COARSE GRINDING ON A ISAMILL?

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ABSTRACT

When the IsaMill™ was first introduced to the market in the late 1990s, the target grind size was in the sub -10-micron range, as this was the specific need to convert the complex Mount Isa Mines and McArthur River Mining lead/zinc ore bodies into economic projects. The IsaMill™ quickly established the leading position in the ultra-fine grinding market. Developments with larger ceramic media in mid-2000s allowed the IsaMill™ to demonstrate that the mill can operate with a feed of 400 microns (P80) and a top size of 1 millimetre using a graded charge of 6-millimetre media. Recently, it has been observed that the market is moving to coarse particle flotation, and feed sizes to stirred mills have slowly increased on average. Ceramic media are now available up to 14 millimetres to treat this coarser feed.

This paper aims to explain how an existing (or new) IsaMill™ can operate in a coarse particle duty, provide examples of testwork where success has been seen with coarser feed streams e.g., hydrofloat concentrate, how to manage wear with coarser feed and outline the journey Glencore Technology (GT) has undertaken to move the IsaMill™ into the Ball Mill equivalent applications (secondary grinding).

INTRODUCTION

When the IsaMill™ was first introduced to the market in the late 1990s, the target grind size was in the sub -10-micron range, as this was the specific need to convert the complex Mount Isa Mines and McArthur River Mining lead/zinc ore bodies into economic projects. The IsaMill™ quickly established the leading position in the ultra-fine grinding market. Initially, when the IsaMill™ was developed, the optimum media selection was around 2 millimetres, due to the low P80 targets (7 microns) for the Mount Isa Mines and McArthur River deposits. Since the first installation, Glencore Technology (GT) has developed larger IsaMills™, and ceramic media suppliers have followed suit with larger ceramic media. This has enabled the IsaMill™ to treat coarser feeds at higher volumetric throughputs, increasing the scope in which it can operate.

HOW THE ISAMILL™ WORKS

Figure 1 illustrates the grinding mechanism within the IsaMill™. The IsaMill™ typically operates around 70% media filling volume of ceramic media. As the shaft rotates, the grinding discs agitate the media via the kidneys and the surface of the discs, such that it is centrifuged out along the face of the discs towards the shell liner. As it reaches the shell liner, the media is redirected back towards the mill shaft area. This happens between the face of each disc, where there is sufficient media present. This sets up a chamber of agitated grinding media between each grinding disc. Slurry to be ground enters opposite the shaft end cap at one end of the IsaMill™. Any particle entering the IsaMill™ must pass through each of the agitated grinding chambers in series before it can exit, making it virtually impossible for any material to short-circuit the IsaMill™ (Gurnett et al, 2021).

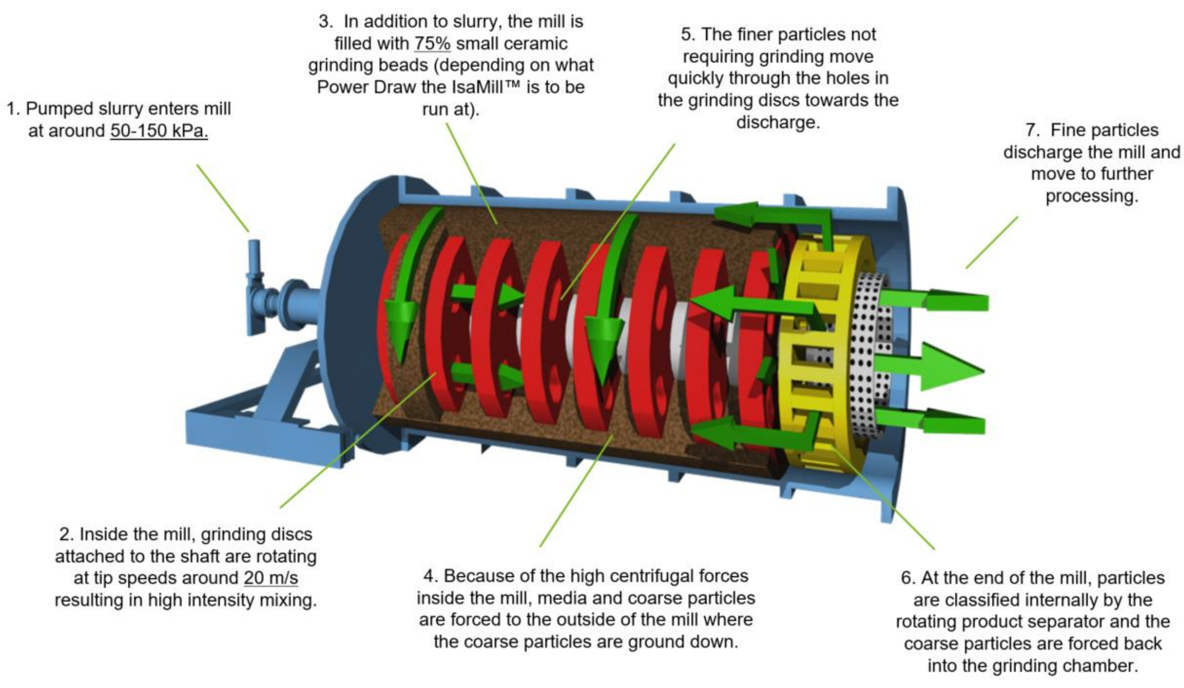

Figure 1: Internal mechanism of an IsaMill™ (Gurnett et al, 2021)

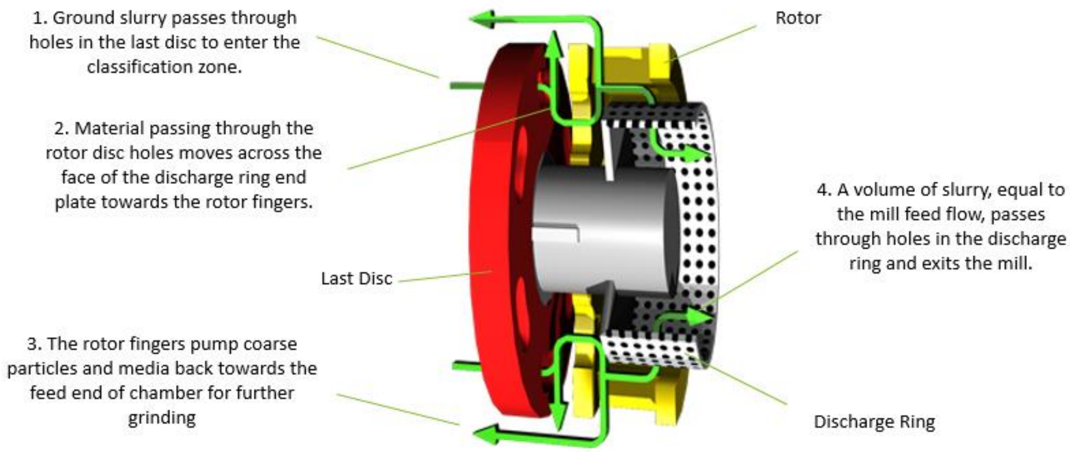

Figure 2: IsaMill™ internal classification (Gurnett et al, 2021**)**

At the discharge end of the IsaMill™ is the patented (Gurnett et al, 2021) product separator (Figure 2), which uses a closer spacing between the final disc and the rotor disc to centrifuge any coarse particles and media towards the shell. The rotor, which acts like a pump, then returns this material to the grinding zones towards the feed end of the IsaMill™. This mechanism allows the ground product to flow through and exit the IsaMill™ whilst retaining the grinding media inside, all without the use of fine screens, allowing for a much sharper Particle Size Distribution (PSD) in the milled product. (Gurnett et al, 2021)

UTILISING THE ISAMILL™ IN A COARSE DUTY

Utilising a HPGR and a IsaMill™ into a single flowsheet is not a new concept and was first proposed back in 2007 and has since been discussed several times in the literature. Valery and Jankovic (2002) proposed the first concept of a combination HPGR/stirred mill circuit in a study examining the need for reducing the energy requirements of comminution. Simulating results for a more energy-efficient circuit, a predicted energy savings of 45% was seen, but no actual testwork was conducted (Drozdiak et al, 2011).

Pease (2007) presented the concept of an HPGR / IsaMill™ circuit in his discussion of coarse-stirred milling at McArthur River. While no HPGR testing was carried out, it was predicted that this circuit could be an example of the comminution flowsheet design of the future (Drozdiak et al, 2011).

Ayers, Knopjes, and Rule (2008) described the first operation of an HPGR/IsaMill™ circuit using pilot-scale equipment. A continuously operating circuit was established using an HPGR in closed circuit with a dry screen, followed by wet screening of the undersize at a cut size of 850 microns. The screened product was fed to an M250 IsaMill™ operating with 3.5 millimetre MT1 ceramic grinding media. With an F80 of 300 microns and a product P80 of 45 microns, the IsaMill™ circuit operated at 1.3 tonnes per hour (Drozdiak et al, 2011).

This pilot research demonstrated that an HPGR / stirred mill circuit is technically feasible and that, based solely on the specific energy requirements for comminution, the novel circuit could achieve a reduction of 9.2% and 16.7% over the HPGR /ball mill and cone crusher/ball mill circuits, respectively as demonstrated in Figure 7. (Drozdiak et al, 2011)

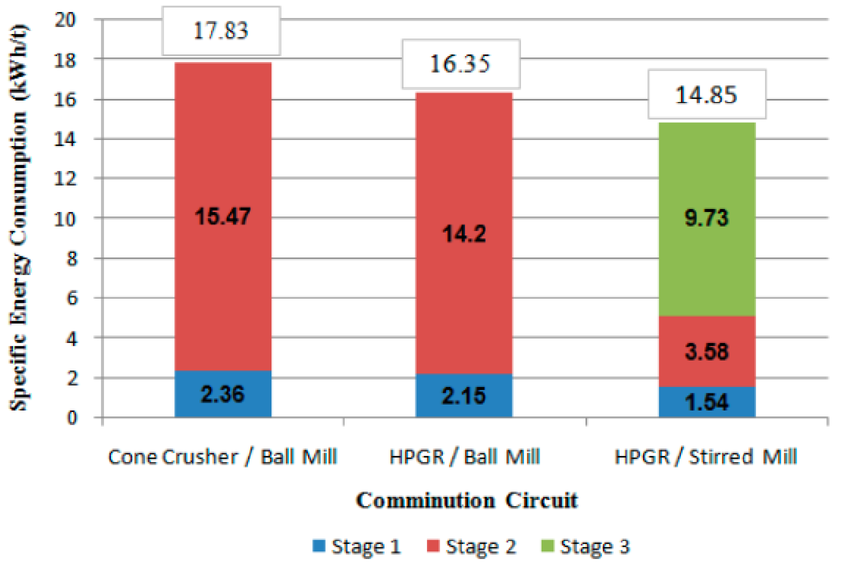

Figure 3: Specific Energy Analysis by Anglo Platinum (Drozdiak et al, 2011)

GT has conducted regrind ball mill replacement studies in the past. A prime example is in 2011, where a Ball Mill and IsaMill™ were reviewed to look at the efficiency of stirred milling in the application of replacing regrind ball mills. This approach made sense when you look at the efficiency exchange between the impact and abrasion mechanism in tumbling/ball mills (with larger media selection) versus the optimised attrition mechanism in a stirred mill. From this study, energy improvements using an IsaMill™ were in the region of 29% (not including the ball mill cyclone feed pump). The ball mill required 24 kWh/t to achieve 32 microns compared to the IsaMill™ needing only 17 kWh/t to achieve 32 microns from an F80 of 100 microns (Larson et al, 2015). Its also important to note that there are also ESG benefits of the smaller footprint of the IsaMill™ and higher energy intensity per unit area are clearly identified in Figure 8.

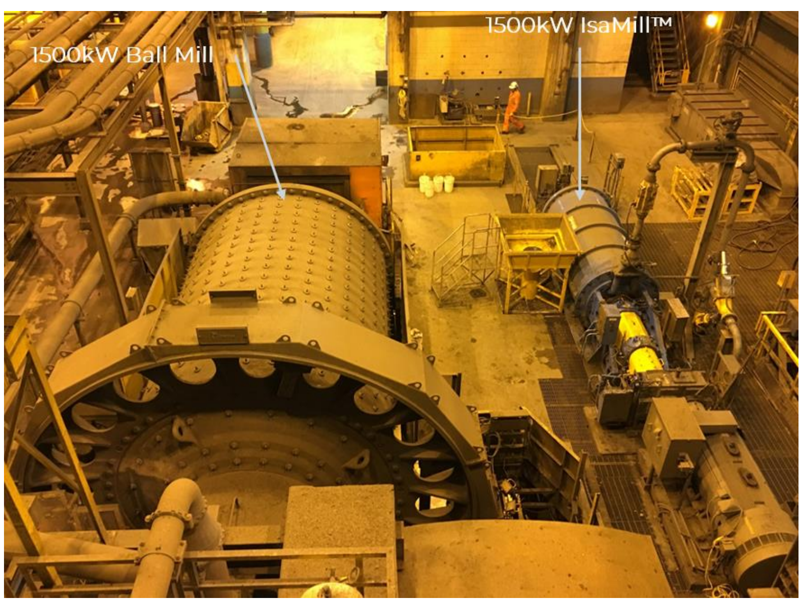

Figure 4: Footprint reduction between Ball Mill and IsaMill™ for same 1500kW motor

Since ceramic media has the potential to be optimised further (sub 1-millimetre feed), it begs to question the efficiency gains that could be seen with ceramic media in secondary/tertiary grinding opportunities. In recent years, ceramic media suppliers now produce 3.7 S.G. media up to 16 millimetres. When GT last investigated coarse grinding in 2010, the largest media available was 6 millimetres (Larson et al, 2015).

As IsaMills™ are getting larger, with the current largest installed mill being a 5 MW M20,000 IsaMill™, and with designs up to a 12 MW in an M50,000, the next logical step will be into the coarser grind territory with this newly available media. It is the author's belief that eventually, future circuit designs that utilise inert grinding media resulting in improved chemistry (no iron grinding media in an HPGR-IsaMill™ or AG Mill – IsaMill™ circuit) in an open circuit design are not too far away.

MEDIA SELECTION

When media is selected for an IsaMill™, it needs to be efficient at grinding the fines whilst having enough momentum to break up the top size of the material entering the IsaMill™. From GT's experience, the following matrix (Figure 3) is typically reviewed to determine the top size of the media to produce the most efficient breakage mechanism in an IsaMill™ (full scale to lab scale). It's important to note that when media is selected, we use a reduction ratio of eight per media type to maintain optimum breakage efficiency.

		Feed Size, F80 (µm)											
		<20	20-30	30-40	40-50	50-60	60-70	70-100	100-130	130-160	160-200	200-250	>250
Product Size P80 (µm)	<7	1.5	1.5	1.5-2	1.5-2	2	2						
	7-11	2	2	2	2	2	2	2.5					
	11-15	2.5	2.5	2.5	2.5	2.5	2.5	2.8	3				
	15-20	2.5	3	3	3	3	3	3	3-3.5	4			
	20-25	x	3	3	3.5	3.5	3.5	3.5	3.5-4	4.5	4.5	4	
	25-30	x	x	3.5	3.5	3.5	4	4	4	4.5	4.5	4.5	5.5
	30-35	x	x	x	4	4	4.5	4.5	4.5	5	5	5	6
	35-40	x	x	x	4.5	4.5	5	5	5	5	5.5	5	6
	>40	x	x	x	5	5	5	5	5.5	5.5	5.5	5.5	6

Figure 5: Media Selection Matrix (Gurnett et al, 2021)

The energy imparted by the ceramic grinding media is proportional to three specific areas: volume, velocity, and density (Glencore Technology, 2018a). The Stress Intensity in the media attrition mechanism has the following relationship (this is important to understand as it identifies what you can leverage when attempting to grind coarser).

$$E \propto d^3 \cdot v^2 \cdot SG$$

d = Media Diameter

v = Media Velocity

SG = Media Density

In an IsaMill™ there are diminishing returns on increasing the S.G. to improve the energy in the collision. This has been demonstrated with previous high S.G. results where 4.5 S.G. media was found to be 20% less efficient than the typical design S.G. of 3.7 -3.8 (Gurnett et al, 2022). Since the IsaMill™ is typically based on a fixed-speed shaft, the media velocity can only be adjusted by physically changing the shape of the internal components (discs and spacers), which have a relatively minor effect on the grinding process and making the media size the easiest item to change having an influence on breaking up coarse material.

If the media selected is too small (i.e., not large enough to break the coarsest particle), the following processes will occur (Glencore Technology, 2018a).

1. Due to the internal classification mechanism, entering particles will not exit the mill until they have been ground sufficiently.
2. If the IsaMill™ circuit feed coarsens significantly, the media may no longer have sufficient energy to break the top-size particles. This creates the potential for coarse particles to start building up inside the mill.
3. Excessive coarse particle build-up may cause the charge inside the mill to “lock”, resulting in a power draw drop, and feed will need to be diverted to allow the IsaMill™ to grind out the coarse material.

If the media selected is too large, there will be an increase in wear on the internal components and inefficacies will be seen in grinding the fines fraction. There is also a point where the mill internals will lock up if the ceramic media exceeds a certain size at a corresponding tip speed (e.g., 14 millimetres at 20 m/s) due to the momentum that the media possesses. This is specifically mentioned as understanding your media will have significant influence in coarse grinding applications, regardless of stirred mill selection.

ADAPTING THE INTERNAL CONFIGURATION FOR WEAR

Moving to a coarser grinding duty will result in additional wear to the components if the mill is not configured correctly. The learnings that GT has used from optimising IsaMills™ over nearly 30 years in varying ore competencies have allowed for the development of strategies to maintain fluidised behaviour in the mill, manage wear to reasonable expectations and minimise downtime. These strategies have helped help mitigate some of the wear issues that are expected or have seen when moving to a coarser duty.

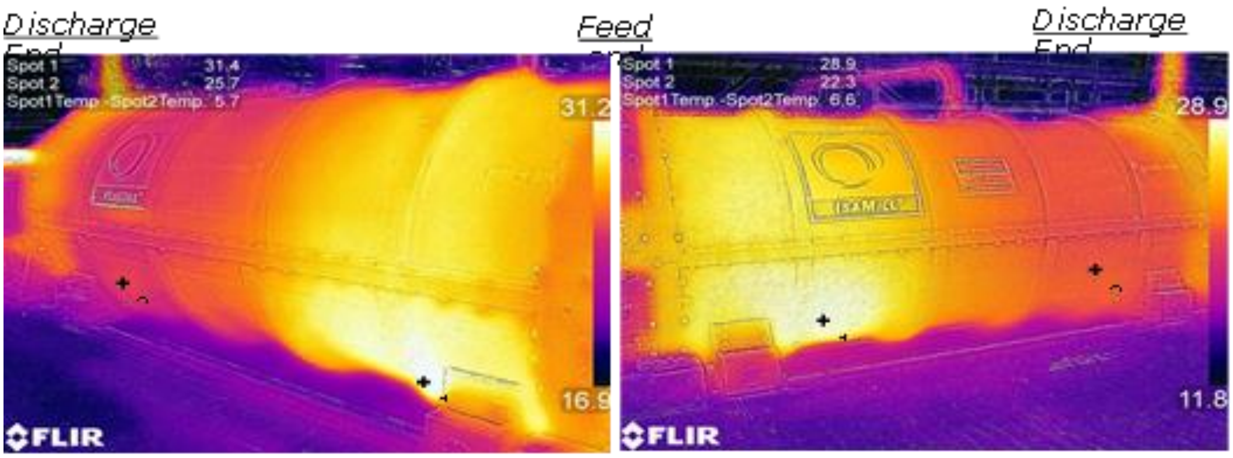

Figure 6: Thermal Surveys of an IsaMill™ (Glencore Technology, 2018b)

When we expect high wear within an IsaMill™, the first step is to analyse the wear mechanism and adjust the zones of high wear/compression to ensure that the fluidised behaviour is occurring in those zones. To review where the media is sitting, it is recommended to conduct thermal surveys (Figure 4) and analyse the process variables and their influence on media positioning (Figure 5). Once the mill has been adjusted from a process perspective, and if there is still a known zone of media, compression is still identified. The internals of the IsaMill™ can be configured to remove heat away from the area.

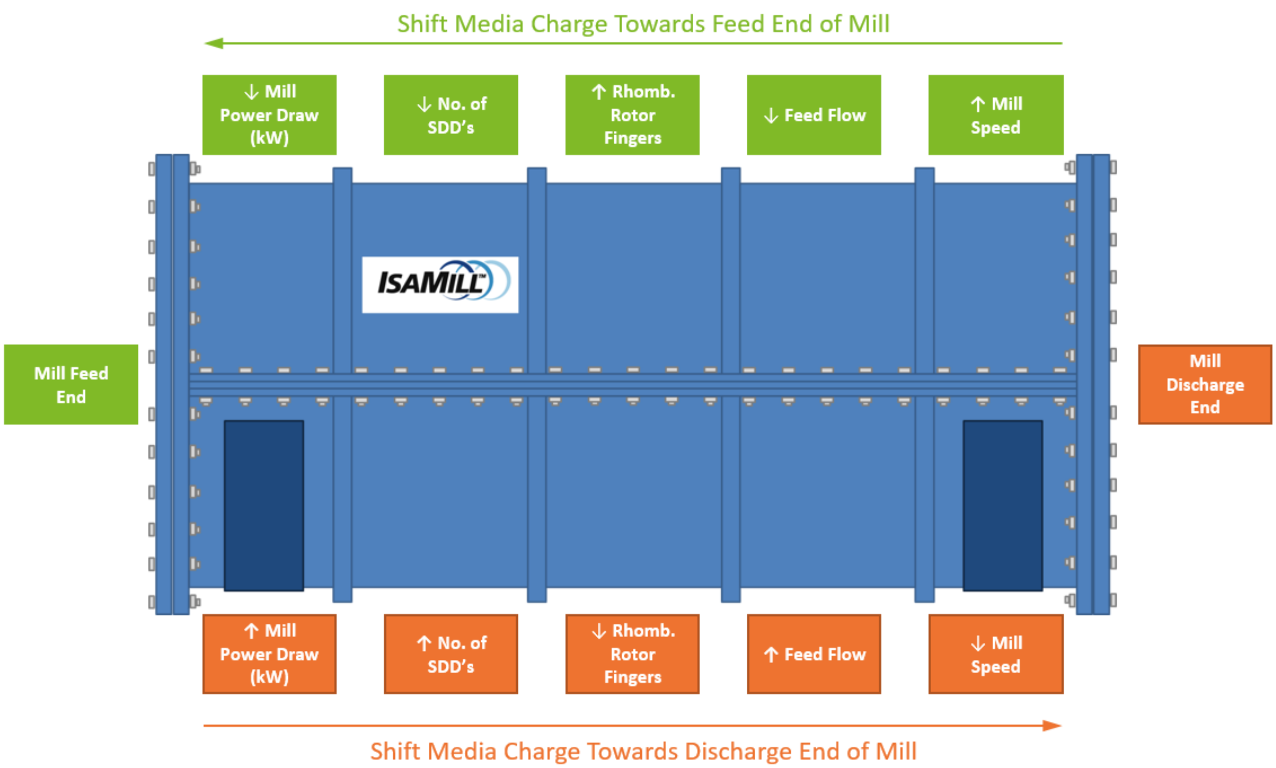

Figure 7: Moving the media within an IsaMill™ (Glencore Technology, 2018b)

We modify the IsaMill to remove the heat generated by the zone of media compression by implementing larger spacers to provide more room to allow the media to remain fluidised between the discs. This will turn the IsaMill™ into a seven-disc mill configuration. As some people in the industry would identify, a seven-disc mill should theoretically draw less power however, with these changes, GT has managed to draw close to 100% of the available power out of this reduced disc configuration through optimising the components and process variables.

From the thermal survey indicating where the zone of compression has been seen, an option would be to install a small diameter disc (SDD) to allow additional room between the shell and the disc (Figure 6). This helps relieve some of the heat build-up that is seen in the thermal survey. Another option would be to try and reduce any localised occurrences of heat build-up along the mill by utilising the HD60 and GD70 rubbers (much harder rubber that has a compound within it to dissipate heat). By following this strategy, it is possible to manage the wear with a coarser and/or harder grind and get significantly better life of the parts whilst operating close to 100% of the available power draw.

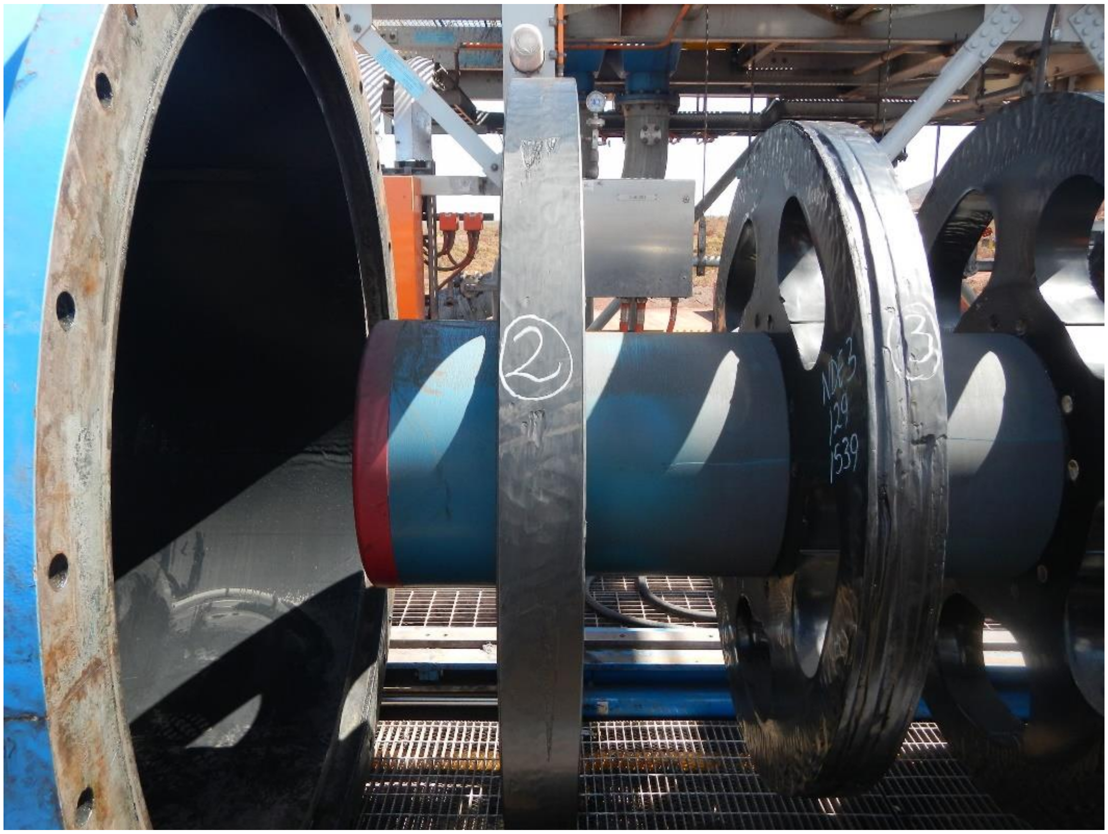

Figure 8: SDD installed at Zone of Compression

CURRENT COARSE GRINDING PERFORMANCE IN AN ISAMILL™

In the development story of the IsaMill™, the IsaMill™ was responsible for pioneering economic mining in complex sub-10-micron applications. Here the IsaMill™ quickly established the leading position in the ultra-fine grinding market. As larger ceramic media was developed in the mid-2000s, this allowed the IsaMill™ to demonstrate that the mill can operate with a feed of P80 400 microns and a top size of 1 millimetre by using a graded charge of 6-millimetre media (Anderson et al. 2011).

When this testwork was conducted on SAG Discharge at McArthur River Mine, it was found that the larger available media (5-6 millimetres) was able to successfully break the top size of the feed due to its ability to impart greater stress intensity as a result of its increased size (stress intensity is proportional to the cube of the media diameter). As a result, the 5-6 millimetre media was more efficient at achieving a given product target size. Figure 9 shows that the product size distribution from the 5-6 millimetre media (P80 of 29 microns and a P98 of 75 microns) was superior to that produced by the commonly available 3.5-millimetre media (P80 of 37 microns and P98 of 220 microns). The improvement was driven by the increased breakage rates at the top end of the distribution from the coarser media. (Anderson et al. 2011).

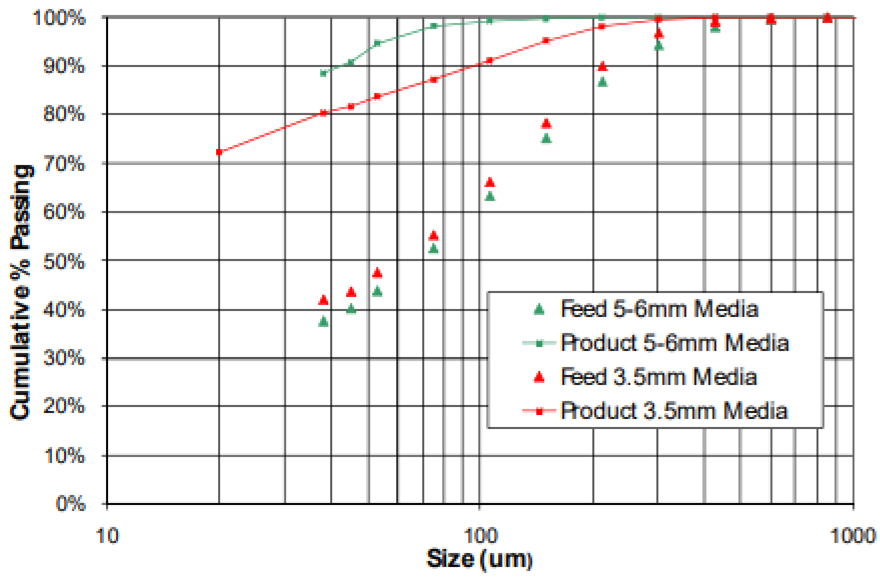

Figure 9: Performance of 3.5 millimetre media at 16kWh/t and 5-6 millimetre at 16 kWh/t (Anderson et al. 2011).

This relationship from the testwork reinforces one of the key points of stirred milling at coarser sizes. That the top size of the media must be chosen to break the top size of the feed adequately. If the top size is not broken quickly enough, it will remain in the mill leading to higher wear rates, coarser and wider product distributions, lower power efficiency and, in worse-case scenarios, sanding of the mill (Anderson et al. 2011).

Since this testwork was conducted, there are over 50 IsaMill™ installations that are currently in operation with an F80 greater than100 microns, at a total installed power base of 129.4 MW. These applications exist in Copper, Lead Zinc, Molybdenum, Tin, Platinum Group Metals (PGM's) and Gold. The current coarsest feed being treated through IsaMills™ is a magnetite regrind at Ernest Henry in Australia (F80 – 350 to 400 microns), a Porphyry Copper regrinds in South America (Las Bambas F80 – 300 microns) and a copper regrind in Kazakhstan (Bozshakol F80 – 300 microns).

These installations are specifically mentioned as industry doesn't always associate IsaMills™ with these coarse grind applications which is typically due to its strong reputation as an ultrafine grinding leader. As the mining industry pivots towards coarse particle flotation the IsaMill™ is more capable of being configured to effectively and efficiently regrind these concentrates. To further demonstrate this point, two accredited lab-based signature plots on separate ore bodies have been provided on hydrofloat concentrates for a single stage grind (Figure 10) and a series grind configuration (Figure 11). As with any IsaMill™ signature plot, these would have a 1:1 scale-up factor.

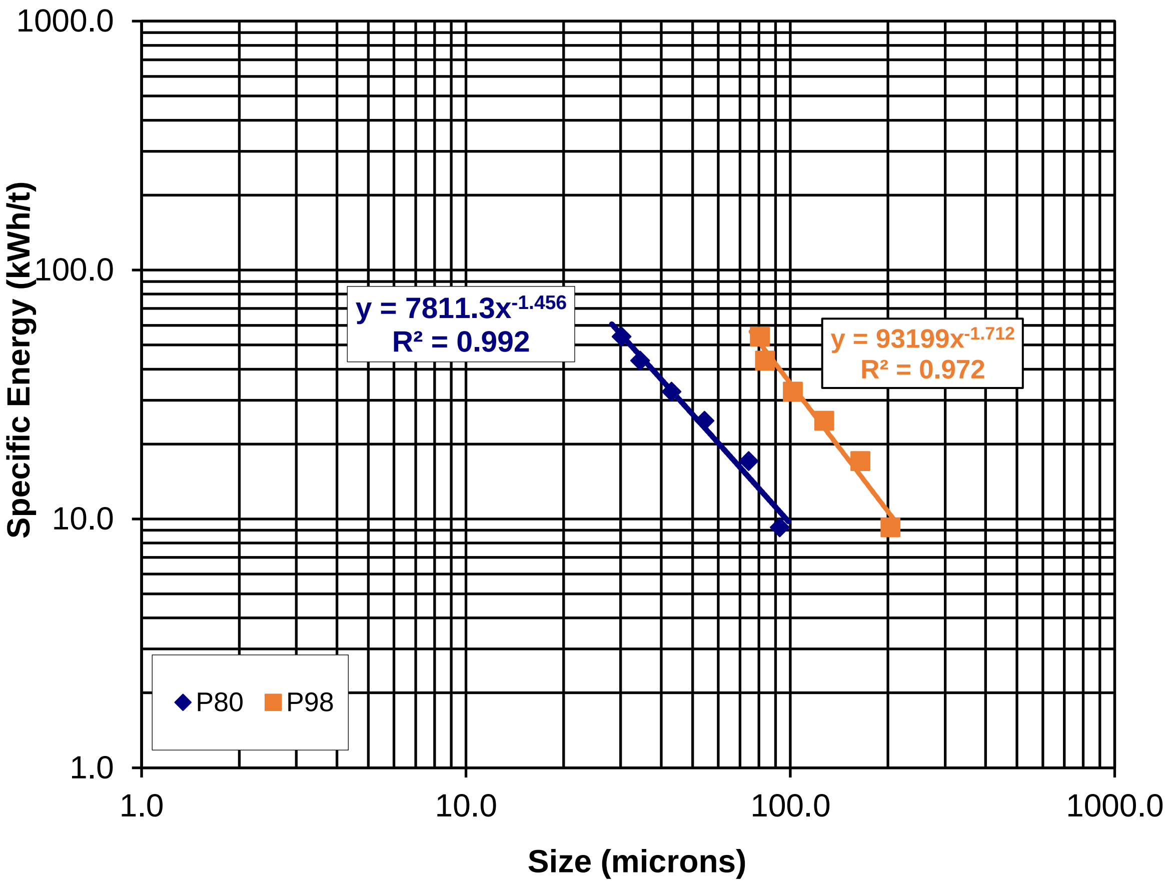

Figure 10: Hydrofloat Concentrate (F80 330 microns, Target P80 30 microns) – Single Stage Grind

Figure 10, which shows the single stage grind, utilises a reduction ratio of eleven. While this is less than ideal when compared to the recommended ratio of 8 per media type, it shows a good correlation (R2>0.99). This highlights the flexibility of the IsaMill™ to deal with coarser than design feed and accurately produce a specific energy determination with a 1:1 scale-up. In practice, typical size reductions for media selection in the IsaMill™ are in the order of five to six times.

In examples, such as shown in Figure 11, where a size reduction of an F80 of 400 microns to a P80 target of 14 microns is requested (reduction ratio of 28), we would implement series grinding. Series grinding initially utilises a larger media (6 millimetresfor Stage 1) to reduce the top size of the incoming feed down to a point where a smaller, more efficient media (2 millimetres for Stage 2) can complete the energy-intensive grinding duty. At ultra-fine product targets, energy efficiency is dependent on media size. However, the media size must still be adequate to break up the coarsest particles in the fee to prevent build-up and potential bogging of the mill (Anderson and McDonald, 2016).

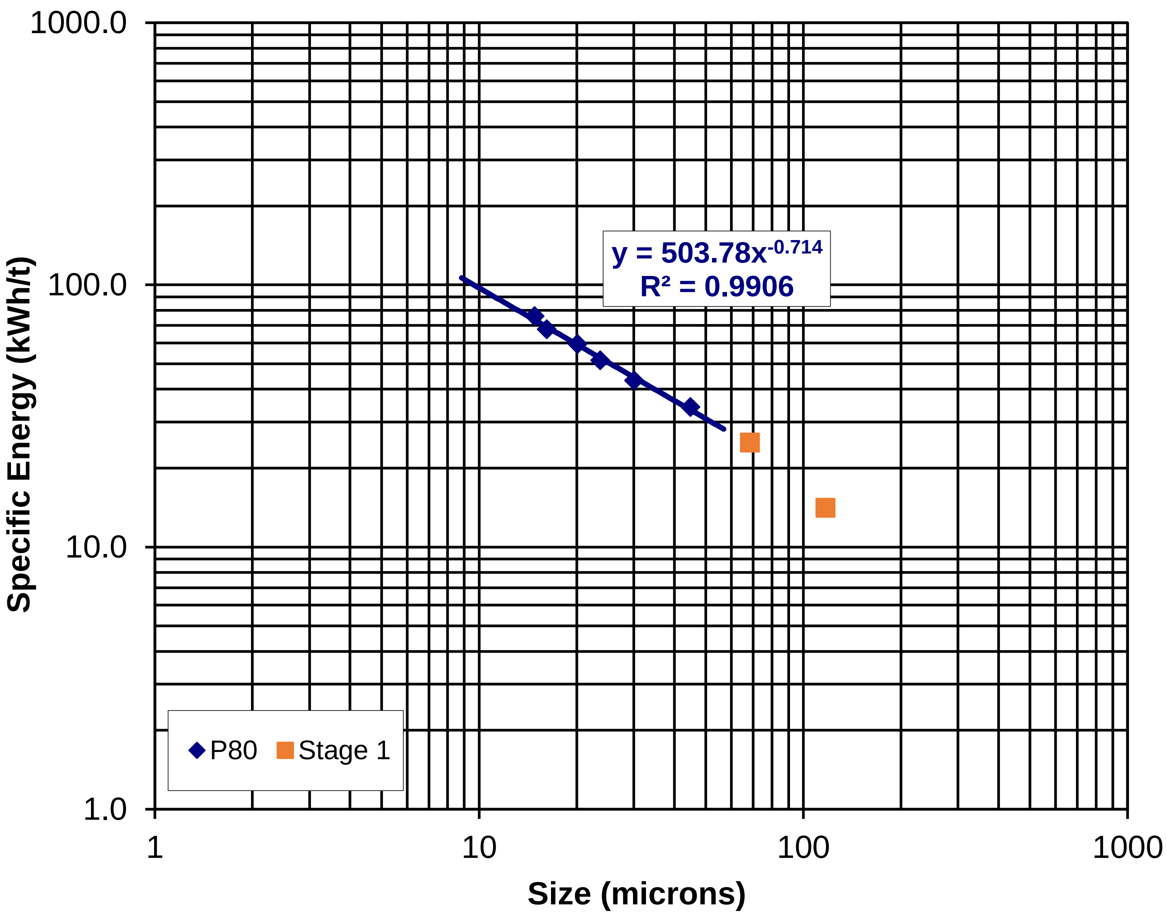

Figure 11: Hydrofloat Concentrate (F80 400 micron, P80 Target 14 microns)- Series Grind

HOW TO CONDUCT COARSE GRINDING TESTWORK FOR BALL MILL REPLACEMENT DUTIES

The laboratory-sized IsaMill™ (M4 and M20), the signature plot scale-up procedure is limited to 6 millimetre grinding media due to efficiency losses caused by grinding beads being caught between the edge of the grinding discs and shell in the mill. The rule of thumb is to measure the gap between the disc and shell with a gap of there and half times your media diameter required to retain fluidised behaviour. Exceeding this rule will damage both the mill internals and ceramic media.

This inefficiency, however, does not impact full-scale IsaMills™ and there are now operating IsaMills™ using grinding media as coarse as 8 millimetres. Utilising 6 millimetre grinding media allows for signature plot tests with an F80s of up to 400 microns and a top size limit close to 1 millimetre. Therefore, if a signature plot is to be conducted with ceramic media greater than 6 millimetres (F80s > 400 microns), testing needs to be completed onsite in an M100 IsaMill™ (Figure 12) with varying loads of media used to determine the signature plot.

Figure 12: M100 IsaMill™ (Current Coarse Grinding Signature Plot Pilot IsaMill™)

SUMMARY

Glencore Technology is eagerly pursuing the potential of using IsaMills™ to treat coarser feeds while benefiting from smaller footprints and higher efficiencies. The authors foresee that grinding circuits of the future will include the well-documented HPGR – IsaMill™ or AG Mill – IsaMill™ flowsheets. These flowsheets remove the use of steel media allowing for more favourable flotation conditions (chemistry and sharper PSD). Reduced steel, concrete and power improves a plants ESG credentials whilst leveraging the safety and height benefits of the horizontally configured IsaMill™.

References

Anderson, G S and McDonald, N W, 2016. IsaMill™ at Kalgoorlie Consolidated Gold Mines - from the M3000 to the M10 000 and Replacement of the Roasters at Gidji Processing Plant, in Proceedings 13th AusIMM Mill Operators' Conference 2016, pp 29–38 (The Australasian Institute of Mining and Metallurgy: Melbourne)."

Anderson, G., Smith, T. and Strohmayr, S. 2011. IsaMill ™ Technology in the Primary Grinding Circuit. Presented at SAG 2011, Vancouver, British Columbia, Canada.

Ayers, C., Knopjes, L., & Rule, C. M. 2008. Coarser feed applications of MIG IsaMilling. MEI Comminution'08 Conference, Falmouth, Cornwall, UK.

Drozdiak, J.A, Klein, B, Naldolski. S and Bamber. A, 2011; A pilot-scale examination of a high pressure grinding roll/stirred mill communition circuit Presented at SAG 2011, Vancouver, British Columbia, Canada.

Glencore Technology., 2018a. Marketing – Module 5: Media, Powerpoint Slides, Glencore Technology, Brisbane

Glencore Technology., 2018b. IsaMill Commissioning – Module 10: Wear Monitoring and Prevention, Powerpoint Slides, Glencore Technology, Brisbane

Gurnett, I,. Swann, A., Stieper. G, and Collier, L,. 2022. Stirred Milling Design – Incorporating the IsaMill™ into the Jameson Concentrator. IMPC Asia Pacific, August 26-28, Melbourne, Victoria, Australia.

Gurnett, I., De Waal, H and Stieper, G, 2021. The IsaMill™ - 25 years of Stirred Milling. CIM 2021 Convention, May 3 - 6, Vancouver B.C, Canada.

Larson, M, Anderson, G, Mativenga, M and Stanton, C, 2015. The Arrium IsaMill from design through commissioning and optimisation, in Proceedings MetPlant 2015, pp 110–119 (The Australasian Institute of Mining and Metallurgy: Melbourne)

Pease, J. D. 2007. Case study coarse IsaMilling at McArhur river. Retrieved January 28, 2011, from Link

Valery, W., & Jankovic, A. 2002. The future of comminution. 34th International October Conference on Mining and Metallurgy - Proceedings, Bor Lake, Yugoslavia. 287-298.