# The Application of Ultra Fine Grinding for Sunrise Dam Gold Mine

A Paz[1], C Ypelaan[2], T Ryan[3] and M McInnes[4]

1. Senior Process Engineer, Metso Outotec, Perth, WA, 6005. E-mail: andres.paz@mogroup.com
2. Metallurgical Superintendent, AngloGold Ashanti Australia Ltd, Sunrise Dam, WA.. E-mail: CYpelaan@AngloGoldAshanti.com.au
3. Manager: Engineering Support, AngloGold Ashanti Australia Ltd, Sunrise Dam, WA. E-mail: TRyan@anglogoldAshanti.com
4. Director Service Technical Support, Metso Outotec, Perth, WA, 6005. E-mail: michael.mcinnes@mogroup.com

## ABSTRACT

The AngloGold Ashanti (AGA) Sunrise Dam Gold Recovery Enhancement Project (REP) was an upgrade project to the existing process plant to increase gold recovery. The project required the existing screened cyclone overflow to be redirected into a new flotation and ultra-fine grinding circuit, producing concentrate up to a rate of 400,000 t/a. Metso Outotec supplied six TC200 TankCell® flotation units, one 14m High Rate Thickener and one HIGmill® HIG3500/23000. At this point in time the HIGmill is the world's largest stirred mill supplied into a pyrite concentrate regrind duty.

This paper discusses the HIGmill test work and sizing, the challenges of commissioning and ramp-up and subsequent design optimizations. The energy efficiency and operational performance is also discussed.

## INTRODUCTION

The Sunrise Dam Gold Mine processing facility commenced operation in 1997 as a two-stage crushing, single-stage grinding plant, treating predominantly oxide material from the Cleo open pit with a capacity of 1 M/a. A second ball mill was added in 1999 to increase capacity to 1.5 M/a. In 2001 a major upgrade to the plant was completed. This consisted of a three-stage crushing circuit, two-stage grinding and a second parallel leach circuit. This upgrade increased throughput to 2.5 M/a and enabled treatment of harder material mined from the deeper levels of the open pit and from the new underground mine. De-bottlenecking projects have incrementally increased throughput to 4 M/a. Ore processed is predominantly fresh material sourced from underground mining activities.

As the amount of sulphide material treated increased, gold recovery decreased in response to the refractory nature of the ore. Flotation and fine grinding to treat refractory ore had been periodically explored since 2005. In 2012 as open pit mining was coming to a conclusion and underground material was to be the major mill feed source, the impact of the sulphide material was fully realised. A feasibility study was conducted to design and construct a flotation and ultra-fine grinding circuit.

Test work indicated that a ~6 per cent increase in recoverable gold could be obtained by grinding the sulphide material to 10 µm and leaching combined with the flotation tails in the existing carbon-in leach (CIL) circuit.

## LOCATION AND MINERALOGY

The Sunrise Dam Gold Mine is located 55 km south of Laverton, Western Australia. The regional geology of Sunrise Dam is well documented but understanding continues to evolve. Sunrise Dam Gold Mine is contained within a regional structural domain known as the Laverton Tectonic Zone, which hosts in excess of 20 individual gold deposits, totalling in excess of 27M oz Au. Of these deposits, only five contain in excess of 1 Moz of gold. The two largest deposits lie within 35 km of each other and Sunrise Dam is the largest deposit in the Laverton Tectonic Zone with at least 11 Moz (AGA 2014).

The Sunrise Dam deposit contains a structurally complex series of gold-rich ore bodies with a variety of ductile and brittle deformation fabrics that influence the nature, geometry and distribution of the mineralization. At Sunrise Dam, gold mineralisation is structurally controlled and vein hosted. The style of mineralisation can be differentiated depending on the structure or environment in which it is hosted. There are three dominant domains that are now recognised (AGA 2014):

1. shear-related and high ductile strain - e.g. Sunrise Shear Zone,
2. stockwork development in planar faults with high strain brittle characteristics
3. placer-style mineralisation hosted within the fluvial sediments

Broadly the ore types can be subdivided into pyritic and arsenical types. Sunrise Dam falls into the latter category where the ore types are dominated by arsenopyrite and arsenian pyrite. Arsenical ores vary in terms of processing from being free-milling to highly refractory depending on grain size. Fine grained arsenopyrite (sub mm) is typically highly refractory because there is a high concentration of sub-microscopic gold which is structurally locked up in the crystal lattice. Gold recoveries for these refractory ores in the Yilgarn Craton are typically in the range of 30 -80 per cent. As a consequence, several operations in the region have adapted their processing plants to treat the refractory ore by roasting (SuperPit), bacterial oxidation (Wiluna) or finer milling.

## PLANT DESCRIPTION

The Sunrise Dam plant has been running since Feb 1997. Ore is treated in a conventional gravity and CIL processing plant. The original design capacity at start-up was 1 M/a and as of 2018 throughput was 4 Mpta. Over the years Sunrise Dam has added extra crushing and ball milling capacity.

In 2017 AngloGold Ashanti (AGA) embarked on a Recovery Enhancement Project to increase gold recovery by ~6 per cent. A flotation cell bank was installed to recover the refractory pyrite, followed by a thickener and a HIGmill to provide fine grinding and liberation before the CIL circuit. Metso Outotec supplied the six TC200 TankCell® flotation units, one 14m High Rate Thickener and one HIGmill® HIG3500/23000 (Figure 1).

**FIG 1** -HIGmill, Thickener, Flotation Circuit

The flowsheet comprises: three stage crushing and two stage grind, to flotation concentrate, to thickener, to HIGmill. Flotation tailings are combined with HIGMill product and sent to CIL.

The HIGmill is in open circuit with all concentrate reporting to the HIGmill for a single pass (Figure 2). Depending on throughput and slurry density, a grind P80 of between 9-12μm is achieved. Metallurgical test work identified that grinding to 10μm would deliver additional recovery in the 6 per cent to 8 per cent range. Since the commissioning of the ultra-fine grind circuit, a total of 7.7 Mt was processed at an average feed grade of 2.15 g/t and 82.1 per cent recovery.

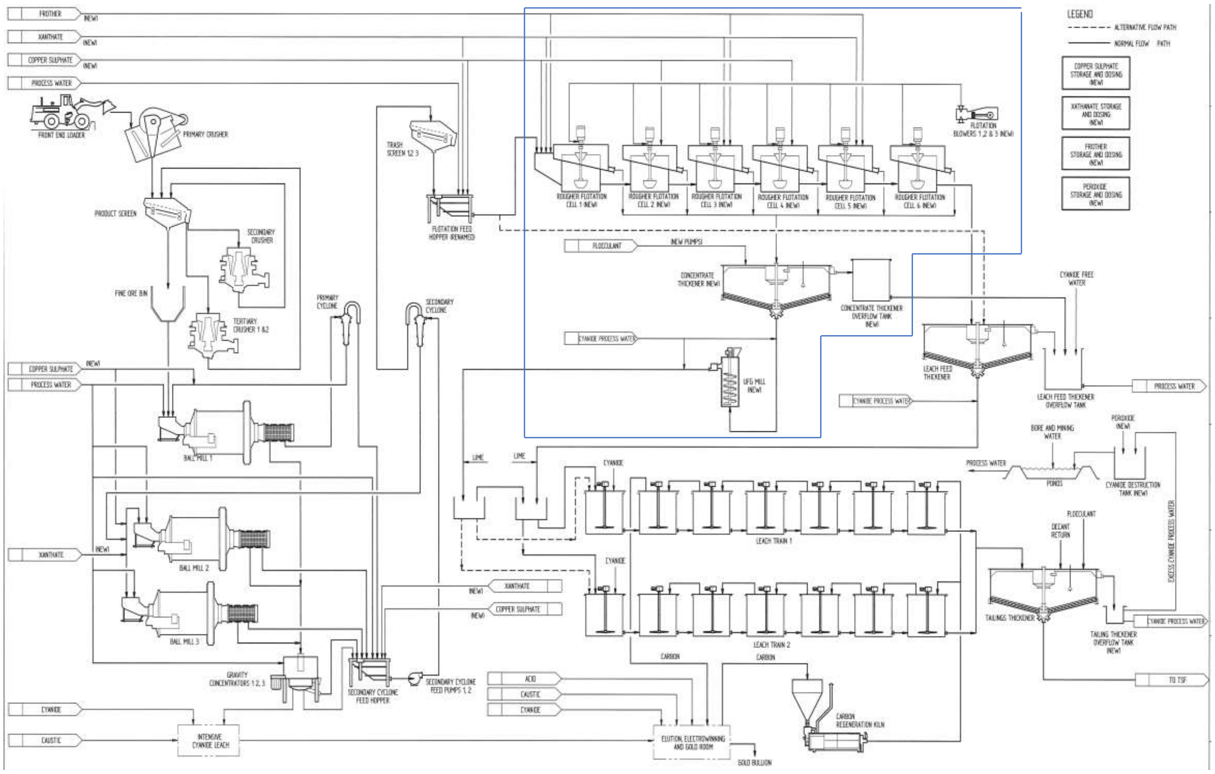

**FIG 2** - Process Flow Diagram (AGA 2017)

The HIGmill grinds pyrite/arsenopyrite concentrate to 10 µm in order to release refractory gold for leaching. A single operator is required for the flotation, thickener and HIGmill area.

## HIGMILL SIZING

### Test work

Metso Outotec conducted HIGmill® grindability test work on a pyrite concentrate sample in 2016. Due to the limited sample size available the Small Sample Test (SST) method was conducted using 5 kgs of solids. The feed F80 measured was 182 µm.

The SST was conducted in a HIG5 unit in closed circuit, with the mill speed and flowrate fixed. The 4 mm media top size was selected based on previous experience of feed and product grind size. In the test procedure slurry is mixed to a target density of 45 %w/w. The test slurry is pumped continuously through the mill and the mill is turned on for a certain amount of time to input power, then the mill is turned off and the sample is allowed to homogenise before taking a product sample. The mill is turned on again and the process is repeated.

The test results are presented as a performance graph (see figure 3) and are used for mill sizing. For the design F80 of 175 µm, the required specific grinding energy (SGE) was found to be 56 kWh/t for 10 µm.

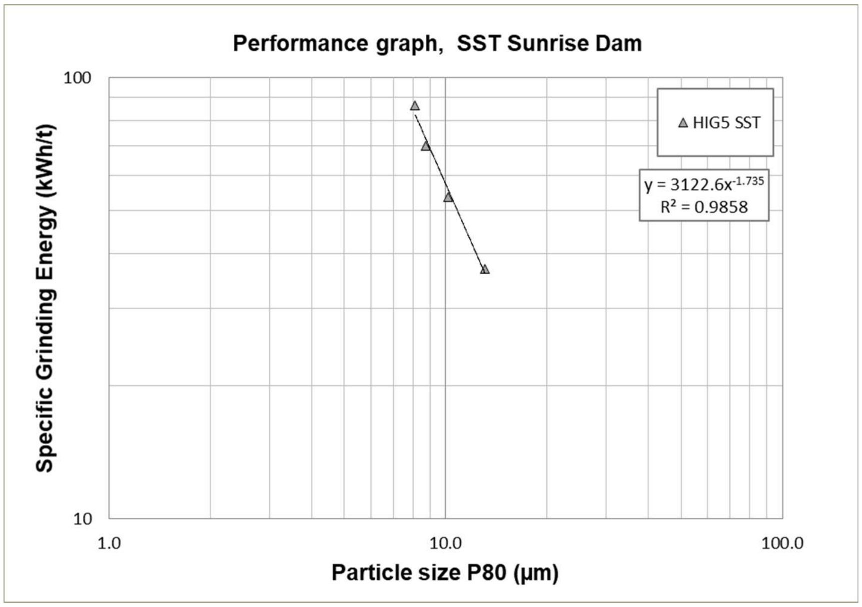


**FIG 3**- Performance graph for SST

## Design

A HIGmill size of 3500 kW with 23,000 L body was selected based on the test work and design criteria. The process design criteria are outlined in Table 1.

**TABLE 1**

Process Design Criteria

| Description | | Design Nominal | Design Maximum |
|---|---|---|---|
| Throughput | tph | 33.1 | 47.3 |
| Milling density | %w/w | 45 | 45 |
| Flowrate | $m^3/h$ | 48 | 53 |
| Solids SG | $t/m^3$ | 3.31 | 3.31 |
| Liquid SG | $t/m^3$ | 1.1 | 1.1 |
| Slurry SG | $t/m^3$ | 1.57 | 1.57 |
| Feed Size F80 | µm | 175 | 175 |
| Product Size P80 | µm | 10 | 10 |
| Reduction Ratio F80/P80 | # | 17.5 | 17.5 |
| Net Specific Grinding Energy | kWh/t | 56.0 | 60.0 |
| Power Draw (Motor Output) | kW | 1912 | 2926 |
| Installed Power (Motor Output) | kW | 3500 | 3500 |

Although the secondary grinding P80 was 175 µm, the P80 of the concentrate was expected to be 135 µm due to sulphide preferential grinding in the closed-circuit configuration. The design SGE was not reduced and instead this was considered design contingency.

The design power draw was 2923 kW and was checked against power models to ensure that the mill would operate in a suitable speed range across the lifetime of the internal wear parts.

Due to the target fine grind size, other design considerations were based on residence time and media retention requirements. The fine grind size required media retention in the mill of a 2 to 3 mm size range and media specific gravity (SG) range of 3.8 to 4.1. Media is retained in the HIGmill due to media fluidisation conditions relating to the settling velocity and flowrate. Media is also held within the chambers (stator compartments) by the centrifugal force generated by the rotors.

An energy balance confirmed that the exit temperature for the design was suitable for the materials of construction. The design inlet temperature of 30°C, 60 kWh/t, 45%w/w yielded an exit temperature of 66°C. The HIGmill was designed with a high alarm temperature limit of 70°C and a trip limit of 85°C.

## PROJECT

AGA worked closely with the engineers to ensure decisions were made during the EPC phase. They reviewed the specifications and mill selection.

The Recovery Enhancement Project was delivered very quickly; installation time for the complete upgrade project was approximately six months, and commissioning was four weeks. The HIGmill delivery time was 30 weeks ex-works.

Once the civil foundations were ready, the HIGmill installation took four weeks. Cold and wet commissioning took one week. Process Commissioning lasted one week, occurring in the last week of May 2018. The Recovery Enhancement Project was completed two weeks earlier than expected and under budget.

## COMMISSIONING

The mill was commissioned in May 2018 and has been operating since June 2018. Wet commissioning requires the checking and implementation of control logic and fine tuning is carried out during ore commissioning. Survey data was collected during ore commissioning to track the performance of the equipment and optimise the mill performance.

### Wet Commissioning

The water calibration curve conducted during wet commissioning, as shown in Figure 4, was performed with 19 tonnes of media, a media size range of 2-4mm and a media specific gravity (SG) of 3.9 t/m$^3$. The mill may draw 30% to 40% less power with slurry compared to water due to the media fluidisation conditions such as buoyancy and viscosity. It is important to measure the speed/power/mill load/flowrate relationship during commissioning for both water and slurry, as the relationship is different for each application. These values are used to assess the mill's capability and are used for future operational guidance. These results can also be put into power models, for prediction of the operation and (if required) assist with future optimisation of the rotor design.

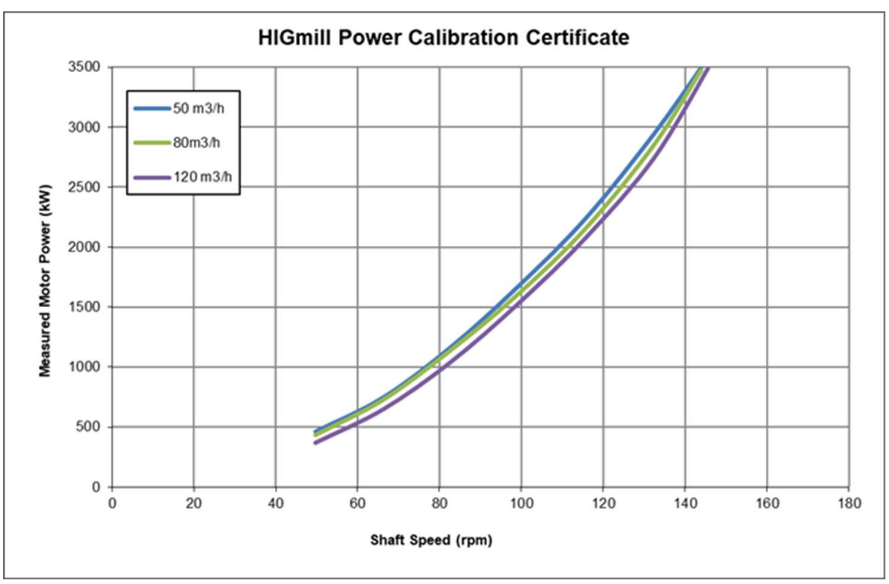


**FIG 4** - HIGmill Power Calibration Certificate

## Ore Commissioning

During ore commissioning, the slurry density was optimised to account for the slurry viscosity effect on energy efficiency. A marsh funnel test (Fann 2017) was conducted on several samples with varying feed densities. The optimum feed density generally corresponds to a marsh funnel time of 36 seconds. As detailed by Larson (2011), the Marsh Funnel is not a comprehensive measurement of rheology but serves as a quick and easy test. The current rule of thumb for this site recommends marsh times less than 36s. The marsh time limit typically comes from a plot of marsh time versus density, where it identifies the limit as the point at which marsh time rapidly increases with increasing density. If the time is greater, then the media movement and energy transfer is restricted, resulting in reduced energy efficiency. For the grind size of 10 µm, the optimum slurry density was found to be 37 - 38%w/w (figure 5), which is considerably lower than the 45%w/w design density. It was observed during commissioning that operating above 38%w/w the media bed location is altered due to buoyancy.

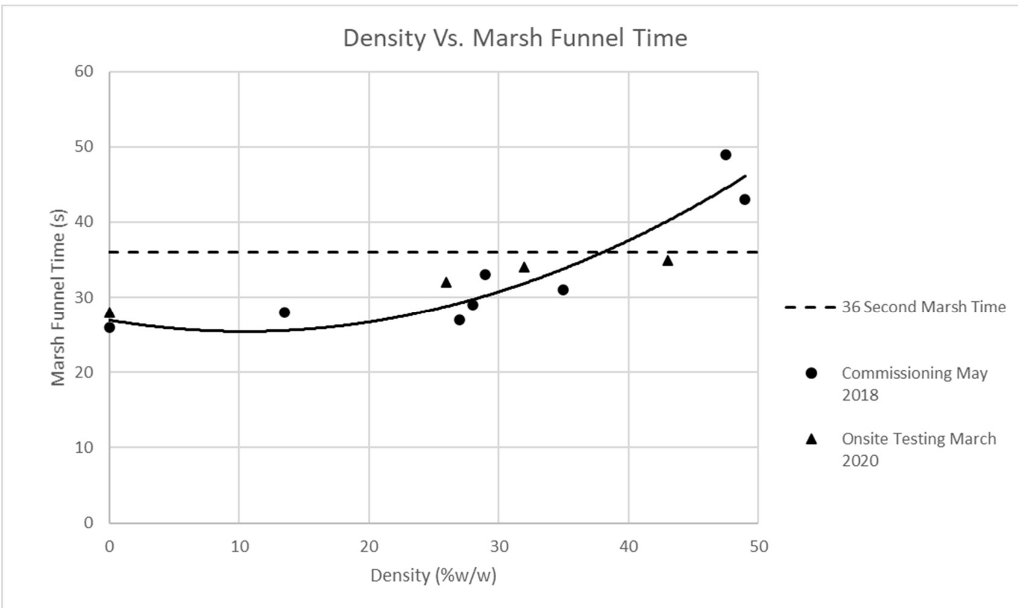


**FIG 5** - Marsh Funnel Test

Subsequent Marsh Funnel testing in March 2020 (Figure 6) indicates that increasing the operational density to 43%w/w might be possible and is currently the subject of further optimisation.

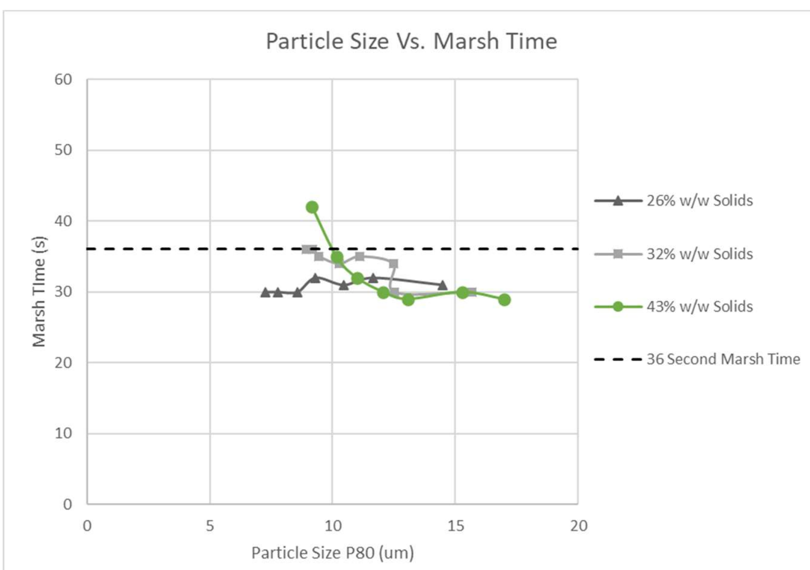


**FIG 6** - Marsh Funnel Test March 2020

During ore commissioning the mill was filled with 2 – 4 mm ceramic media with an SG of 3.9 t/m$^3$. The process performance was tracked to target the P80 = 10 µm. It was observed that operating the mill with greater than 50%v/v media filling, combined with longer run time for media wear in, improved the energy efficiency. It is believed that this is due to the near plug-flow conditions experience at these filling levels, and the graded charge containing finer 2-3 mm media better suited to the feed size and target product size. A signature plot was generated for the first week of operation (Figure7) and indicates the SGE required to achieve 10 µm was 59 kWh/t. During commissioning the feed size F80 was in the 30 to 60 µm range (laser measurement). This range, combined with the improved energy efficiency from media charge wear-in, lead to future media charges being 2 – 3 mm in top size.

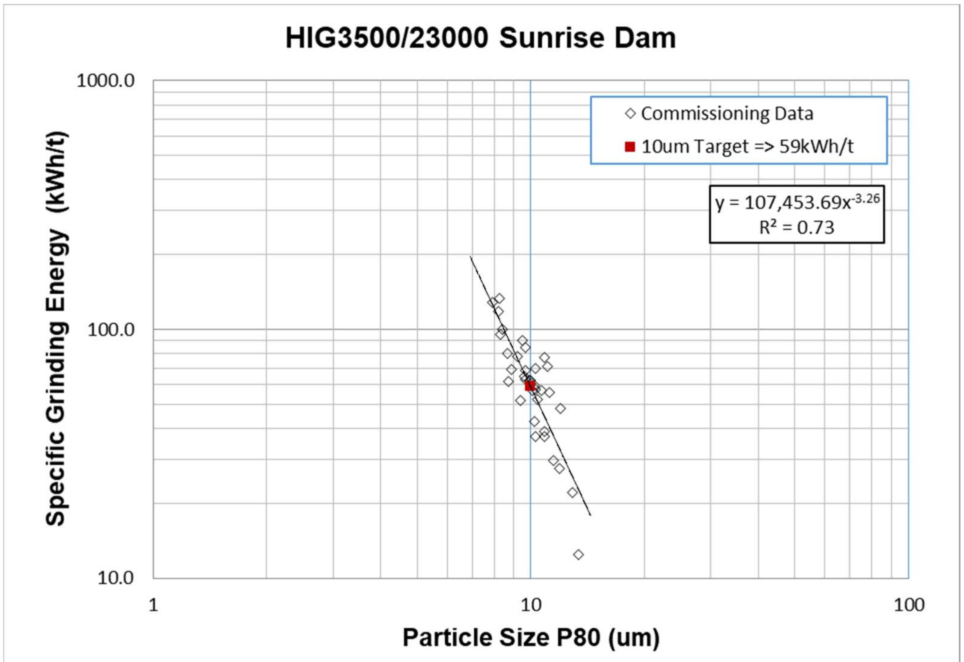


**FIG 7** - Commissioning Survey Data: 2-4mm media

One of the main challenges associated with obtaining the target grind size was the accurate measurement of P80 at the 8 – 12 µm grind size. P80 variances depended on: the operator experience from shift to shift; the average P80 of three tests versus the maximum P80 of one test; and the laser machine type and model. It should be noted that an online particle size analyser was not purchased for this plant expansion due to the reasonably stable feed size and concentrate mass flowrate. Automatic samplers are used, and the product size is verified manually in the laboratory's laser size machine.

The HIGmill feed pipe velocity is designed for 0.75 to 1.1 m/s for nominal and design flowrates. During commissioning, it was noticed that on start-up, when the pipe velocity reached 0.7 m/s, the 2-4 mm SG 3.9 t/m3 media quickly cleared and the flow was unrestricted.

During the first week of ore commissioning, the mill was tested to obtain P80s in the 7 to 8 µm range inputting up to 110 kWh/t energy. The mill discharge temperature reached 80 °C at one stage, which is less than the HIGmill trip limit of 85°C.

## RAMP UP PHASE (6 MONTHS POST COMMISSIONING)

The Sunrise Dam HIGmill achieved the design grind size and desired throughput quickly after commissioning. The key development area during the ramp up period was optimisation of wear component life and design to prevent component failure. During this ramp up period three failures occurred over the first five months, requiring unplanned shutdowns. These events, in order of occurrence, are listed below:

- The bottom cover plate polyurethane liner lifted from its backing plate the day after commissioning, due to a bonding issue, and damaged the bottom rotor. This required rebuilding the shaft (replacement of the broken rotor in position one) and exchange of the bottom plate liner with a rubber lined unit.

The decision to change to rubber wear material was due to a delay in the spare parts package and a quick turn-around was required. As of 2021 the same rubber wear material bottom cover plate liners are operating with change out cycles of 26+ weeks.

- After approximately seven weeks of continuous operation, one of the shell liners in the middle section of the mill failed and caused a subsequent rotor failure. The root cause analysis found the cast stator ring eroded away at the shell wall, which exposed the liner carrier steel structure to media and slurry ingress. Rubber on the liner carrier lifted and impacted on the rotor, causing the failure.

  As a result of this failure, Metso Outotec and AGA implemented a development programme to design, trial and refine different stator ring materials and manufacturing techniques. Further details of this are found later in this paper.

- Approximately five months into the ramp up period, and after the failure in item two above, another unplanned shutdown occurred, and a solution was developed to rubber line hard cast stator rings. Errors in the surface preparation by a third-party contractor led to stator bonding failure and required another unplanned shutdown.

  This failure led to the development of new stator ring construction methods and rubber destructive testing techniques to verify bonding strength.

## OPTIMISING SHUTDOWN INTERVALS

Post commissioning, AGA advised that a key expectation was for the HIGmill to meet a minimum plant shutdown interval of 17 weeks. Total plant shutdown durations of approximately three to four days were available if required. Within 18 months, post commissioning, the HIGmill service interval between shutdowns was ramped up progressively to 23 weeks and effectively met AGA's target. Current operating campaigns are approximately 26+ weeks, with the aim to extend where feasible and attempt to phase into normal plant shutdowns. By matching the HIGmill shutdown timing to normal plant shutdowns, the annual HIGmill availability is improved, in addition to machine utilisation and gold recovery. When the HIGmill maintenance cycles do not match the plant shutdown schedules, the flotation and HIGmill is simply bypassed and selective ROM feed is processed based on expected ore grade and mine to mill planning.

Since commissioning, the HIGmill reline times have been optimised to approximately 36 hours, whilst maintaining safety expectations. This period captures machine shutdown through to handover back to the plant operations for re-start. This timing is achieved using rotable shell and shaft assemblies, specific tooling to match the works, various lifting equipment and Metso Outotec service technicians.

The two major components, which were the focus of wear life optimisation post ramp up, were the castellated grinding rotors and shell liner stator rings. The original designs and geometries were satisfactory, but the material selection did not meet AGA's wear life/shutdown schedule expectation. The grinding rotors were a cast material, which worked well in light duties or in smaller HIGmills, but were not fulfilling the expectations for this larger diameter, high tip tangential velocity, power-intensive fine grinding application.

## CASTELLATED ROTOR DEVELOPMENT

The development of the castellated rotor is detailed in various papers with reference to the Kevista site (Heath *et al*, 2017; Nielsen *et al,* 2016; Keikkala *et al,* 2018) where rotors with castellations were first designed and installed. The next evolution for the castellated rotor was a change in construction material and was implemented at Cracow (Paz 2019). At Cracow, the rotor wear material was changed to rubber. Based on the feedback from this first trial at Cracow, AGA and Metso Outotec agreed to implement rubber castellated rotors in the Sunrise Dam HIGmill in December 2018. As this was a staggered approach, the initial quantity of rotors was four units mounted from the bottom of the shaft (rotor position one through four), as this location is exposed to the highest pressure and wear. This orientation is illustrated in Figure 8. As illustrated in Figure 8 the reduction in cast rotor diameter led to increase in media and slurry packing between the grinding chamber stator rings. The packing protected the shell carrier lining but led to increase in wear on the rotors' outside diameters and stator ring internal diameters/surfaces.

**FIG 8** - First use of flat rubber castellated rotors at Sunrise Dam (rotor position 1 through 4). Note the worn/reduced diameter of the cast rotors in position 5 through 12.

The improvement in wear life observed with these four rubber rotors led to the decision to ramp up the installed quantity from four to eight units in the next cycle and eight to eleven in the subsequent cycle. The latest shaft operating designs have eleven flat rubber castellated rotors in addition to two cranked cast castellated units. The cast units are from the original stock holding and are part of the phase-out consumption plan. The wear life on these cast units in rotor position 12 and 13 is sufficient to match the current operating cycles as shown in Figure 9. The cast non-castellated rotors, in position fourteen through eighteen, are not always consumed per operating run and can be re-used when assessed fit for operation. When the stock of the cast rotors is depleted, the plan is to replace with rubber lined units.

**FIG 9** - Rotor assembly with flat rubber castellated rotors prior to despatch from MO workshop

The original castellated rubber rotors were flat in orientation. This flat definition means the rotor hub is in the same plane as the rotor ring. The cranked definition relates to the rotor hub being offset to the rotor ring via the use of spokes (Figure 10). Cranked rotors have the benefit of rotor spokes engaging the media zone between grinding chambers and ensuring the media is continuously stirred.

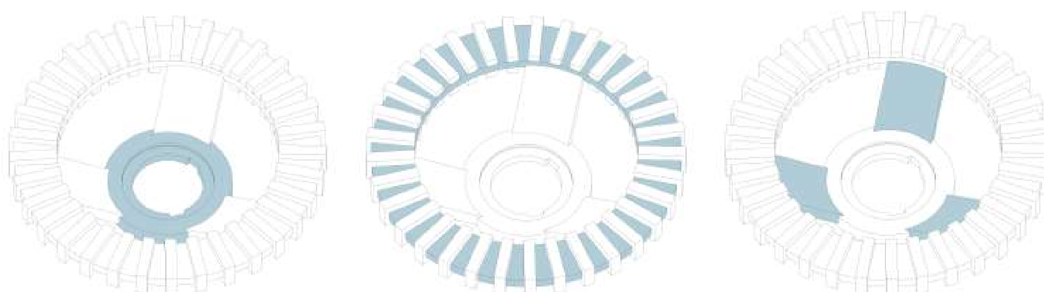

**FIG 10** – Castellated Grinding Rotor Terminology (LHS –hub, Middle – rotor ring, RHS - spokes)

In addition to the previous developments in the castellated rubber rotors, a recent development is a moulded cranked design. The moulded rubber cranked rotors were previously field tested and three units were trialled for Sunrise Dam. These three units have been used in two operating cycles over 50 weeks. The assembly as shown in Figure 11 was installed during April 2021 and will have ten cranked rubber castellated rotors installed plus one flat unit. Operating power draw will be monitored and measured to observe possible process improvements.

**FIG 11** - Rotor assembly installed April 2021 prior to despatch from MO workshop

## STATOR RING DEVELOPMENT

Following the failure of a cast stator ring seven weeks post commissioning, an intensive product development period started. Various materials and structures were trialled. In the initial period protective coatings, such as spray urea and hand laid poly urethanes, were applied on site to existing cast units, with no success. Special plastic material was also used with some novel designs, but the product erosion resistance was not satisfactory. Whilst these smaller trials were underway, other designs, with longer manufacturing requirements, were also being investigated.

After resolving the bonding issues, rubber lined cast units were installed and have been successfully operating for long 20-26 week shutdown cycles. These rubber-lined cast units are deemed too expensive but were part of a stock phase out plan.

The two best performing stator ring materials at Sunrise Dam have been cast polyurethane (PU) stators and pressure moulded rubber stators, both with mild steel skeleton cores. Various grades of PU and rubbers have been trialled as shown in Figure 12. Metso Outotec and AGA have selected one of the cast PU designs as the machine standard due to optimised lead times, cost and wear life performance.

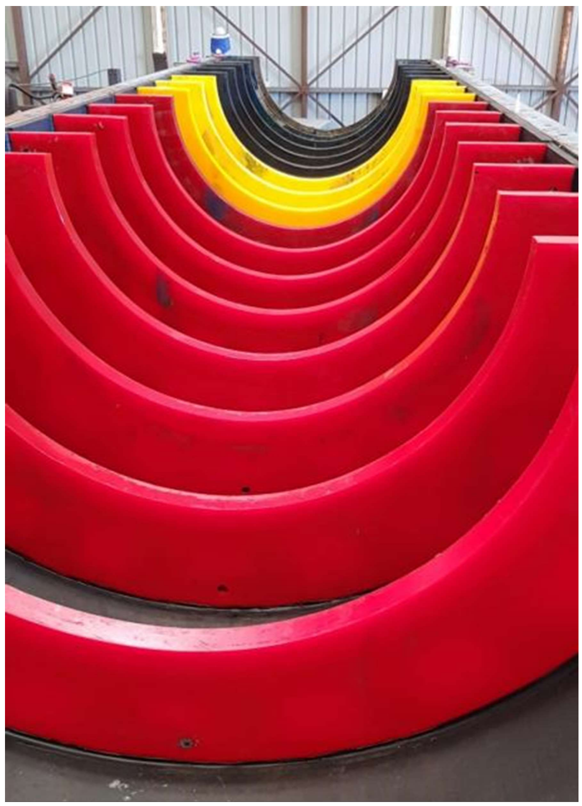

**FIG 12** - Shell with assembled shell liners and stator rings. Note different grade PU (red/yellow) mounted from the bottom/feed end of the mill shell through to rubber lined cast and cast only stator rings positioned higher up in the shell arrangement, above the media transition zone.

## WEAR LIFE OPTIMISATION SUMMARY

As the operating/shutdown cycles increase for the Sunrise HIGmill, new wear challenges arise and the critical components driving shutdown timing are shifting. Sunrise Dam's optimisation journey continues with a joint AGA and Metso Outotec effort, intent on reducing the total cost of ownership whilst maintaining safety, machine availability and key performance parameters.

## PLANT AND MACHINE AVAILABILITY

The HIGmill overall utilisation is 97 per cent and has an availability of 98.6 per cent. The availability is governed by the shell liner wear life interval of approximately 26 weeks, harmonizing with other general plant shutdowns, and allows for a further two inspections per annum.

The HIGmill reline periods run for 36 hours each, excluding operator shutdown and start up time. The main plant shutdown period is generally between 36 – 48 hours, governed by the primary milling circuit relines.

## SCALEUP AND OPTIMISATION TEST WORK

Metso Outotec conducted onsite scaleup pilot test work in 2020 to study the effect of residence time and operational density on the energy efficiency. A full scale HIGmill survey was conducted over a three hour period where feed sample was collected for further HIG5 test work.

It was shown that residence time of 2 and 3 mins in the HIG5 unit didn't affect the energy efficiency significantly compared to the full scale (Figure 13 and Table 2). The results indicate that the full-scale operation is slightly more energy efficient than the HIG5 pilot test work. Please note the full scale power measured was the VSD output, and a system efficiency of 92.63 per cent was used to compare the data against the HIG5 test work. The system efficiency allows for the gearbox efficiency, motor under partial load and motor cable transmission.

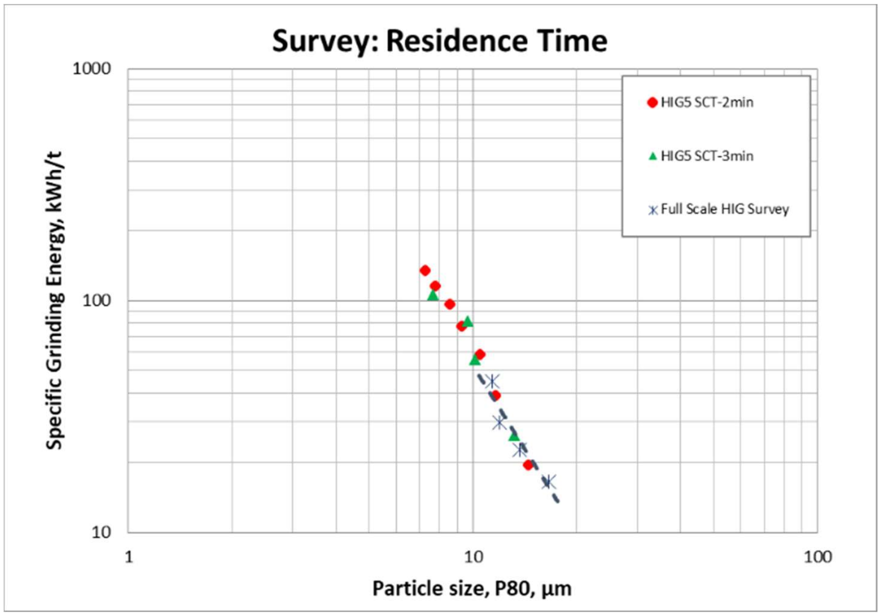


**FIG 13** - Scaleup Test work: Residence time

**TABLE 2**

Scaleup Test work: Residence time

| Test Description | Density %w/w | Time | P80 | A (Power Model - exponent factor) | B (Power Model - coefficient) | Specific Grinding Energy for P80 | $R^2$ coefficient of determination |
|---|---|---|---|---|---|---|---|
| Full Scale HIG Survey | 35.7 | 612.3 | 10.0 | -2.4 | 12722.3 | 52.4 | 0.894 |
| HIG5 SCT-3min | 27.5 | 181.0 | 10.0 | -2.6 | 25162.3 | 59.1 | 0.935 |
| HIG5 SCT-2min | 26.5 | 129.3 | 10.0 | -3.1 | 71961.2 | 62.5 | 0.996 |

Note: The line of best fit is based on a power model, where A is the exponent and B is the coefficient.

It was shown that a slurry density of 43%w/w was more energy efficient than the 26.5% and 32%w/w tested in the HIG5 unit. However, this was counter to expectations with regard to slurry viscosity measured in the Marsh Funnel indicating a 37 – 38%w/w density limit. The full-scale survey was conducted at a density of 35.7%w/w and coincidently lies between the 43%w/w and 32%w/w density lines for the HIG5 (Figure 14). Considering the Marsh Funnel time, it was realised that the full scale HIGmill was running at the optimum slurry density. Furthermore, the lower slurry density supports a reduced exit slurry temperature from the mill and therefore doesn't soften or weaken the wear part materials inside the HIGmill.

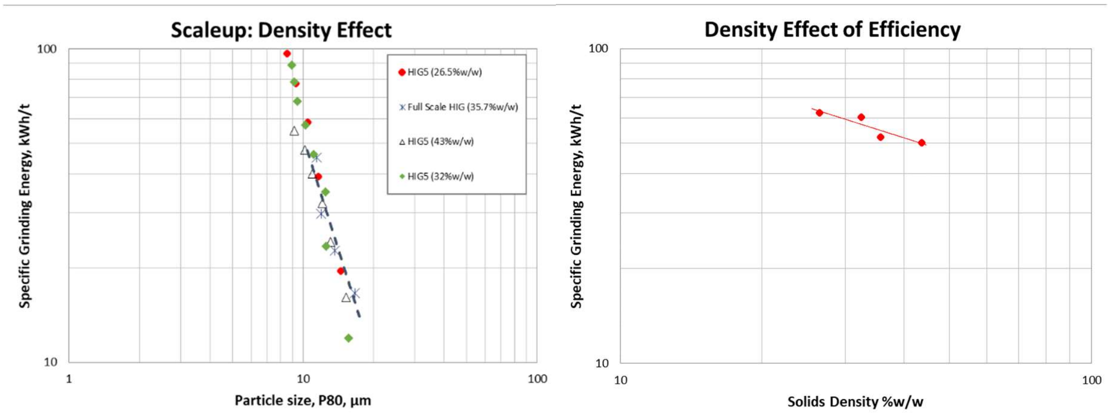


**FIG 14** - Scaleup Test work: Slurry Density

**TABLE 3**

Scaleup Test work: Slurry Density

| Test Description | Density %w/w | Time | P80 | A (Power Model - exponent factor) | B (Power Model - coefficient) | Specific Grinding Energy for P80 | $R^2$ coefficient of determination |
|---|---|---|---|---|---|---|---|
| HIG5 (26.5%w/w) | 26.5 | 129.3 | 10 | -3.1 | 71961.2 | 62.5 | 0.996 |
| HIG5 (32%w/w) | 32.5 | 133.6 | 10 | -3.5 | 179091.1 | 60.6 | 0.971 |
| Full Scale HIG (35.7%w/w) | 35.7 | 612.3 | 10 | -2.4 | 12722.3 | 52.4 | 0.894 |
| HIG5 (43%w/w) | 43.6 | 129.3 | 10 | -3.1 | 58731.1 | 50.2 | 0.947 |

The daily averages of the operational data have been plotted against the signature plots obtained from site scale-up HIG5 and its full-scale survey (Figure 15). The scaleup test work and survey is aligned with the bulk of the operating data. We can see that the operational data varies with respect to P80 and SGE, and we believe this is due to the following main reasons:

- The mine operates with open pit ore and underground ore and has a wide range in mineralogy.
- The HIGmill was run at a fixed speed.
- The operational density is operating in a range from 30%w/w to 38%w/w.
- Natural variability due to 12 hr testing frequency is observed in the daily operating data. Sampling frequency is a 12-hr shift composite.
- With SGE control it is much easier to target a P80 product size with variations in throughput. There is no online Particle Size Analyser (PSA) installed in the circuit, and as such no P80 control loop was implemented to account for natural variations in mineralogy.

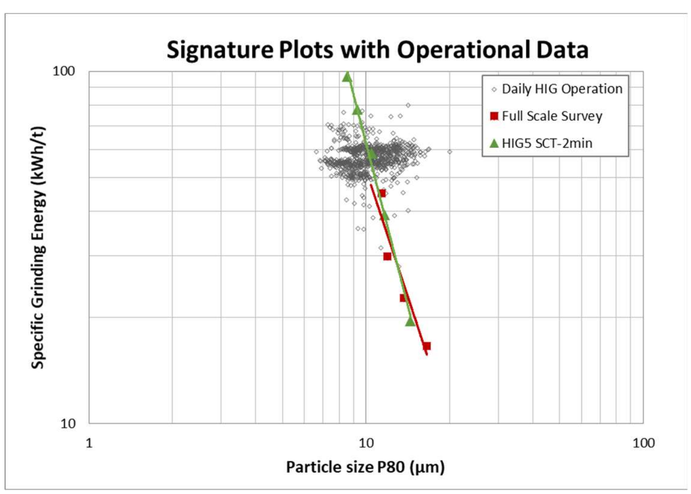


**FIG 15** - Signature Plots with Operational Data

## PROCESS AND OPERATIONAL PERFORMANCE

In the first eighteen months of operation the HIGmill has obtained an average product size P80 = 9.4 µm. The corresponding gold recovery for the period was 81.5 per cent. For the twelve months after, the HIGmill grind size was 12.5 µm with a corresponding gold recovery of 82.6 per cent.

Gold recovery is impacted by grind size above 12.5 µm. This increased grind size is attributed to a number of factors including highly variable mineralogy of the feed ore and high talc concentrations. Overall recovery improvement of ~6 per cent has resulted from the installation of the fine grind circuit, with further optimisation of the circuit continuing.

Historically the CIL recovery can be correlated accurately with the As/Au ratio, which formed the theoretically recovery for the plant prior to the fine grinding recovery upgrade and is currently used to demonstrate recovery improvement attributed to the Recovery Enhancement Project (REP).

The key HIGmill operating results are presented in Table 2. The highest average throughput achieved was 46.2 tph with a power draw of 2571 kW and a product size P80 of 10.1 µm. This scenario is close the design throughput requirement of 47.1tph in Table 1, however the specific grinding energy of 52.6 kWh/t to achieve 10 µm is much lower than design.

The mill is achieving the product size (P80) design expectation of 10 µm. The mill has not processed the feed size (F80) design parameter of 175 µm. The coarsest feed size processed in the mill was an F80 of 101.3 µm with high reduction ratio 10.55, which achieved a product size P80 of 9.6 µm with an SGE input of 47.1 kWh/t (Table 4).

In figure 16, the operational data exhibited a consistent trend for a five month period, where we can see that most variables, such as P80 and SGE, are steady with the exception of F80. F80 varied significantly, however this didn't affect the P80 as much. The P80 was below 10 µm up until the September quarter 2019, when there was an increase in ore hardness (due to more silica in the above ground ore) and SGE set point not being increased.

**TABLE 4**

Operational Results

| | **Operational** | | | | |
|---|---|---|---|---|---|
| | **Ave first 18 months** | **12 months later** | **Highest Daily Ave. Throughput** | **Highest Daily Ave. Flowrate** | **Highest Daily Ave. F80** |
| Date (from) | 20/05/18 | 12/11/19 | 17/12/19 | 9/03/20 | 27/09/20 |
| Date (To) | 11/11/19 | 9/11/20 | 17/12/19 | 9/03/20 | 27/09/20 |
| Throughput | 35.1 | 37.8 | 46.2 | 35.8 | 28.3 |
| Milling density | 35.9 | 35.2 | 38 | 30.8 | 27.7 |
| Flowrate | 69.2 | 75.6 | 85.5 | 87.7 | 75.3 |
| Solids SG | 3.31 | 3.31 | 3.31 | 3.31 | 3.31 |
| Liquid SG | 1.065 | 1.065 | 1.065 | 1.065 | 1.065 |
| Slurry SG | 1.41 | 1.40 | 1.43 | 1.35 | 1.31 |
| Feed Size F80 | 31.0 | 38.8 | 21.1 | 47.1 | 101.3 |
| Product Size P80 | 9.4 | 11.9 | 10.1 | 11.6 | 9.6 |
| Reduction Ratio F80/P80 | 3.31 | 3.26 | 2.09 | 4.06 | 10.55 |
| Net Specific Grinding Energy | 51.9 | 54.0 | 52.6 | 42.8 | 46.0 |
| Power Draw (VSD Output) | 1963 | 2196 | 2571 | 1703 | 1511 |

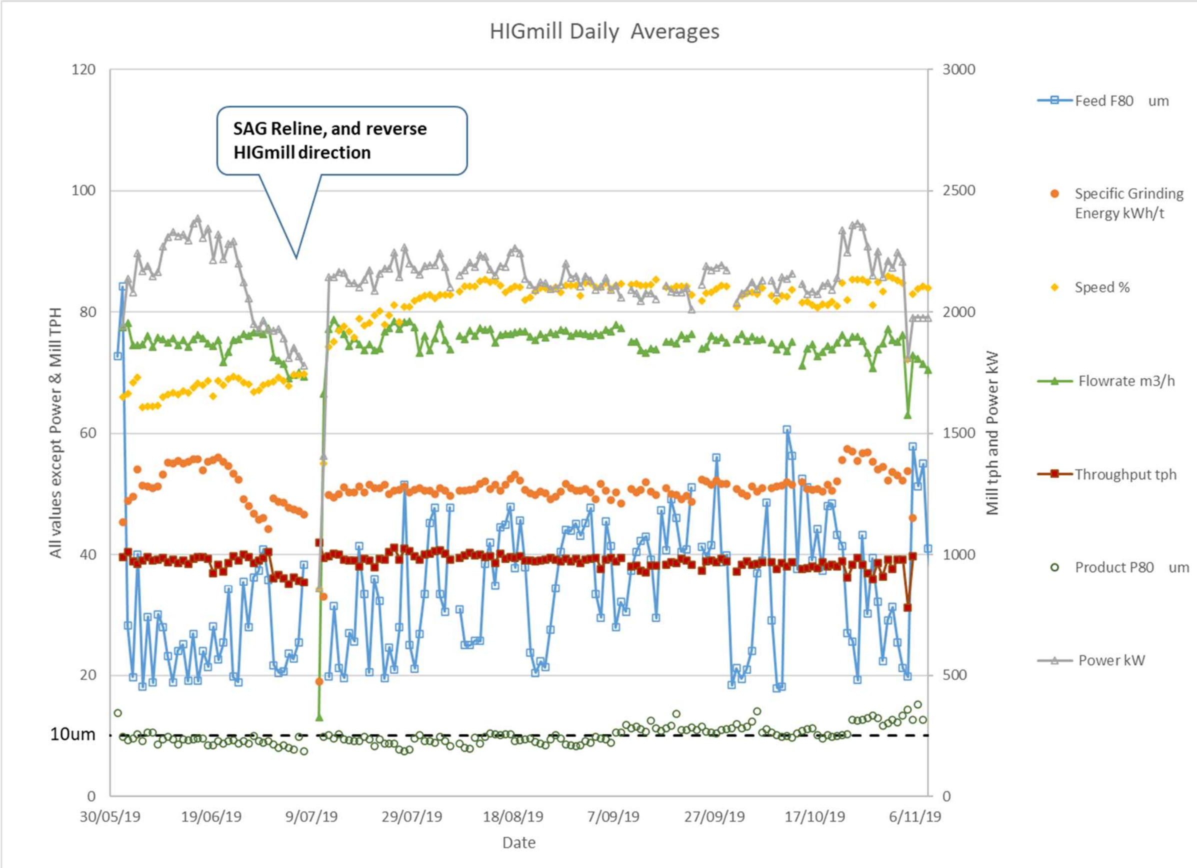


**FIG 16** - HIGmill Operation – Daily averages for a 20 wk period.

The flotation circuit is operating well, and to ensure that pyrite is not depressed, there is a need to keep the Weak Acid Dissociable cyanide level in the process water below 20 ppm via cyanide detox.

There were some challenges during commissioning with lower adsorption kinetics observed due to the flotation reagent Potassium Amyl Xanthate (PAX), which resulted in the requirement for more carbon loading in CIL. A new kiln to allow for higher carbon regeneration rates has been installed to manage xanthate fouling of the carbon. The pre-oxidation tank in the existing CIL circuit was contributing to reduced recovery as the fine grind product, which had a high oxygen demand, was introduced and passivation of the surfaces resulted. This was overcome by converting the pre-oxidation tank to a leach tank through the addition of cyanide. Further test work and trials are continuing to identify the optimal leaching conditions and further increase recovery.

## Operator feedback

According to operators, the HIGmill is running well. It is very easy to change the mill speed, adjust the energy input and change the P80 during operation. As the thickener has been installed prior to the HIGmill, with large ~45 min mass inventory, a steady state process is easily achieved, delivering consistent throughput, flowrate and density.

In theory the rotor life can be maximised by increasing the media load in the mill and slowing the rotor speed down. Wear rate is proportional to the rotor speed to the power of a factor. Once the maximum media fill level or an upper torque limit is reached, the mill speed can be increased as the rotors wear to maintain the required power draw.

Media level measurements needed to be taken frequently during the first three months, as the media wear rate was unknown. There are various methods to measure the media level, including vibration (or acoustic) measurements between each shell segment, a special strain gauge, or a Boroscope camera. A Boroscope camera with light is used at Sunrise Dam to inspect the wear components or media fill level. The time it takes to conduct a Boroscope mill inspection is 10 hours: one hour grind out, four hours media dump, one hour inspection, and four hours to return media to mill. The current method of monitoring media fill level is to stop the mill, drop a weighted rope with measurement markers to the charge level and calculate the percentage of mill filled. This process takes less than an hour to complete and is performed weekly. This frequency is due to the highly variable viscosity of the mill feed and allows for accurate monitoring of the media wear and ejection from the mill.

The media charging mechanism is a six tonne capacity davit crane, loading media into a charging hopper mounted over the mill. The ceramic media is loaded into the mill using a 4.5t kibble. The current media charge is about 30t with new rotors, and the aim is to maintain this level during operation. The removal of 30 tonne media from this sized mill is labour intensive due to the use of the kibble and bags to remove media, therefore for future optimisation projects a media handling system would be reviewed.

The mill scats 1 to 1.5 mm media due to various factors, including the media vortex in the mill, buoyancy of the media size, combined with the media sphericity and slurry viscosity. AGA has re-directed HIGmill discharge slurry to an existing trash screen arrangement which is scalping this extremely small size media from the CIL feed. This arrangement is working successfully, and operators have monitored a steady state of media scat generation. Media loss from the mill can wear out the CIL pumps prematurely. Media can also become entrained in the carbon and downstream ball valves in the elution circuit.

In terms of the shutdown time for the flotation, thickener and HIGmill, once the fresh feed is cut from the primary ball mill, it takes six hours for the shutdown sequence to be completed: two hours for feed off, two hours for the concentrate thickener to empty, and 50 minutes to flush the HIGmill. The reason for these large flush times is the residence time in the flotation cells and HIGmill, where the HIGmill requires two volume changes to ensure slurry is cleaned from the media. It is not possible to shut down the HIGmill on its own, so future consideration of a bypass line around the HIGmill or a thickener closed recirculation line is required.

The HIGmill is achieving consistent and continuous operation. The mill can be run for the life of the wear components and does not need to be stopped and opened for regular wear inspections, resulting in high availability.

## CONCLUSIONS

The regrind project at Sunrise Dam has achieved an estimated average increase in gold recovery of ~6 per cent from commissioning to April 2021.

This HIGmill has achieved its required performance and continues to be operated with minimal operator input. After a challenging commissioning and wear part optimisation process, the HIGmill has exceeded operating and maintenance expectations. The HIGmill overall utilisation is 97 per cent and has an availability of 98.6 per cent. The mill currently targets P80s of 10-12µm, while achieving a rotor wear life of up to 45 weeks and a shell liner component life of minimum 26 weeks.

According to operators, the HIGmill is running well. The mill can be run for the life of the wear components and does not need to be stopped and opened for regular wear inspections, resulting in high availability. It is very easy to change the mill speed, which adjusts the energy input and change the P80 during operation. With regards to maintenance, the HIGmill reline periods run for 36 hours, excluding operator shutdown and start up time, with the main plant shutdown period generally between 36 – 48 hours.

There are various areas where the HIGmill could be further optimised, which include:

- A specialised media handling system, where media can be pumped from and to the mill. Metso Outotec now has various Media Handling Systems for this purpose.
- An external trash screen to capture media and prevent it from entering the CIL circuit.
- Consideration of a bypass line around the HIGmill or a thickener closed recirculation.
- Online PSA to enable accurate P80 control.

Closing comment from Tony Ryan, Manager: Engineering Support at AngloGold Ashanti Australia Ltd

*"The HIGmill is still on a continuous improvement journey. Both the OEM and customer have an obligation to work together to get the continuous improvement benefits for both parties. As an industry we need to strive for wider participation with end users where we can all benefit from the larger knowledge base."*


## ACKNOWLEDGMENT

The Authors would like to thank AngloGold Ashanti Australia Ltd and Metso Outotec for permission to publish this work.


## REFERENCES


AGA 2014, AngloGold Ashanti Australia Ltd, Sunrise Dam Gold Mine Recovery Enhancement Project PFS, Internal document.

AGA 2017, AngloGold Ashanti Australia Ltd, Sunrise Dam Gold Mine Recovery Enhancement Project, Process Flow Diagram, SDGM300F701 rev0, 18th August 2017

Fann, 2017, Marsh Funnel Viscometer Instructions (for Fann No. 201), online

https://www.fann.com/content/dam/fann/Manuals/Marsh_Funnel_Instruction.pdf, accessed 12/12/2015.

Heath, A., Belke, J., Lehto, H., and Orser, T. (2017). Fine grinding rotors with improved service life by DEM modelling, Procemin-Geomet 2017, Chile, Chapter 4.

Keikkala V., Paz A., Komminaho T., Lehto H., Loucas J., 2018, Energy Efficient Rotor Design for HIGmills, 2018 Minerals Engineering, Volume 128, November 2018, Pages 266-274

Larson, M., Anderson, G., Morrison, R., Young, M., 2011, Regrind Mills Challenges of Scaleup, page 13, SME Annual Meeting, Feb 27/3/2011, Denver, Colorado, USA.

Nielsen, B., Lehto, H., Musuku, B., (2016) Design, Installation, Comissioning and Operation of Fine Grinding Technology at the Kevitsa Mine, In: 13th AUSIMM mill operators' conference, Perth WA 10-12 Oct., 2016.

Paz A., Ghattas, R., Loro, S., Belke, J., 2019, Fine Grinding Implementation at The Cracow Gold Processing Plant, MetPlant 2019, Perth WA, 9 - 10th September 2019.