

**AN INITIAL REVIEW OF THE METALLURGICAL PERFORMANCE OF THE HIGmill™ IN A  
PRIMARY MILLING APPLICATION IN THE HARD ROCK MINING INDUSTRY**

\*H. Erb<sup>1</sup>, M. van de Vijfeijken<sup>1</sup>, Y. Hanuman<sup>2</sup>, C.M. Rule<sup>2</sup>, W.C.E. Swart<sup>3</sup>, H. Lehto<sup>4</sup>, and V. Keikkala<sup>4</sup>

<sup>1</sup>*Swiss Tower Mills Minerals Ltd  
Haselstrasse 1, Baden, Switzerland, CH-5400  
(\*Corresponding author: hanspeter.erb@stmminerals.com)*

<sup>2</sup>*Anglo Platinum  
55 Marshall Street, PO Box 62179, Marshalltown, Johannesburg, South Africa*

<sup>3</sup>*Kumba Iron Ore  
124 Akkerboom St, Centurion, 0157*

<sup>4</sup>*Outotec  
Rauhalanpuisto 9, P.O Box 10000, 2231 Espoo, Finland*

## **AN INITIAL REVIEW OF THE METALLURGICAL PERFORMANCE OF THE HIGmill™ IN A PRIMARY MILLING APPLICATION IN THE HARD ROCK MINING INDUSTRY**

### **ABSTRACT**

The economic demand to reduce energy in the comminution circuit is the focus of today's minerals processing industry. Anglo American Platinum together with Swiss Tower Mills Minerals and Outotec embarked on a technology testing program to review the HIGmill™ in the hard rock comminution circuit. It was tested in a tertiary application on a laboratory scale and in a primary application on a pilot scale using Platreef and UG2 ores. The target is to verify whether the HIGmill™ can handle coarse feed (3 – 5 mm), ultimately aiming to provide a more energy-efficient alternative with a smaller footprint to ball milling.

### **KEYWORDS**

Energy efficient, coarse-grinding, vertical mill, stirred media mill, HIGmill™

### **INTRODUCTION**

The aim of milling is to reduce particle size to the point of economic liberation of valuable minerals. In today's challenging economic climate, the need to achieve this is high with decreasing costs and energy consumptions becoming more and more critical in realizing sustainable profit margins. The ball mill has been used for grinding since the early 1800's and has since increased its popularity as a versatile and robust tumbling mill operating over a wide range of conditions in primary, secondary and tertiary applications. However, since ball mills have low size reduction efficiencies and high energy consumptions, they are relatively inefficient breakage devices. Hence, ball mills are usually operated in closed circuit with classification units in order to increase their efficiency. Despite this, the practical and economic limit to the fineness of a ball mill product is approximately 40 – 45 µm (Gao & Weller, 1994).

With the need to grind finer to liberate minerals, stirred mills present quite an attractive energy efficient alternative. Stirred milling technology dates back to 1928 and the need for this technology has grown over the last 20 years (Radziszewski & Allen, 2014). However, the application of stirred mills exists mainly in fine grinding and ultra-fine grinding. Anglo American Platinum (AAP) together with Swiss Tower Minerals Ltd (STM) and Outotec embarked on a technology testing program to review the HIGmill™ in the hard rock comminution circuit. It is AAP's technology drive to ensure that they continue to explore new technologies to reduce the cost and improve liberation. As part of this drive, the HIGmill™ was tested in a tertiary milling application on a laboratory scale. In addition to this initial test work, alternative comminution circuits were reviewed on pilot plant scale with the HIGmill™ in a primary application. The aim of these tests is to provide a more energy-efficient alternative with a smaller footprint to ball milling.

### **A BRIEF OVERVIEW OF HIGmill™ TECHNOLOGY**

In 2012, Outotec launched the HIGmill™, a new fine grinding technology for the mineral processing industry. Over 200 HIGmills™ are installed in the industrial minerals industry that covers a wide power range of between 5 kW to 5 MW. Today, there are nine 5 MW units in operation; the first 5 MW unit was successfully commissioned two decades ago and is still in operation today. The unique milling technology can therefore be considered as being well-proven. Until recently, HIGmill™ was unavailable to the hard rock minerals processing industry, however, further development backed by intensive test work have now made this possible.

## Mill Structure

Outotec's HIGmill™ is a “stirred media” grinding mill where the stirred effect is caused by rotating grinding discs together with static counter discs situated on the shell. The shape of the mill offers a smaller footprint. The general structure and its main components are presented in Figure 1.

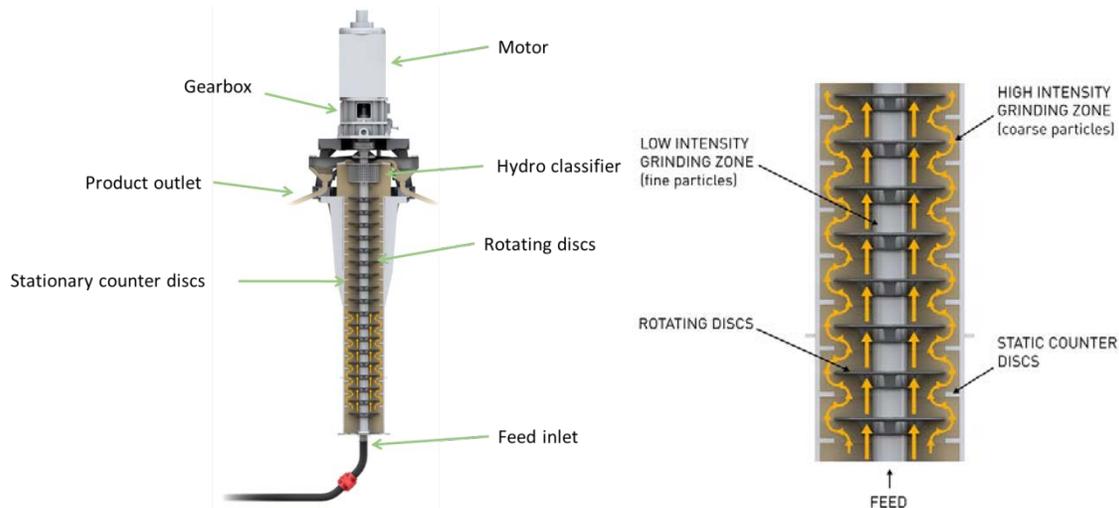


Figure 1 - Outotec HIGmill™ (Outotec, 2013)

## Mechanism of Grinding

Feed is pumped tangentially into the mill from the bottom. As the material passes upwards, it passes through all consecutive grinding stages. The rotating discs stir the charge and the grinding takes place between beads by attrition. Due to the tall, narrow, vertical mill body arrangement, grinding media is evenly distributed and the gravitational effect ensures inherent classification of particles. The final product discharges at the top of the mill at open atmosphere. The hydrostatic pressure ensures optimal contact between grinding media and the mineral particles, significantly increasing grinding efficiency. The number of discs (grinding stages) depends on the application. The grinding chamber can be filled with up to 70% of media. Ceramic, high density ceramic and steel media have been tested in the HIGmill™ and may be used as required. Flow fluctuations to a HIGmill™ can be dampened by maintaining the net energy via control of the mill shaft speed. Product fineness is controlled by maintaining the feed rate, feed density, media level, and shaft speed. The mill offers high power intensity with reduced energy consumption.

## High Energy Efficiency Design

The energy efficiency of the HIGmill™ is based on over 40 years of experience with the designs of special discs and counter discs in a vertical arrangement. This design also enables the unique combination of high power intensities with relatively low tip speeds. The typical power intensity is approximately 200 kW/m<sup>3</sup> with up to 300 – 400 kW/m<sup>3</sup> that can be achieved. The tip speed can be varied and is typically around 9 to 12 m/s.

## Simple Process Design

Due to the vertical design and the internal classification effect during grinding, external classification is not needed for the mill product. If the incoming feed from the upstream process is diluted, or already contains a significant amount of product size material, a scalping cyclone (classification) should be used. A simplified process flow sheet is presented in Figure 2.

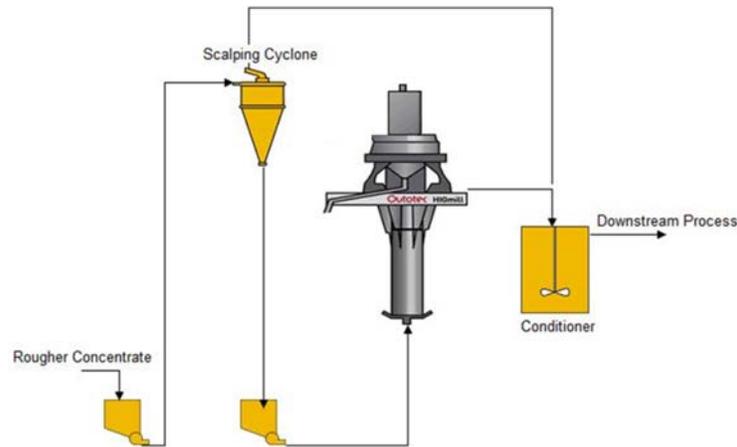


Figure 2 - HIGmill™ flow sheet (Outotec, 2012)

### **BENEFITS OF THE HIGmill™**

We believe that the HIGmill™ can achieve comparable and, in some cases, improved grinding energies to that of the ball mills in primary, secondary and tertiary milling applications in current concentrator plant operations. Table 1 shows a comparison of the potential benefits of using HIGmill™ technology.

Table 1- Benefits of using HIGmill™ technology

Parameter	Typical Process Flow Sheet	Process Flow Sheet with HIGmill™	Comment
Foot print	Large	Smaller	Saving of 50-70%
Piping	Large (200 – 300%)	Smaller (100%)	No recirculating loads
Pumping power	High	Lower	Saving of 40-60%, no recirculating loads
Cyclones	Large (200 – 300%)	Smaller (100%)	No recirculating loads, scalping only if applicable. Higher throughput/capacity
Specific grinding energy for the complete circuit (mill & auxiliaries)	High	Lower	-
Product quality	Good	Good	

### LABORATORY SCALE TESTING OF THE HIGmill™

AAP had sent samples of UG2 ore to Outotec/STM to perform tests using a 25 liter laboratory scale HIGmill™. Figure 3 shows the HIG25 test mill as a true scaled-down HIGmill™, complete with rotating grinding discs and static counter discs. The slurry is also fed from the bottom with the discharge at the top. Hence, the grinding mechanism in the HIG25 test mill is the same as in the larger production mills.



Figure 3 – HIG25 laboratory test mill with auxiliaries and mill internals

The UG2 ore was prepared to represent a typical tertiary mill feed having a grind with a  $F_{80}$  of 100  $\mu\text{m}$ . The objective of the test work was to achieve a product grind with a  $P_{80}$  of 53  $\mu\text{m}$ . The mill was run at various incremental speeds so as to generate a signature plot. Before a product sample was taken, a slurry of at least four times the mill volume was pumped through the mill for each point on the signature plot, in order to ensure a steady state condition in the HIGmill™. Both the feed and the product samples were analyzed with a laser analyser. A graded media charge of 60 % mill volume filling comprising 40 % of 2.2 – 2.4 mm ceramic beads and 60% of 3.5 mm was used in the HIG25 laboratory mill. The bulk density of the media was 2.4  $\text{t}/\text{m}^3$ . The diameter of the discs was 169 mm giving a range of tip speeds between 2.4 – 6.6 m/s.

The signature plot for the tertiary mill application with the UG2 ore is represented in Figure 4. A benchmark comparison was made against the performance of a pilot scale tertiary horizontal stirred mill on the same ore type, feed size and slurry density. The 100 L horizontal stirred mill used a seasoned charge of ceramic media with a top size of 4 mm and a bulk density of 2.4  $\text{t}/\text{m}^3$ , and was operated at a tip speed of approximately 10 m/s. This mill may not be fully optimised but is operated under these conditions for various project works. It achieved a grind with a  $P_{80}$  of 45  $\mu\text{m}$  using a specific energy of 16.4 kWh/t. The signature plot shows that the HIGmill™ achieves the same grind with 10 kWh/t. This shows that for this fine grinding application the HIGmill™ used 39 % less energy to achieve the same product size. Note that the HIGmill™ was also not optimised and further extensive tests would need to be done to establish optimum operating conditions.

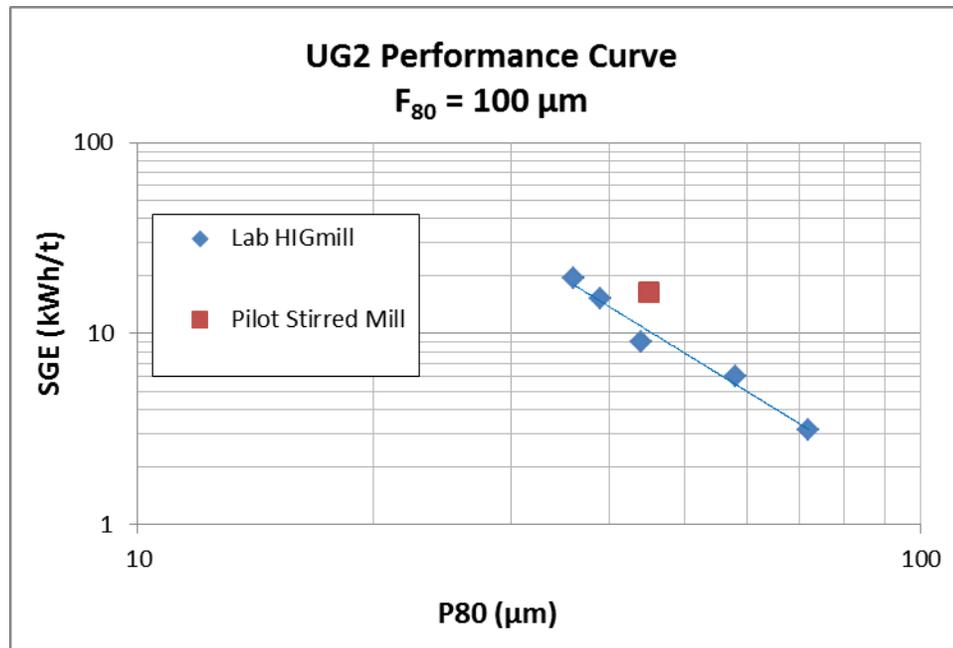


Figure 4 - Signature plot of the HIGmill™ in a tertiary application laboratory test on UG2 ore

The particle size distribution curves of the feed and discharge of these mills are shown in Figure 5. It shows a similar reduction between the two mills for the coarser particles down to 40  $\mu\text{m}$ ; all the coarser feed particles are being ground. Below 40  $\mu\text{m}$ , the feed to the HIGmill™ was finer and consequently a finer HIGmill™ product was achieved.

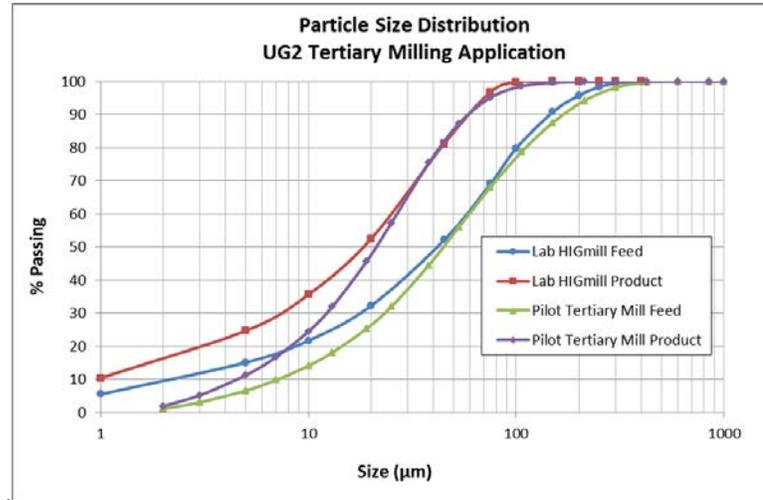


Figure 5 - Particle size distribution curves of the HIGmill™ against a horizontal stirred mill in a tertiary application

### PILOT SCALE EVALUATION OF THE HIGmill™

Following the encouraging results from the laboratory tests, it was decided to conduct coarse milling application tests using UG2 and Platreef ores with the HIGmill™ on pilot scale. The smallest size production HIGmill™ was arranged for pilot scale testing at AAP's DML Pilot Plant in Rustenburg. This mill is a HIG 75/200, with a 200 liter capacity, an installed power of 75 kW and equipped with unique interchangeable mill internals specially developed for both fine and coarse grinding. The mill was installed and commissioned in August 2014. Figure 6 shows a picture of this installed unit.



Figure 6 - The HIG 200/75 installed at AAP's DML Pilot Plant

## **Plant Setup and Feed Ore Preparation**

AAP's DML Pilot Plant in Rustenburg is equipped with a crushing and screening plant, a full milling and flotation plant, and a sample preparation laboratory. The dry and wet plants are set up to configure any circuit as required by a project. For the HIGmill™ tests, both the dry and wet plants had to be re-configured. All ore used for the test work are trucked from the relevant Mines to the pilot plant where it is prepared accordingly.

In order to prepare the ores from the respective Mines for primary milling tests, they were jaw crushed and then impact crushed in closed circuit with either a 3 mm or 5 mm aperture screen in order to provide the respective feed top sizes of 3mm for UG2 ore and 5mm for Platreef ore. The respective feed was then fed to the HIGmill™.

In terms of media loads, the HIGmill™ was set up with a graded steel ball charge of 63 % of 18 mm and 37 % of 12 mm. This charge occupied 40 % of the mill's effective volume. The coarse grinding discs used in the HIGmill™ had a diameter of 280 mm giving tip speeds of between 3.7 – 9.4 m/s for shaft speeds ranging between 250 – 640 rpm respectively.

## **Test Design**

A series of combination tests were done using solids feed rates ranging between 1.2 – 2 TPH and mill feed slurry densities ranging between 38 – 52 % solids. At each of these conditions, various mill speeds were tested. This was done to generate data around the HIGmill™. These conditions achieved specific energies in the HIGmill™ of between 3 – 23 kWh/t. The ranges of feed rates and densities were selected based on the limitations of the DML Pilot Plant pumping system. It must be noted that pumping challenges were experienced during the Platreef test as the feed line to the HIGmill™ choked continuously at the point of entry into the mill when a feed of 5 mm and larger was pumped. As a result, only part of the test was completed and the test on 5 mm feed was abandoned. As a note, the feed entry design of new units has changed since the time of this test, in that, the feed now enters tangentially at the bottom of the mill as opposed to directly from the base of the mill.

## **Sample Preparation and Sample Analysis**

All samples taken of the mill feed and discharge were subjected to size grading analysis. Composite belt cuts were taken for primary mill feed samples and manual size gradings were done on them. All slurry samples were sized using a laser analyser. It has to be noted that the plant benchmark data has been sized by physical screening instead of using a laser analyser, which makes it difficult to make a direct comparison; typically, physical screening leads to a much finer result. Slurry densities were measured using a portable densitometer. Flow rates were obtained using the mill feed belt weightometer and flow meters in the plant; HIGmill™ discharge flow rates were also measured manually using a bucket and stopwatch method to use as a check against the feed rates.

## **Pilot Scale Tests**

### Primary Milling Application Using 3 mm UG2 Ore

Stirred milling in a primary milling application is a new concept in the hard rock minerals industry. The signature plot in Figure 7 shows the energy input of the pilot HIGmill™. The data set used was for limited sets of operating conditions, and all spurious data were omitted. As a result, and as a cautionary note, this will only show a partial picture of the full milling capability of the HIGmill™. The top size of the feed was 3 mm with a  $F_{80}$  of 700  $\mu\text{m}$ ; the PSD was a result of reproducing a sub 3 mm feed via the dry plant at the DML Pilot Plant. The HIGmill™ does exhibit its applicability as a primary mill. Due to significant differences in the respective feed PSDs of the HIGmill™ and a typical UG2 plant primary mill, as well as the fact that the primary ball mill is operated in closed circuit whereas the

HIGmill™ is operated in open circuit, the specific energies were not compared. However, the aim of the test was to establish proof of concept that the HIGmill™ can, in fact, handle a coarse feed to be used in a primary milling application.

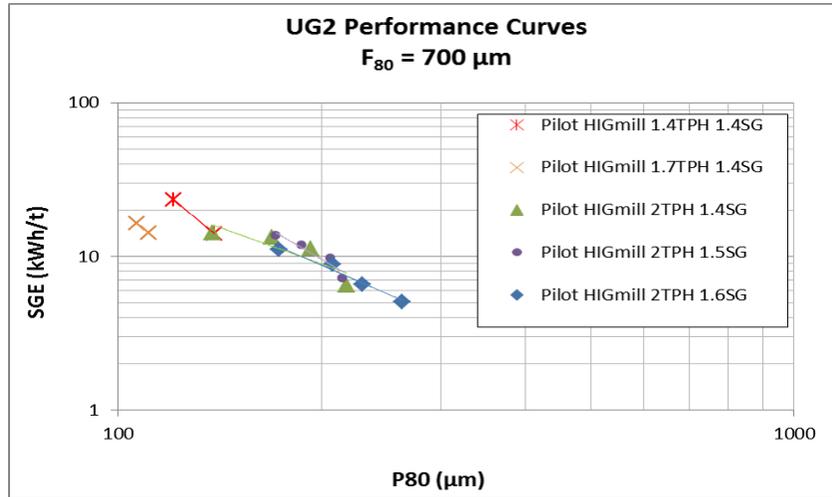


Figure 7 - Signature plot of the HIGmill™ in primary application pilot tests on UG2 ore

Figure 8 shows how the product PSD of the HIGmill™ aligns with that of a typical UG2 plant primary ball mill circuit. We understand that apart from achieving the required product PSD, milling efficiencies must also be evaluated. The predominant mode of breakage in stirred mills is attrition where particles are broken due to stress acting between the grinding media. Stress intensity is the most important parameter affecting milling efficiencies in stirred mills. The grinding media stress intensity in vertical stirred mills has a gravitational component and a centrifugal component. For a given specific energy input, there exists an optimum stress intensity range for which the finest product is achieved. Hence, further test work would have to be structured to accommodate the factor of stress intensity in order to compare milling efficiencies of the HIGmill to other stirred mills and ball mills.

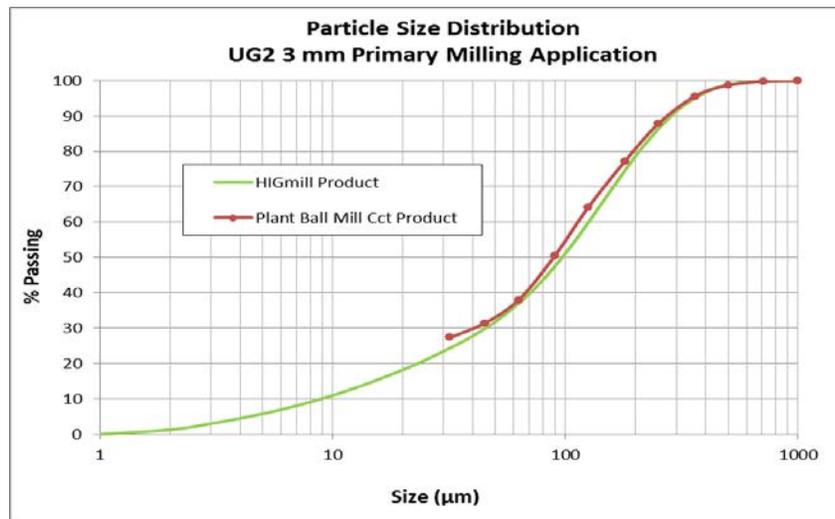


Figure 8 - Particle size distribution curves of the HIGmill™ product against a UG2 plant primary ball mill circuit product

Primary Milling Application Using 5 mm Platreef Ore

Using a coarser Platreef feed with a top feed size of 5 mm and a  $F_{80}$  of 2000  $\mu\text{m}$ , the HIGmill<sup>TM</sup> produced a  $P_{80}$  of 194  $\mu\text{m}$  with 12.8 kWh/t of energy, as can be seen in Figure 9. The test was abandoned as a result of the pilot plant pumping constraints hence further test work is required. Figure 10 illustrates the capability of the HIGmill<sup>TM</sup> to achieve the required grind even from a 5 mm top size feed.

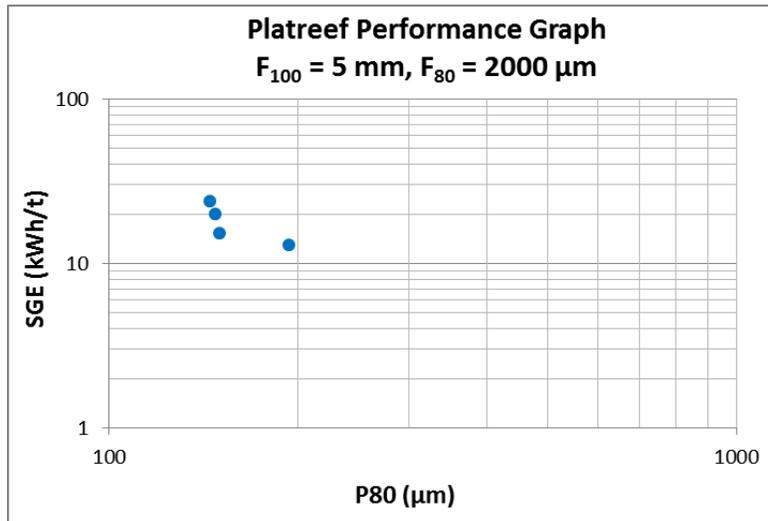


Figure 9 - Signature plot of the HIGmill<sup>TM</sup> on a 5mm Platreef feed

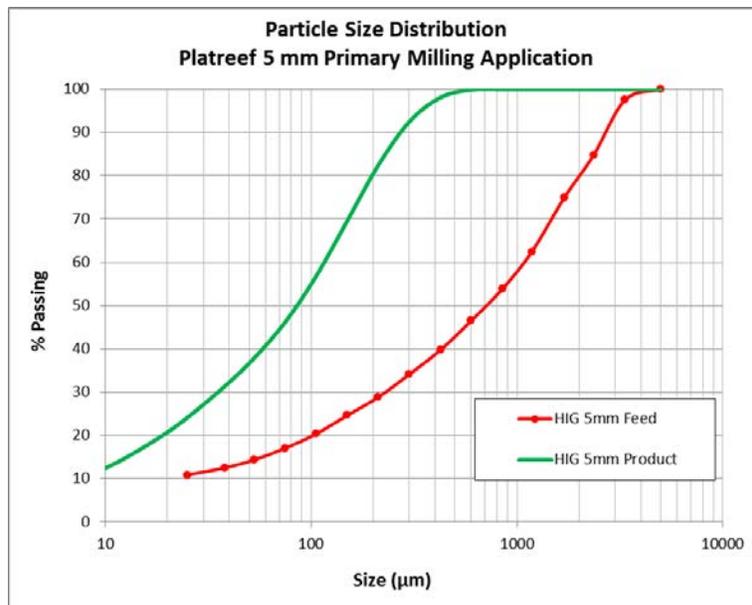


Figure 10 - Particle size distribution curves of the HIGmill<sup>TM</sup> using a 5mm feed in a primary milling application

Again, it can be clearly observed that all the very coarse particles have indeed been reduced in size. On the other hand, the amount of fines sub 50  $\mu\text{m}$  increased slightly by approximately 20%. It has to

be noted that in the pilot installation, neither scalping nor screening before the HIGmill™ had been used and the internal classification in the small 200 liter HIGmill™ is rather challenging. Typically, a scalping cyclone is installed, of which only the underflow reports to the HIGmill™, whereas the finer feed particles will bypass the HIGmill™; this would lead to an even steeper product PSD curve.

These results showcase the potential of the HIGmill™ to be used as a primary mill. This implies that the HIGmill™ can potentially replace ball mills in the process circuit; Figure 11 illustrates this process flow setup.

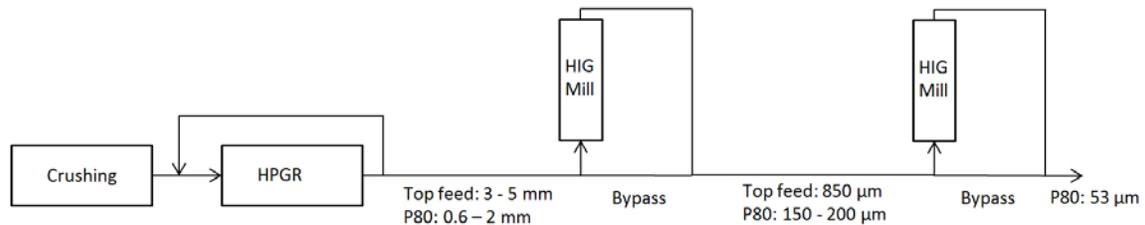


Figure 11 - Alternative process flow using the HIGmill™ in both primary and secondary applications

## CONCLUSIONS

It is evident that the HIGmill™ has the ability to function as a tertiary mill, as well as, a primary mill showing multiple benefits of using this technology. However, further extensive test work must be done to establish optimum operating conditions for the HIGmill™, as well as, establish the scale-up factor between laboratory and pilot scale, and eventually to plant scale. Furthermore, the wear rates of the mill internals must be evaluated. It would also be beneficial to investigate whether the HIGmill™ can be used to replace both the secondary and the tertiary grinding mills; over and above the potential energy saving, there would then also exist the benefit of using one mill instead of two which translates to a smaller footprint, less spares, possibly lower CapEx and OpEx, and an opportunity for an inert environment.

## REFERENCES

- Bond, F. C. (1961). Crushing and grinding calculations. *Br Chem Eng*, 16, 378-385, 543-548.
- Gao, M. W., & Weller, K. R. (1994). *A comparison of tumbling mills and stirred ball mills for wet grinding*. Australia.
- Jankovic, A. (March 2001). *Media stress intensity analysis for vertical stirred mills*. Brisbane, Australia: Comminution '01.
- Jankovic, A., Dundar, H., & Mehta, R. (n.d.). Relationships between comminution energy and product size for a magnetite ore.
- Kurki, P. (2013). *Outotec HIGmill grinding test on Anglo American PGM material*. Finland: Outotec Research Centre.
- Lehto, H., Paz, A., Loucas, J., van de Vijfeijken, M., & Erb, H. (n.d.). *Pilot scale studies in fine grinding with Outotec HIGmills*.
- Morrell, S. (2008). A method for predicting the specific energy requirement of comminution circuits and assessing their energy utilisation efficiency. In *Minerals Engineering* (Vol. 21).



VANCOUVER 2015

- Napier-Munn, T., Kojovic, T., Morrell, S., & Morrison, R. (1996). *Mineral Comminution Circuits - Their Operation and Optimisation*. Queensland: Julius Kruttschnitt Mineral Research Centre.
- Radziszewski, P., & Allen, J. (2014). Towards better understanding of stirred milling technologies - Estimating power consumption and energy use. *46th Annual Canadian Mineral Processors Operators Conference*. Ottawa, Ontario.
- Samanh, S., Cuhadaroglu, D., & Kizgut, S. (n.d.). Comparison of grinding performance between stirred mill and ball mill.
- Shi, F., & Morrison, R. (2009). Comparison of energy efficiency between ball mills and stirred mills in coarse grinding. In *Minerals Engineering* (7-8 ed., Vol. 22).