Ultra fine grinding of intermediate flotation concentrates in the PGM industry at the Pt Mile operation on Anglo Platinum tailings

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Platinum Mile operates a flotation plant treating the tailings from Anglo Platinum’s Waterval concentrator operations. The contained PGMs and base metals are recovered as a low grade flotation concentrate and are further treated for the recovery of saleable metals at Anglo Platinum’s integrated downstream smelting and refining operations in Rustenburg.

To improve the financial returns of the Pt Mile operation and to gain operating data and experience; Pt Mile and Anglo Platinum agreed to a collaborative investigation of concentrate ultra fine grinding (UFG) at the Pt Mile plant.

Anglo Platinum loaned a 355 kW Metso SMD™ unit and proposed a joint investigation programme at the Pt Mile plant, after consideration and discussion of initial promising laboratory-scale work conducted by Pt Mile at Mintek.

Introduction

The retreatment, by scavenger flotation, of PGM concentrator tailings has become a recent trend in the industry. Impala commissioned the first plant at its Rustenburg operations in November 2003.

Anglo Platinum had also decided to initiate tailings scavenging but through third party, BEE involved companies. The operations selected were the large tonnage arisings at Rustenburg Platinum’s (RPM’s) Rustenburg and Amandelbult operations.

The logic behind the strategy is to treat, in a relatively low capital and low operating cost facility, all the tailings tonnages, after the streams have left the upstream concentrator tails thickener/pumping plants. The opportunity is to recover lost metal values caused by flotation and plant instability inefficiencies. Upstream plant stoppages and start-ups are well known to be periods of extraction inefficiency in milling and flotation plants. The intense mixing and surface attritioning in the pumping system may have a further beneficial effect, permitting previously ‘coated’ value particles to be recovered by further flotation.

Platinum Mile Resources approached Anglo Platinum in late 2003 with a proposal to treat tailings from Anglo Platinum. The commercial operation commenced in June 2005, construction of the facility having been completed in less than 12 months after the agreement was concluded. The treatment of current tailings arisings from the Waterval concentrators was sited at Paardekraal tailings dam, adjacent to the tailings system booster pump station.

The plant treats two streams separately, a UG2 stream and a mixed UG2 and Merensky stream. These are respectively, the final tails from the Waterval UG2 Concentrator, with a capacity of 485 000 tpm, and the final tails stream from the Waterval Merensky Concentrator, with a capacity of 460 000 tpm. (Subsequently this plant became the Waterval Retrofit Concentrator in third quarter 2007, with a maximum capacity of 620 000 tpm.) The tailings from the Waterval Smelter slag treatment plant is co-processed with arisings from the retrofit plant.

The feed to the plant is low grade, generally less than 0.8 ppm 4T PGM (4T refers to platinum, palladium, rhodium and gold content) and consists, in the majority, of slow floating value mineral species. Table I is a typical composite sample for the Merensky stream at Platinum Mile’s plant; the majority of recovered PGMs is from this stream.

The plant is sited adjacent to the Paardekraal booster pump station, on the corner of the Paardekraal tailings dam complex. Feed and tails to and from the plant are delivered from and returned to the booster station for onward deposition.

Platinum Mile circuit pre the SMD and column circuits

Over the roughly two years of operation, June 2005 to July 2007, when the UFG circuit was added, the Platinum Mile plant has averaged around 1% delta recovery—i.e. recovery expressed as a percentage of the Anglo Platinum upstream plant feed grades. This represents a yield or plant recovery between 4 and 10% of the tailings scavenging plant feed, see Figure 1.

This bears witness to the operational steadiness and efficiency of the upstream concentrators. Anglo Platinum plant recoveries, dependant on UG2 feed proportion, currently range between 82 and 87% 4T PGM. The Platinum Mile plant operated during the time that the ‘brownfields’, Waterval retrofit commissioning was taking place. Some of the ‘peaks’ shown in the graph reflect the circuit instability during these ‘tie-ins’, equipment changeovers and commissioning activities.
In addition to the low, <10% plant potential yields, it has been historically difficult to achieve the desired smelter feed grade in the product from the plant. Selectivity in the cleaner circuits is an issue when ‘slow floating’ species are being recovered in these types of scavenger operations. This results from the removal of the easy floating well-liberated and relatively coarse PGMs and base metals in the upstream operations (Rule and Anyimadu 2007.) The feed to the scavenger flotation at Platinum Mile is preferentially ‘middlings’ and fine PGMs and base metal values. In general the majority of the recovered PGMs has emanated from the Merensky stream. The proportion of UG2 mined at Rustenburg section has increased rapidly in recent years; from 57% in 2005 to 69% in 2007. With the closing of the Klipfontein Concentrator in late 2006, all UG2 tailings passed through the Platinum Mile plant enroute to the tailings dams. The Klipfontein plant feed was made up of mostly UG2 and this was subsequently processed through the retrofit plant when the plant was shutdown in early 2008.

Platinum Mile has invested in a focused effort to improve the plant operational efficiency. After the initial commissioning optimization, a programme of work at Mintek and then later on site with a pilot Deswik UFG milling unit was initiated. Anglo Platinum has provided technical support and advice in these efforts.

The plant, commissioned in June 2005, was set up as a two-stream operation with roughing, cleaning and re-cleaning to final product as per the flow sheet shown in (Figure 2).

The tailings lines from the UG2 plant feeds one stream via the feed tank and the other stream, the Merensky stream is fed from the tailings lines from the Waterval Retrofit tailings disposal area. This discharges into the Merensky feed tank and comprises the Waterval Retrofit and Slag plant tails. The circuits operate essentially in parallel, thus allowing comparative analyses.

### Metallurgical and mineralogical analyses

Initially Platinum Mile final concentrates were analysed and reported by Anglo Platinum—information of what could be recovered is inherently useful to tune the upstream operations. The data showed the characteristics of what could be recovered in the circuit. Tables II and III show the speciation and particle size data from these samples.

The data shows the very fine grain size of PGMs in Platinum Mile feed and the marked distribution of middlings and locked PGMs in the +10 and +25 micron fractions. Clearly, fine grained PGMs are recoverable even when they are not fully liberated.

Hence the potential for improving concentrate grade is evident; by the application of fine grinding to liberate locked and middling PGMs in composite silicate gangue particles.

Further mineralogical work was initiated to understand what was happening within the plant circuits. The plant operations were sampled after operational stability was achieved to analyse operational performance and to understand where potential to improve yields and final product grade lay. It was clear that the largest potential improvements lay in improved liberation and better cleaner selectivity and subsequent yields.

The recovery of PGMs from the rougher concentrates treated in the cleaning circuits was low—indicating poor selectivity and hence difficulty in recovery to final product grade. PGMs were often contained as either locked or

<table>
<thead>
<tr>
<th>Size fraction (μm)</th>
<th>Mass %</th>
<th>Pt</th>
<th>Pd</th>
<th>Au</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr₂O₃</th>
<th>S</th>
<th>PGE (3E)</th>
<th>%</th>
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<td>0.56</td>
<td>0.54</td>
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<td>0.03</td>
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<td>6.67</td>
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<td>20.1</td>
<td>0.25</td>
<td>0.16</td>
<td>0.03</td>
<td>0.44</td>
<td>0.02</td>
<td>&lt;0.1</td>
<td>8.52</td>
<td>0.06</td>
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<tr>
<td>&gt;25</td>
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<td>0.26</td>
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Figure 1. Plant yields pre SMD operation June 2005 to July 2007

Table I
Typical assay and size analyses of the feed to the Merensky stream of the Pt Mile plant—samples from an on-plant survey conducted by Anglo Platinum and Pt Mile in 2006
ULTRA FINE GRINDING OF INTERMEDIATE FLOTATION CONCENTRATES

Middling particles—most often with silicates and typically less than 5 microns in size. This is shown in Figure 3 of a particle showing typical mineral association that is lost in the circuit. The very small PGM particle, -5 micron ‘black’, is included within a small sulphide particle, -30 micron, ‘light grey’, and attached to a large silicate particle, +100 micron, and ‘dark grey’. (Figure 3).

Figure 4 shows the PGM speciation information for various plant samples taken during the 2006 survey. Clearly the potential for improved liberation is indicated both in mainstream and in the intermediate concentrates. The rougher feed to rougher tails change indicates an increased proportion of middlings and locked losses. Inspection of the cleaner and recleaner feeds and tails shows the same trend.

It is clear from the above that, to improve the recovery of the valuable mineral species, the degree of liberation required and improved flotation of liberated fines would need to be addressed.

New and practical fine grinding technology for the recovery of partially or fully liberated fine PGM species has historically been limited. However, over the last number of years, much development work has been ongoing in terms of the development of fine grinding technology in the base metal and PGM mining industry, leading to the commercial application of equipment such as Vertimills™, IsaMills™ and the stirred media detritor (SMD™) (Lichter and Davey 2002). Other vertical stirred mills have been developed in recent years—in South Africa the Deswik™ mill has been

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**Table II**

<table>
<thead>
<tr>
<th>Association</th>
<th>-10</th>
<th>+10</th>
<th>+25</th>
<th>Combined</th>
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<td>51.3</td>
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<tr>
<td>Attached to BMS</td>
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<td>16.8</td>
<td>10.5</td>
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<td>2.0</td>
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<tr>
<td>Enclosed in silicate</td>
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<td>9.7</td>
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<td>13.6</td>
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**Table III**

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<td></td>
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<tr>
<td>Total</td>
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<td>100.0</td>
<td>100.0</td>
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</tbody>
</table>

*p50 = 50% of the grains are finer than the specific value

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![Figure 2. Schematic flow sheet of the Platinum Merensky plant—pre UFG operations](image)

![Figure 3. Photomicrograph of typical composite particle in the rougher tails stream](image)

![Figure 4. PGM speciation information](image)
PLATINUM IN TRANSFORMATION

introduced in chrome plant arisings and old dump PGM scavenging operations. The use of ceramic and other inert grinding medias, i.e. not steel balls or shot, has added another metallurgical dimension. Fine grinding in an inert media environment is known to have significant beneficial impacts on surface chemistry in flotation. (Pease et al., 2005).

Two opportunities for the metallurgical improvement of the Platinum Mile process in terms of increased mineral liberation were identified: (Gloy and van Staden 2006).

- Metal lost in rougher tailings
- Metal recovered in the rougher concentrate but rejected to cleaner tailings due to the inability of this source to be upgraded to final concentrate grade.

To improve liberation of the material in the final tailings stream, a large plant is required with considerable capital investment. The process risk is further increased by Anglo Platinum optimization and expansion plans upstream at the Waterval and Waterval UG2 concentrator complex, (including the application of finer grinding technology using mainstream inert grinding, (MIG) and fine concentrate regrinding, (UFG), using IsaMills™ technology, (Walstra et al., 2008) which aim to reduce the amount of coarser nonliberated PGM material in the tailings feeding the Platinum Mile operation.

For this reason, the PGMs being lost via the cleaner tailings stream were initially targeted. The tonnage associated with this stream warrants a very much smaller plant with lower capital investment. Furthermore, if the rougher concentrate arisings were processed, the existing cleaner/reclaimer circuits could be utilized, further reducing capital requirements.

Samples of both Merensky and UG2 cleaner tailings were subjected to standard flotation tests with the objective of determining the effect of additional grinding power on PGM recovery (Figure 5). (Knopjes et al., 2008).

For both ore types there is a significant improvement in recovery associated with increasing fineness of grind from approximately 15% with no additional grinding to over 30% recovery.

Laboratory-scale grinding of plant samples, conducted at Mintek, showed that intermediate concentrate regrind showed potential for better yields and higher final product grade. This test work provided the motivation to investigate this on the plant, using a small-scale vertical fine grinding stirred mill. A Deswik 100 litre unit was employed. The results confirmed the earlier laboratory findings. (Schroeder 2006). The conclusions were supported by the findings from widespread Anglo Platinum test work in the laboratory, at the DML pilot plant, and in recent years on-site testing at pilot-scale of UFG on various plant streams at the group concentrator operations.

The pilot plant was configured to treat a blend of Merensky and UG2 flotation cleaner tailings. The tailings were thickened to approximately 45% solids prior to being pumped to a 25 litre Deswik™ mill with an installed power of 30 kW. The mill is a vertical stirred mill operating in a
not dissimilar way to the Metso SMD™. The mill was filled with a 70% ceramic grinding media charge with the media having an SG of 6.2. Thickened feed was pumped into the bottom of the mill and the mill product overflowed through retaining screens at the top of the mill. The mill product was then pumped to the head of a flotation plant which comprised 3 conditioners and 2 x 400 litre flotation cells.

The pilot-plant results confirmed that there was significant potential for enhanced metallurgical performance in terms of recovery and concentrate grade with the introduction of a fine grinding stage of the cleaner tailings.

However, practically, the introduction of a regrind stage for cleaner tailings would require additional flotation equipment to process the milled product—resulting in significant capital cost, possibly affecting the feasibility of the project.

To minimize capital outlay, consideration was given to either treatment of the rougher concentrates or cleaner feed (which comprises rougher concentrate combined with re-cleaner tailings) as this would allow for the processing of the milled product through the existing cleaner/recleaner flotation circuits.

Anglo Platinum had previously evaluated a 335 kW Metso Stirred Mill Detritor (SMD™) at its Amandelbult operations and this unit was offered to Platinum Mile for evaluation purposes on the basis that Anglo Platinum would obtain access to the generated technical data. This arrangement between the two companies allowed for Platinum Mile to achieve early additional production benefits as well as operational experience, and allowed Anglo Platinum to gain valuable commercial scale information on the liberation and subsequent flotation response of finely ground concentrates—a technology which Anglo Platinum is implementing currently on its own operations. In addition, the opportunity is provided for the comparison of performance of the SMD™ unit relative to other fine grinding equipment alternatives available on the open market.

Platinum Mile Resources and Anglo Platinum agreed, in the terms of the existing contract, to proceed with the installation of a full-scale commercial UFG unit. Anglo Platinum loaned an available 355 kW Metso SMD™ unit, thus allowing the plant to be constructed quickly—commercial operation was achieved within 9 months of the go-ahead decision. The plant required the installation of feed preparation thickener pumps and the wraparound circuit and modifications to the existing plant.

### The post SMD and flotation column Platinum Mile operations

The Metso SMD™ circuit was commissioned quickly and began operations in August 2007. The impact on the circuit was immediate. The unit was added to the circuit, initially treating thickened cleaner concentrate, and within a month was reconfigured to treat Merensky circuit rougher concentrate, (Figure 6).

During the period to date, much progress has been achieved in terms of stable and consistent operation of the SMD™ unit and the main operating parameters may be summarized as per Table IV.

Further development work is ongoing with respect to the SMD™ unit, specifically in terms of media development where, it is believed, additional benefits may be attainable.

<table>
<thead>
<tr>
<th>Operating parameter</th>
<th>SMD™ operating parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>Tons per hour Up to 35</td>
</tr>
<tr>
<td>SMD power draw</td>
<td>kW 310 to 315</td>
</tr>
<tr>
<td>Media capacity</td>
<td>Tons 6 (3.6 m³)</td>
</tr>
<tr>
<td>Media size</td>
<td>mm 4</td>
</tr>
<tr>
<td>Media SG</td>
<td>2.7</td>
</tr>
<tr>
<td>Feed density</td>
<td>t/m³ 1.5</td>
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<tr>
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<tr>
<td>Product d80</td>
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</table>

![Figure 6. Application of the SMD™ circuit to the Platinum Mile plant circuits](image-url)
with the use of a higher density media, which could potentially provide increased throughput and/or a finer mesh of grind.

During the initial month of operation of the SMD™, significant improvements in final concentrate grade in excess of that historically achieved were attained. However, there were limitations in respect of thickener capacity in terms of achieving satisfactory underflow densities and this provided constraints in terms of tonnage throughput.

With the application of the UFG using the SMD™ in processing the Merensky rougher concentrate stream, there was a minor reduction in both the PGM recovery and the final PGM concentrate grade produced. Consideration was given to regrinding a proportion of the rougher tailings to provide additional liberation and potentially increase overall recovery. This is actually a partial ‘MIG’ circuit – the Merensky rougher tail is cycloned to extract a small volume of tails, which is added to the UFG feed thickener. This was implemented earlier this year with further benefit to overall plant results both in terms of increased recovery and improved concentrate grade. Since February this year, recovery has more than doubled relative to early 2007 and the concentrate grade has increased by 170%.

One side effect of UFG on rougher concentrates floated from a high UG2 flotation feed is the entrainment and flotation of chromite spinel. The data shown in Table I earlier in the paper is for a 2006 Merensky circuit feed with a Cr₂O₃ of 6.5%—this tenor has subsequently increased during 2007 and 2008. With high Cr₂O₃ in plant feeds, the chromite in rougher concentrates can reach values as high as 10%. The UFG process thus grinds the chromite spinel finer—leading to increased entrainment and capture during the cleaner and reclaimer flotation steps following the UFG circuit. The net result is higher chromite tenors in final products and consequential increases in financial penalties according to the smelting contract terms. Conventional PGM furnace operations do not want high chromite levels in feedstock and hence impose punitive financial penalties to third party concentrates.

Due to the trend of increasing UG2 in the Merensky stream and the imminent future UG2 stream rougher UFG application, a need to develop a technical solution to an increasing chromite entrainment scenario was initiated/discussed. Historically chromite entrainment and deportment to smelting in the PGM industry has been addressed by a number of actions:

- Removal of chromite utilizing gravity separation equipment—in plant practice a spiral plant installed between the primary and secondary grind/flotation circuits in a typical UG2 MF2 or mill-float-mill-float, concentrator operation; (practised, for example, at Ivan and Mortimer concentrators historically)
- Split regrinding operations in an MF2 circuit—employing silicate and chromite streams; the chromite circuit employs a coarser grind—normally an open circuit ball mill; current standard flowsheet design for Anglo Platinum UG2 concentrators
- Mixed ore processing—lower Cr₂O₃ in plant feed leads to lower flotation tenors; not generally done by design in the industry but as a consequence of the inability to process separately
- Column flotation—utilizing the more selective operating conditions of column flotation in concentrate cleaning; as practised in recent years at Northam’s UG2 plant (Minnaar et al., 2004)
- The practice of ‘dilution’ where mass pulls from Merensky processing are operated at higher levels to dilute UG2 concentrates at lower mass pulls, thus enabling percentage Cr₂O₃ levels below a defined critical ceiling value in the particular smelting furnace operation feedstock; practised historically by Impala Rustenburg operations
- Breaking the converter-furnace recycle cycle—converter slag is not returned to the furnace operation but either processed in a milling and flotation plant after granulation or sent to slag cleaning furnaces prior to milling and flotation for the recovery of value metals; practised at both Impala and Anglo Platinum smelter operations in recent years.

There has been much historical work in the area of column flotation for this purpose. In the early 1990s it had been demonstrated on plant scale at Impala’s main plant during a circuit optimization programme that a hybrid circuit employing mechanical and column flotation technology offered a potential improvement in this chromite management-PGMs recovery optimization dilemma (the author was involved in this work).

However, in recent years the technology has been installed at Northam UG2 Concentrator and has proven to be very effective in managing the problem and maintaining good PGM recovery and product grades (Minnaar, et al., 2004).
Platinum Mile made the decision to pursue the column flotation route and by May 2008 had commissioned a single final concentrate re-releaning column treating all final products from the Merensky and UG2 streams in the Platinum Mile plant.

The first month’s results vindicated this decision as the combination of grade increase and better management of the chromite entrainment has resulted in a dramatic reduction in chromite tonnes to the smelter—a reduction to approximately one-third of the average levels achieved since the SMD was installed in August 2007.

Optimization of the mass pull, chromite levels and PGM yield is currently underway within the contractual financial environment.

**Conclusion**

The SMD™ unit has exceeded the initial design criterion and has confirmed that the application of fine grinding technology, UFG, will adequately address issues associated with liberation and selectivity—both in terms of improved concentrate grade as well as enhanced metal recovery.

Based on this work, a decision was made to increase the fine grinding capacity of the Platinum Mile operation even further and the additional grinding units are planned to be commissioned during the third quarter of 2008. Two Deswik™ 2000 litre vertical stirred mills, equipped with twin 350 kW fluid drives are being installed currently. This increased milling capacity will allow for the introduction of increased selective fine grinding of the coarser fraction of the main slurry stream—leading to enhanced liberation of this important contributor to platinum group metal loss within this circuit.

To address an increasing UG2 proportion in feed and hence increasing chromite entrainment potential, especially with the implementation of UFG fine grinding on all rougher concentrates; column flotation technology has been successfully introduced and initial results have been extremely promising.

Overall the project and operations to date have demonstrated that common benefits to both parties are achievable by working together to rapidly introduce new technology aimed at improving the operations of the Platinum Mile tailings scavenging plant.

**References**


Chris Rule

*Head of Concentrator Technology, Anglo Platinum*

28 years in the PGM industry in Southern Africa. Held senior positions in operations, project execution, technical support and process and technology development for various companies including Impala Platinum, Genmin, BHP and Anglo Platinum. Currently, Head of Concentrator Technology at Anglo Platinum; responsible for the technical support to operations, technology development and process engineering functions for the group Concentrators. Director of Masa Chrome.