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The Arrium IsaMill from Design through Commissioning and Optimisation

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ABSTRACT

Arrium's magnetite concentrator has recently completed a modification program to improve the process that has been in operation in Whyalla, South Australia for the previous seven years. The magnetite concentrate is pumped via pipeline to the coast and serves as pellet plant feed, eventually being turned into steel in the Whyalla blast furnace. With the addition of a new 3MW IsaMill at the concentrator, the plant has seen increased production from a reduced feed grade, enabling Arrium to treat ores previously stockpiled as waste. This paper will focus on the design work and commissioning of the fine grinding circuit along with the year of optimisation that followed, taking the IsaMill up to 350+ tph of throughput.

INTRODUCTION

The original Arrium magnetite flow sheet that began operation in 2007 consisted of two stages of grinding, utilizing two HPGRs with a total installed power of 1.8 MW and a 7.5 MW ball mill. The complete flow sheet is shown in Figure 1.

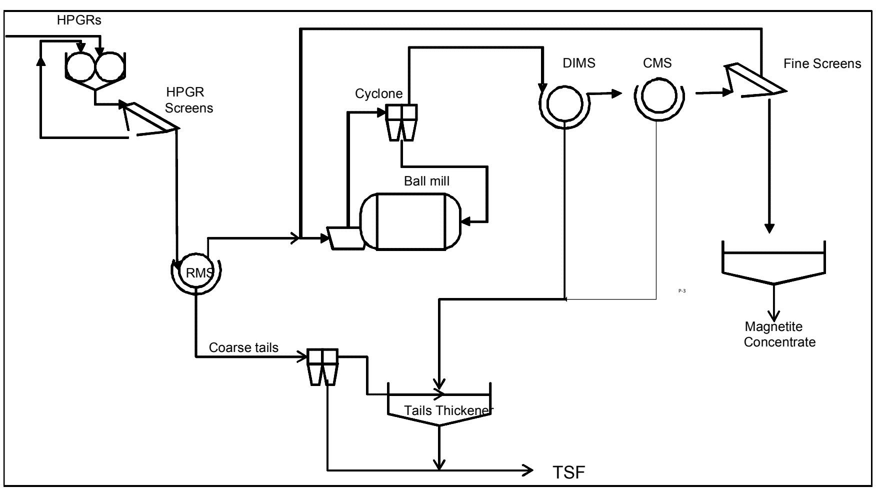

Figure 1 – Original Arrium magnetite flow sheet.

In 2009 Arrium began a review of the plant with the aim of debottlenecking and optimisation. Much of this early work is covered in the AUSIMM Iron Ore 2015 paper *Unlocking Plant Capability through Targeted Debottlenecking of Arrium's Magnetite Concentrator* (Mativenga, et al 2015). The main outcome of this work was the conclusion that if the plant was upgraded to improve liberation a large portion of stockpiled waste could be converted to plant feed while also increasing mill throughput. Arrium then began investigating different options to add grinding power to the plant through both conventional and stirred milling options.

BALL MILL VS ISAMILL COMPARISON

In 2011 Arrium Mining ran their first IsaMill lab test at ALS AMMTEC in Perth WA. This was a straight comparison of the existing ball mill circuit to the IsaMill. With an F_{80} of +350 microns it is coarser than most operating IsaMills. With 5-6 mm media the IsaMill was able to break the coarsest feed and still efficiently reach the final product size in significantly less energy than the ball mill. The ball mill reached a P_{80} of 32 microns in 24 kWh/t, not including any cyclone pump energy. The M4 IsaMill with the same feed from the ball mill survey reached a 32 micron P_{80} in 17 kWh/t as shown in Figure 2 (Steele, 2011). This results in a 29% improvement over the ball energy to 32 microns.

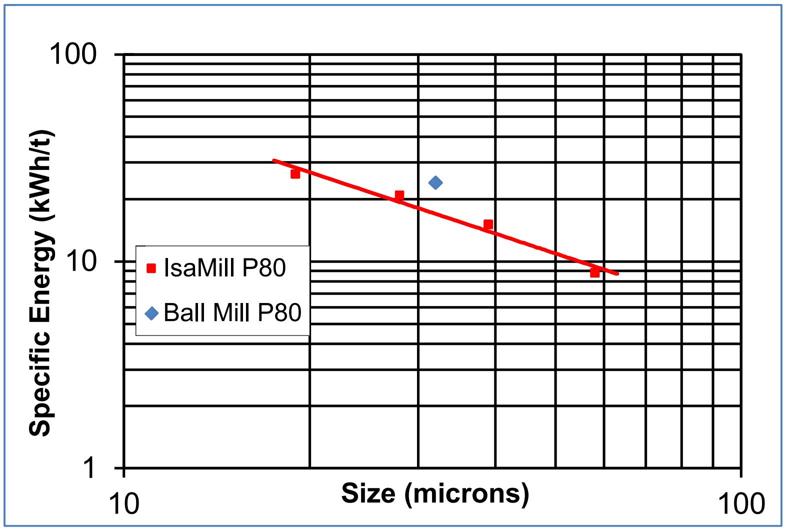

Figure 2 – Arrium ball mill versus M4 IsaMill.

The basic principle of the IsaMill is that it fluidizes a charge of small ceramic grinding media. Media ranging in size from 1.5 to 6.5 mm and coarse particles from the mill feed are centrifuged to the outside of each disc where backflow compression from the product separator keeps them in the mill until the particles are ground fine enough by attrition and compressive forces to pass down the middle of the mill and discharge. Due to this process external classification is not necessary.

As long as the IsaMill can break down the coarsest particles as quickly as they enter the mill it can compete with a ball mill. The M4 IsaMill testwork showed this was possible when grinding a 300 micron Arrium ore feed to P_{80} values below 100 microns.

However, the Arrium flowsheet has a functional ball mill and the goal of this exercise was not to replace it, but to modify the flowsheet to increase plant capacity and improve grinding energy efficiency.

Through previous Australian magnetite testwork it was known that running the IsaMill with the same feed (i.e. in parallel) as the ball mill is not the most efficient flow sheet. From pilot and lab work presented at MetPlant 2011 in the paper *Optimising Western Australian Magnetite Circuit Design* it is shown that 3 stages of grinding efficiently utilizes each grinding mill to the best of its abilities (David *et al*, 2011). As shown in Figure 3 the ball mill is perfectly suited for a coarser grind which then reduces the feed size to the IsaMill. From the graph it can be seen the IsaMill is only more efficient at grinding to product sizes below 100 microns in this particular case. With smaller reduction ratios both mills can be optimised with the correct media sizes. As an added benefit the separation step between the two milling stages reduces the amount of gangue material needing to be ground down to 32 microns.

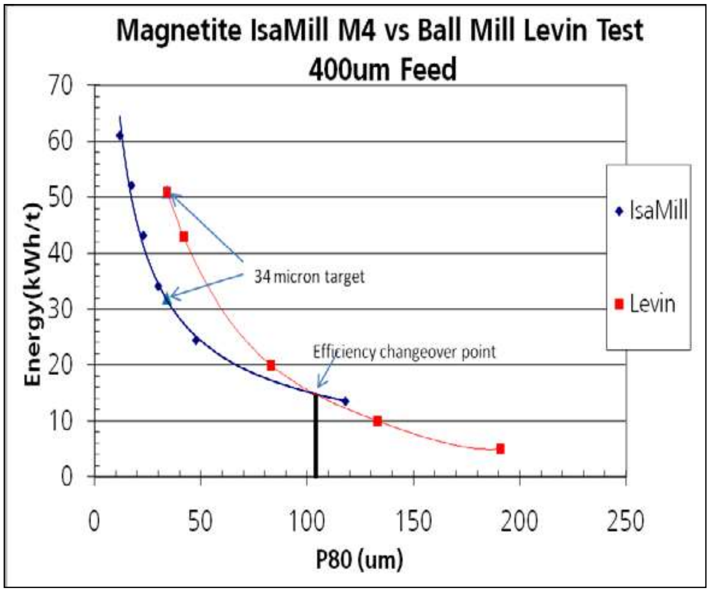

Figure 3 – Previous magnetite (not Arrium) IsaMill vs Levin ball mill lab tests.

Large reduction ratios and lack of intermediate gangue rejection work against the two stage flow sheet shown in Figure 3. The ball mill, though not ideal for grinding fine, is well suited for an intermediate grind, which can then be followed by an extra step of magnetic separation. This produces a reduced mass of feed which is ideally sized for the IsaMill. This idea was incorporated into the next phase of the Arrium M4 IsaMill work at ALS AMMTEC completed in 2012.

ISAMILL VARIABILITY SIGNATURE PLOTS

Test work was next undertaken at ALS AMMTEC with Arrium personnel present to understand how different sections of the ore body grind in the M4 IsaMill. Figure 4 shows three of these tests which display a considerable variation in the energy required to reach 32 microns, with values of 14.2, 12.3 and 18 kWh/t respectively (Ladhams, 2012). These three samples were each taken from different areas of the ore body. It should be noted these three samples were a harder, higher waste material than the first material tested in Figure 2. The test feed was ground down to an F_{80} of 90 microns with no intermediate magnetic separation prior to being run through the IsaMill. Removing liberated gangue material would have the effect of reducing this variability somewhat. It does show the importance of understanding the ore body and not relying on just one sample to design a regrind circuit.

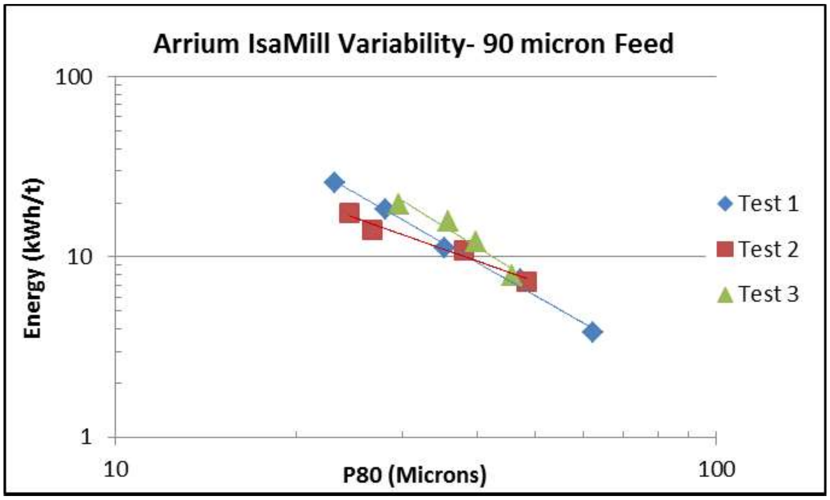

Figure 4 – Arrium variability signature plots.

FINAL MILL FLOW SHEET

After numerous signature plots and some pilot testing it was determined that one 3 MW M10000 IsaMill would be suitable to grind a maximum design 300 tph of 60 micron feed to a desired 32 µm P_{80} and Davis Tube silica grade of 2-3%. The mill would be in a tertiary grinding step rather than run in parallel with the ball mill. The design concept is to allow the HPGRs to produce a coarser product at higher tonnage, optimise the ball mill to treat this coarse material and then provide a suitably fine feed for IsaMilling. The IsaMill product would be fed to an installation of Derrick Stack Sizer screens with 63 micron panels to ensure steady silica grade. The role of the Derrick Stack Sizers is primarily to eliminate any remaining oversize material both for silica grade control and pipeline protection. This flowsheet is shown in Figure 5. There are additional 1 mm screens ahead of the IsaMill serving to remove trash from the feed rather than providing actual classification.

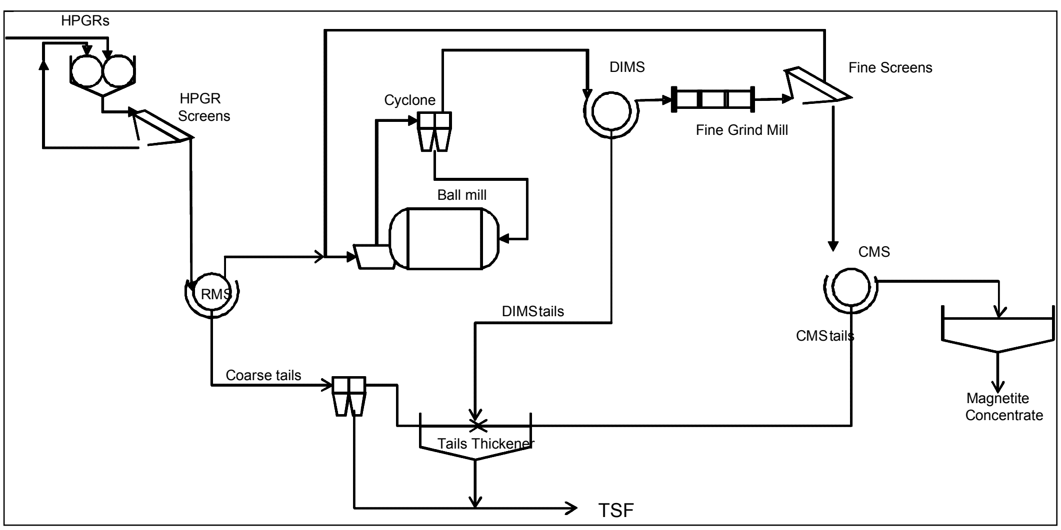

Figure 5 – Arrium modified flow sheet.

ISAMILL START UP

The M10000 IsaMill at Arrium is shown in Figure 6. Feed enters the mill at the non-drive end and discharges from the drive end already classified. Grinding is achieved by discs on an internal rotating shaft, and the discs are designed to keep a ceramic grinding media load of about 70% of the mill volume agitated.

Figure 6 – Arrium M10000 IsaMill installation.

The IsaMill was commissioned in November of 2013. Performance Acceptance Testing (PAT) was conducted on a dedicated ore stockpile shortly after start up. Comparison test work had been run on an M4 IsaMill at ALS AMMTEC from samples of this same stockpile. Minor differences from these feed samples included the media size used and lower solids SG due to there being no DIMs upgrading applied in the case of the M4 feed. The M4 sample was also slightly coarser, resulting in more residence time and a sharper size distribution once it reaches the final P_{80}. A comparison of the average results from both the lab and full scale is given in Table 1 (Bandarian, 2014).

Table 1 – Average PAT plant sizing data versus average AMMTEC signature plot test work data.

	Specific energy input (kWh/t)	Feed F80 (µm)	Discharge % passing 32 microns
Average Plant Data (PAT)	8.0	41.5	86.1%
Average AMMTEC Data	8.6	41.9	85.6%

Considering the differences in operating conditions and feed, the agreement between the two data sets is acceptable. For all of the M10000 product size distributions measured during the PAT period the average percent passing 32 microns was 86.1%. The average percent passing 63 microns was 98.1%. With an extrapolated P_{80} of 27 or 28 microns that gives a P_{98}/P_{80} ratio of about 2.33. The ratio for the three AMMTEC PAT comparative tests averaged around 2.3. The percent passing 75 microns averaged 99.1% in full scale surveys. ALS AMMTEC test C at pass 3 had a P_{80} of 26 microns and 99.5% passing 75 microns. Test B was a P_{80} of 28 microns and 99.6% passing 75 microns. The slight discrepancy between full scale and the M4 is likely due to the larger media and longer residence time in the M4. Consequently, the M4 produced a sharper size distribution once it reduced the feed to the ~50 micron P_{80} size that was feeding the M10000. It should be noted that test A is not included in these comparisons simply because none of the passes were at sizes directly comparable to individual survey results.

Average comparisons of the full feed and product size distributions between the M4 and M10000 for this test are shown in Figure 7 (Bandarian, 2014).

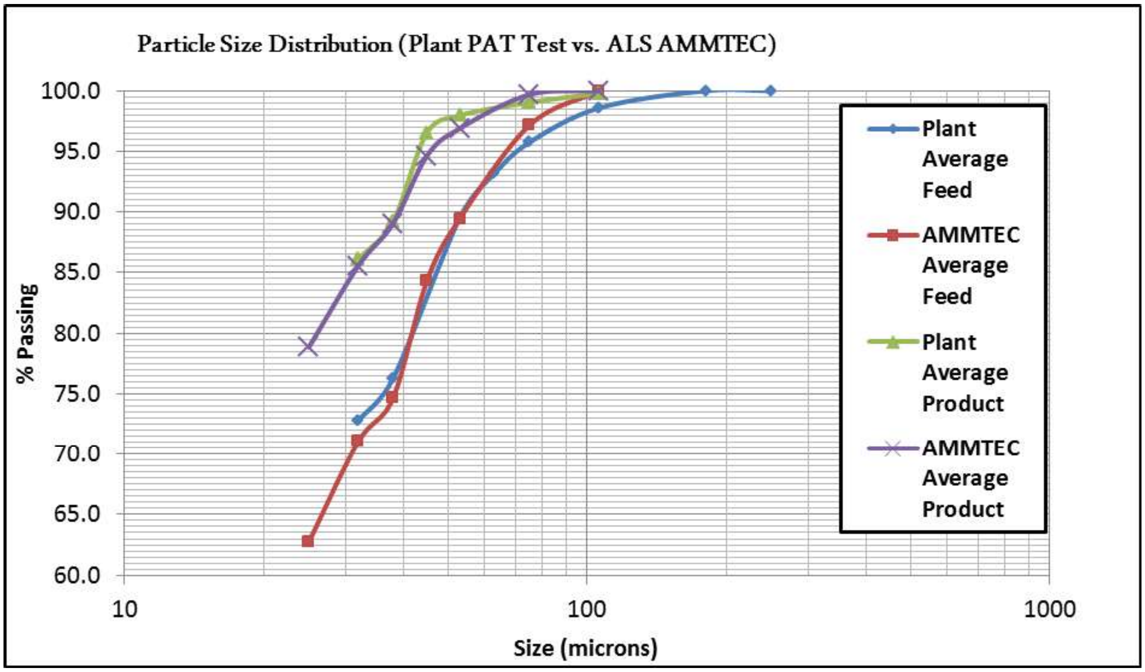

Figure 7 – M4 and M10000 complete size distribution comparisons.

MILL CONFIGURATION OPTIMIZATION

As is standard commissioning and operating practice, temperature checks are regularly taken along the IsaMill shell. These are tracked to monitor for compression and build-up of heat in the mill. Through the first two months of commissioning it was clear that there was more compression at the shell than is recommended for optimum mill liner life. Different mill configurations were implemented to improve the fluidization inside the mill and reduce shell liner and disc wear. Through small incremental changes the ideal mill setup was found. This spread out the temperature profile in the mill and also acoustically gave a more fluid sound inside the mill. Full mill operation with minimal internal wear was realized in early February 2014, about 3 months into commissioning and well ahead of the June deadline to reach full run time and throughput.

The main indicator of this success was the condition of the mill when opened for inspection, shown in Figure 8 (Ziki, 2014). After the optimisation phase wear of the discs and shell liner was found to be more consistent across all surfaces leading to an increased maintenance interval with better predictability of spares use.

Figure 8 – IsaMill maintenance opening February 2014.

Currently the IsaMill is inspected every 6 weeks in the line with the rest of the plant. Having the IsaMill maintenance line up with the rest of the plant was critical to ensuring a minimization of disturbances to the pellet plant feed, both in terms of grade and throughput.

ISAMILL SCALE-UP AND OPTIMISATION

Once it was confirmed that the mill was achieving the design grind duty and required maintenance interval, work began to fully optimize the operation. An M4 IsaMill was once again used, this time at the University of Queensland. A short survey of the IsaMill was performed to collect sufficient feed sample for multiple M4 tests. A graded charge of media from the M10000 IsaMill was shipped to Brisbane to perform test work. Product was sampled to determine the discharge sizing by sieve screens. The average results of the full scale survey are shown in Table 2.

Table 2 – IsaMill feed and product sizes, February 2014 survey for M4 scaleup (Villadolid, 2014).

Size µm	%Passing Feed	% Passing Discharge
106	98.3	99.9
75	94.3	99.5
53	87.3	97.6
38	61.3	84.9
25	52.7	74.6

The media size of 4-5 mm was initially decided upon by IsaMill rules of thumb as it was thought to give the best product size distribution for the 32 micron P_{80} of product and ~50-60 micron F_{80} design feed at a higher than average expected feed rate. At the University of Queensland a GT engineer tested this media against a laboratory 3.5 mm charge and a 5-6 mm charge that had been used at Ernest Henry Mine in their much coarser M10000 magnetite tails operation (Villadolid, 2014).

The M4 at UQ accurately predicted the required Arrium M10000 energy with 4-5 mm media, although the signature plot line shown in Figure 9 needed to be extrapolated due to the fine first pass produced in the M4 (Villadolid, 2014).

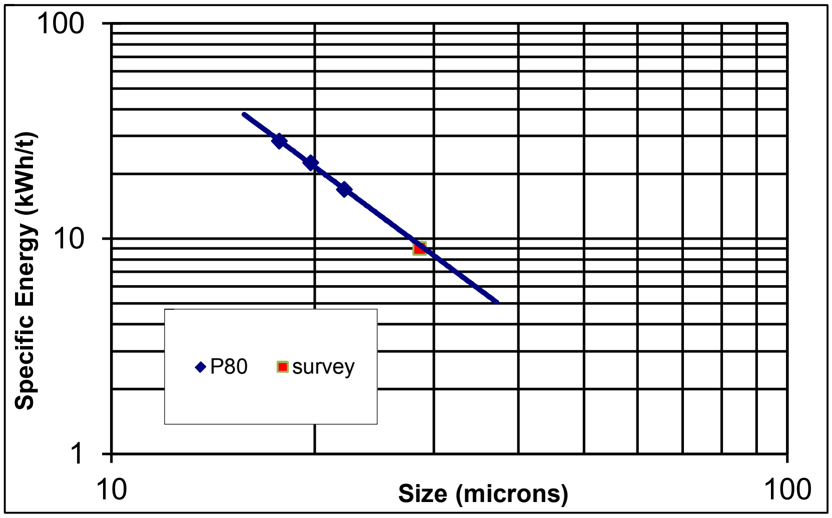

Figure 9 – IsaMill M4-M10000 scale-up.

When comparing the different media size options it would appear that the current 4-5 mm is correct for the full scale application. To a P_{80} of 32 microns the 4-5 mm media required 7.2 kWh/t, the 5-6 mm 11.2 kWh/t and the 3.5 mm 7.6 kWh/t. Due to the superior product size distribution inherently produced by the larger 4-5 mm media compared to any smaller media sizes, and its ability to cope with potentially coarser feed, it was recommended that Arrium continue to use the current size of ceramic media.

Satisfied that the media size was appropriate, a program to push the IsaMill well past its design maximums was implemented in April/May of 2014 just over two months after commissioning was officially ended. Mill feed density was slowly increased while monitoring the mill for proper fluidization and compression. It was found the mill slurry density could be increased from 1.64 to 1.68 kg/l in this period, increasing the solids feed rate by about 20 t/h at a constant flow rate. Next the feed flow rate was increased while monitoring the mill media load to be sure rotor pumping capacity was not exceeded. The flow was gradually increased until it reached 400 m^3/hr. The end result was an increase in tonnage from about 300 tph to 350 tph. Through this period the P_{80} increased slightly along with the feed size but the product top size and Davis Tube silica were barely changed, increasing by less than 0.5% silica.

One realization during this trial was that the Derrick Screen oversize typically contained less than 4 t/h of material that was actually coarser than 63 microns (the oversize mass was much more than 4 t/h but the majority of it was misreporting fines). In essence, the Derrick screens were underutilised because the IsaMill does not leave much +63 µm in the product. It was possible to use the excess capacity in the Derrick Screens and final grade to process additional material equivalent to IsaMill feed, while still processing the full flow if IsaMill product. The Derrick screens control the top size reporting to the cleaner magnetic separators and all oversize is returned to the ball mill cyclone feed rather than the IsaMill feed. In this way total tonnage for the plant could be increased further without exceeding the silica grade limit and without coarsening the product P_{80} significantly. Typically the liberation from the IsaMill even when flow constrained was above what was necessary. With a bypass line installed to the Derrick screen the plant could increase total new feed to the HPGR and ball mill. The coarsest fraction containing the most silica that bypassed the IsaMill would be removed by the Derrick screens, providing the necessary control over silica grade.

CURRENT OPERATING CONDITIONS

From May of 2014 until March 2015 the IsaMill was treating an average of 350 tph while the design maximum tonnage was 300 tph. Mill power draw has run consistently at 2,600 kW. Design disc consumption was predicted to be 26 per year. It is currently under 14 discs per year and continues to drop as the IsaMill Information System (IMIS) program provided by GT receives more information to better predict and utilize the full life of a disc. Though accelerated wear was experienced at the start of operations, current indications predict a liner life of 8-12 months, which is about on budget. Arrium has taken on a methodical approach to moving the shell liner every second mill opening to spread wear to all available rubber areas. Availability for the IsaMill has been excellent, with almost all downtime related to issues outside of the IsaMill circuit. Mill stability has been steady due to consistent upstream operation. The yearlong average for the Cenotec grinding media wear has been 6 g/kWh, versus a budget of 10 g/kWh. The media has worn smooth and round as shown in Figure 10, also contributing to improved disc and shell liner wear.

Figure 10 – Arrium IsaMill graded media charge.

Future work

Beginning in March of 2015 the IsaMill internal configuration was changed again to allow more flow through the mill. This brought the IsaMill to 485 m3/hr of flow and about 425-435 t/h of solids. As of the writing of this paper analysis continues into the sustainability of this production increase. Publications on progress will be made available in the future.

CONCLUSIONS

This project has seen the magnetite operation undergo an overhaul, allowing it to produce magnetite concentrate using a lower grade feed material at an increase in production capacity of greater than 400,000 tonnes per year. (Arrium news webpage, 2014) This throughput has continued to be expanded as the maximum capacity of the IsaMill has been pushed well beyond the original design. After a challenging start, handover of the plant was completed on budget and ahead of schedule. Through methodical implementation procedures, step by step improvements in throughput and mill wear have been realized allowing the plant to process tonnage well beyond anything for the original design.

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