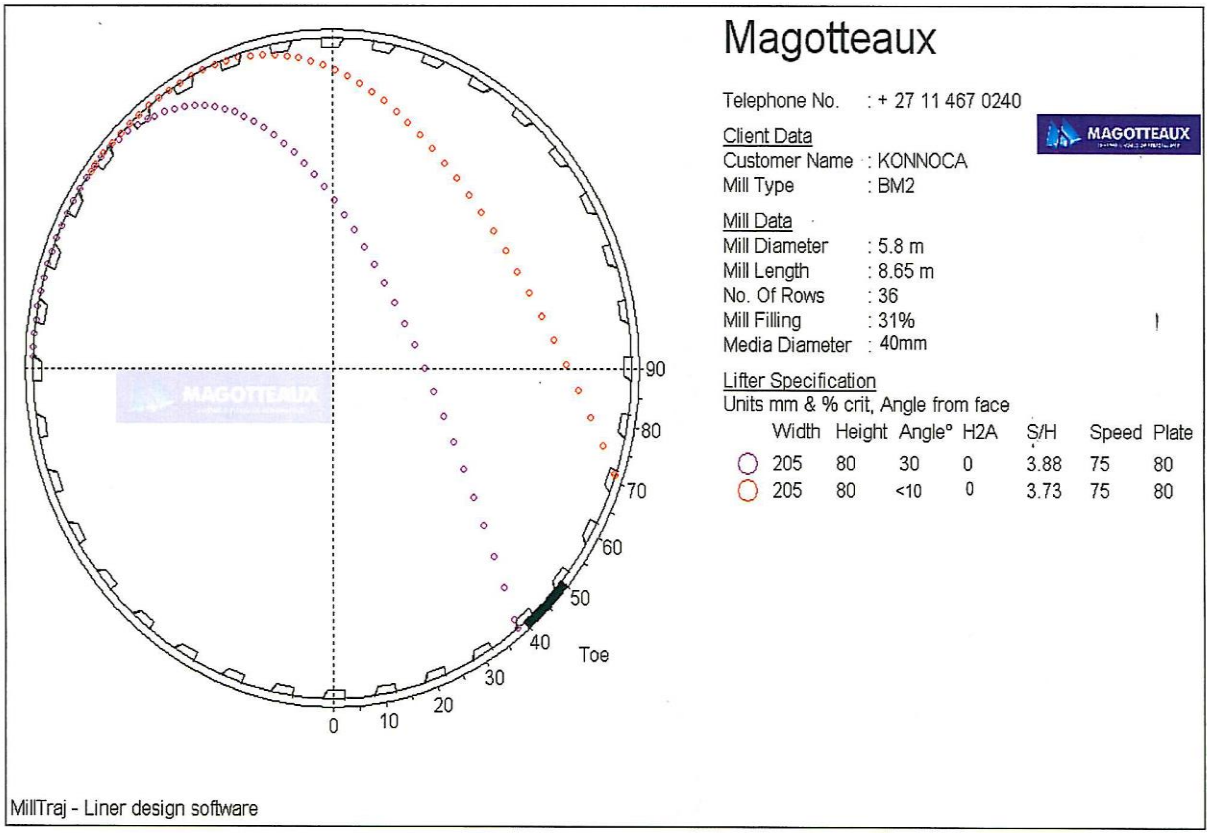


Figure 5: Design vs. operational trajectories .

Liners and Grates

Mill discharge configurations

Ball mills are classified by the nature of the discharge. They may be simple trunnion overflow mills operated in open or closed circuit, or grate discharge (low-level discharge) mills. The latter type is fitted with discharge grates between the cylindrical mill body and the discharge trunnion. The pulp can flow freely through the openings in the grate and is then lifted up to the level of the discharge trunnion. These mills have a lower pulp level than overflow mills, thus reducing the residence time of particles in the mill. Very little overgrinding takes place and the product contains a large fraction of coarse material, which is returned to the mill by some form of classifying device. The higher the grate open area, the higher the pumping efficiency. If the open area is over designed, the charge is very dry and slurry pull will not be maintained in the mill due to the mill pumping effect. This increases grinding media consumption.

The trunnion overflow mill is the simplest to operate and is used for most ball mill applications, especially for fine grinding and regrinding. Energy consumption is said to be about 15% less than that of a grate discharge mill of the same size. In an overflow, a slurry pool is formed up to the discharge trommel; this softens ball-on-ball impacts and reduces the grinding media consumption.

Shell liner design and condition

The shell liner profile affects ball trajectories, thus affecting impact conditions inside the mill. For a given mill speed and filling degree, there is an optimum liner profile for proper ball trajectories. Using the toe of the charge as the reference point, reducing the liner attack angle shifts the trajectory towards the shell and increases ball-to-ball contact, which leads to breakages; increasing the liner lifter bar attack angle shifts the trajectory into the charge.

Height-to-attack angle (H2A).

When the liner lifter bar attack angle is adjusted, it is essential to ensure that the attack angle is up to the base plate or within the H2A as explained in Figure 6. For 40 mm balls, if the H2A is more than 20 mm, there will be a zero attack angle at the bottom of the lifter bar. This will cause media projections to the shell as explained hereunder.

The height to attack (H2A) is the vertical part of the liner lifter bar before the attack angle. If (H2A) > 0.5*D*, where *D* is the ball diameter, the ball will see an angle of zero degrees. This will result in ball overthrow, causing spalling and ball breakage. For a 40 mm ball top size, the H2A has to be less than 20 mm.

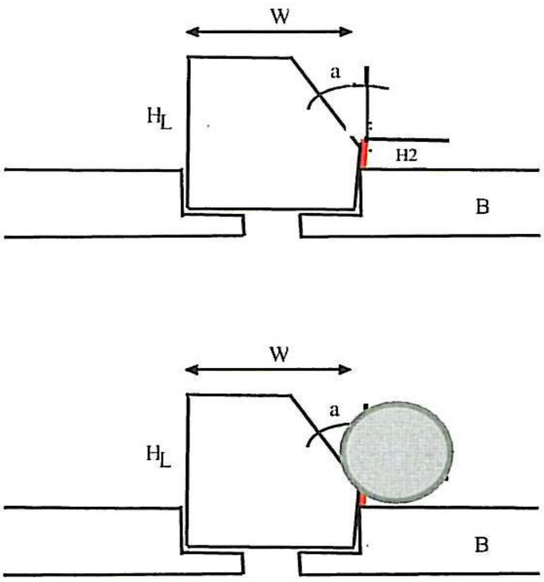


Figure 6: Height-to-attack angle (H2A).

Ore Pulp Characteristics
The abrasivity, particle size distribution and corrosivity of the pulp also influence the grinding media wear rate.

LUMBAMBE SECONDARY MILL LINERS

The Lubambe secondary mill was designed as a grate discharge type configuration. The ball mill discharge configurations and shell lifter bars have undergone significant modifications and changes to improve mill performance. The ball mill was initially fitted with 100% rubber liners and discharge grate. The mill had a total number of twenty installed 15 mm × 30 mm opening discharge grates. The initial liners had lifter bar lifting angle of less than 10° and a total grate opening area of 8%. Figures 7 and 9 shows the mill grate discharge configuration.

During the mill initial inspection, the following findings on mill balls (grinding media), mill shell liners and discharge grates were observed:

- spalling and breakage were evident on the grinding media, as seen in Figure 3;
- the degree of mill fill was 8%, against the target of 25%;
- inner and outer feed end liners were found to be in very good condition, with a minimum lift of 80 mm and the liner attack angle was very aggressive at zero degrees;
- shell liners were in very good condition, with a lift of 80 mm and liner attack angle aggressive at l0° (Figure 8);
- discharge end lifter bars were in a very good condition of around 80 mm and an aggressive angle of zero degrees;
- the condition of the discharge grates was also good, with slot widths of 15.5 mm and 28 mm, and an open area of 8%.


Figure 7: Ball mill grate discharge arrangement.


Figure 8: Ball mill shell liner profile.

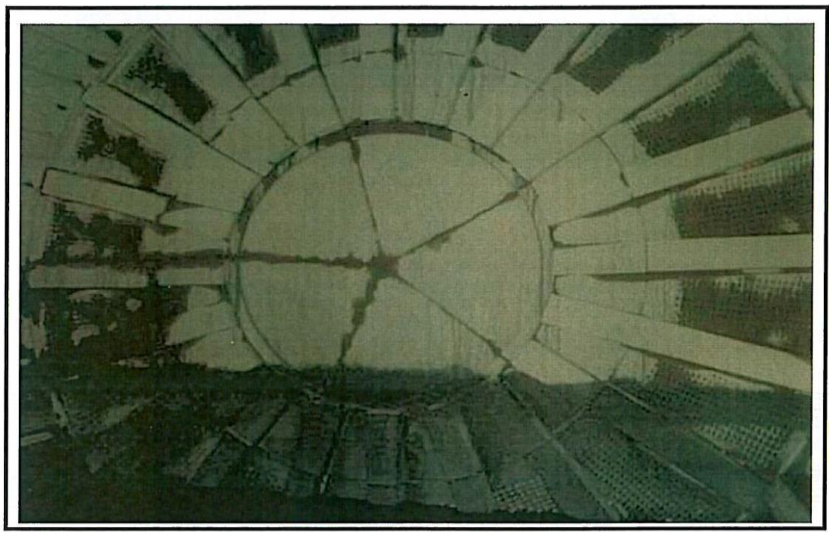


Figure 9: Initial mill discharge configuration.

SOLUTIONS TO BALL BREAKAGE AND HIGH CONSUMPTION PROBLEM

The milling conditions were too aggressive for secondary milling and the high-chrome media supplied. This was the main cause of media breakage and the very high mill balls consumption.

To significantly reduce the grinding media wear rate, it was recommended that the shell liners lifter bars be cut, the lifting angle increased from an aggressive 10˚ to 35˚ and some openings on the grate discharge panels blanked off. This was done in situ within a short period. Lifter bars were cut to recommended angle of 35˚ and the grate open area was reduced from 7.7% to 4.0%.

After running for a month, the mill balls wear rate dropped from 2500 g/t to 1800 g/t It was further recommended that the grinding media type be changed to forged (50 mm) from high-chrome (40 mm) because the forged type withstands high impact conditions. This was done and mill balls consumption further dropped to 1100 g/t.

The mill ball loading was gradually increased from 8% to 25%. This showed an improvement in the grind and flotation recoveries. The mill inspection showed that after grinding out for 20 minutes, there was no pull of slurry, only balls, which was an indication that the ball breakage had reduced. Figure 10 shows the condition of the mill at 25% ball loading after 20 minutes of grinding out.

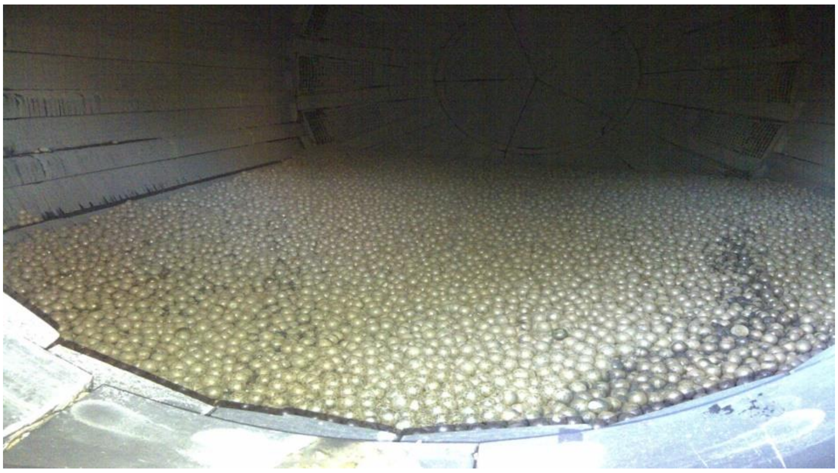


Figure 10: Ball mill condition after 20 minutes of grinding out.

To see the benefits of the mill liners and grate modifications, the next set of mill liners were manufactured with 30˚ attack angle on both mill ends and shell, and a grate total open area of 4.7% from the initial open area of 8%.

FURTHER BALL MILL MODIFICATIONS AND OPTIMISATION

After successfully increasing the mill liners lifting angle to 30°, reduced discharging the grate open area and dropping the mill balls consumption from 2400 g/t to 1100 g/t, a two-stage modification plan was considered to further reduce mill balls consumption, which was still higher than the expected value of 500 g/t or less. The two options considered were:

- discharge cone removal;
- converting the mill to 100% overflow type if the consumption did not drop.

Option 2 of converting the mill discharge to an overflow type was selected because this was expected to immediately achieve the target wear rate of below 500 g/t. The ball mill discharge was successfully converted to 100% overflow on 19 March 2015. This was achieved by removing the pulp lifters, discharge cone and grate plates and replacing them by base plates and lifter bars similar to those at the feed end.

After converting the mill, balls started discharging prematurely from the centre and a 20 mm slotted ball retainer screen was fabricated and installed. This stopped balls from discharging.

RESULTS

Figure 11 shows the ball mill discharge arrangement after a successful conversion to an overflow type. Figure 12 shows that ball consumption increased to > 2500 g/t in Dec 2012 due to breaking of mill balls. After changing the lifting angle to 30°, closed some grate openings and changing the steel balls to forged from high-chrome, consumption dropped to 1100 g/t. After conversion in March 2015, ball consumption dropped to 500 g/t. Mill conditions became favorable for 40 mm high-chrome mill balls, which were reintroduced in October 2016 as a top charge, replacing the 50 mm forged balls. This saw consumption dropping further to 280 g/t. Figure 12 also shows that the desired grind was achieved at low ball consumptions.

Figure 11: Ball mill discharge end after conversion.

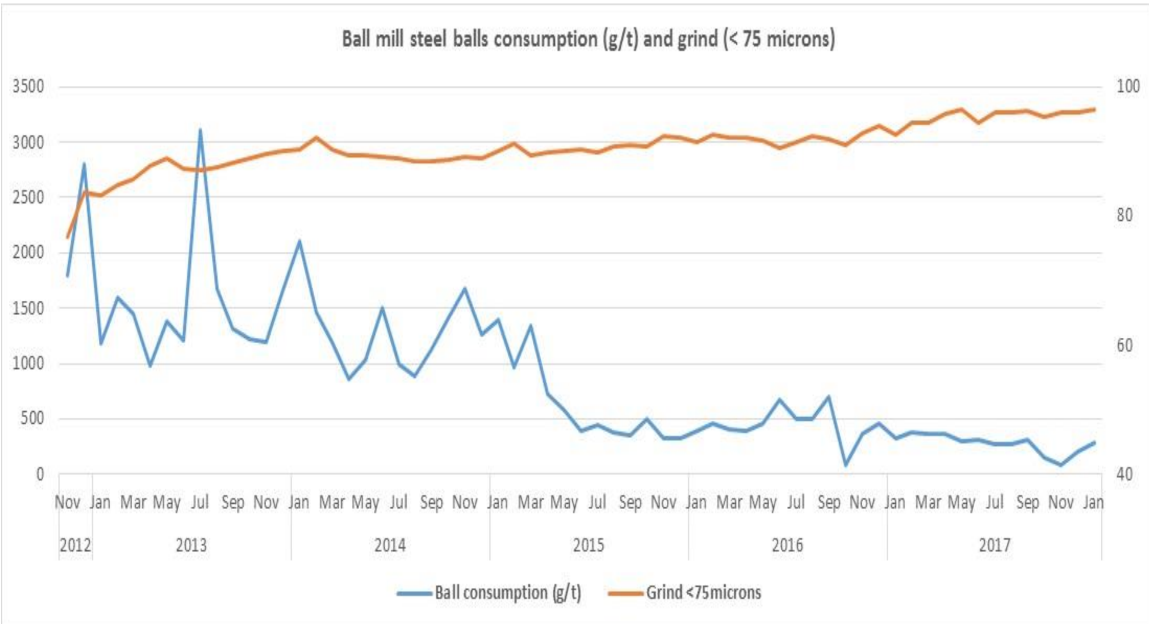


Figure 12: Secondary mill steel balls consumption and grind before and after conversion.

Benefits Achieved after Ball Mill Conversion

The following benefits were observed:

- mill balls consumption reduced from 1100 g/t to 280 g/t;
- liners life doubled;
- low maintenance and high mill availability;
- power draw reduced by 17 to 20%;
- consistent feed to flotation grind achieved.

CONCLUSION

The Lubambe Copper Mine ball mill was successfully converted to an overflow-type configuration and mill ball consumption dropped to 280 g/t from 1100 g/t. There has been consistency in the feed to flotation grind after this conversion.

ACKNOWLEDGEMENTS

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