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STIRRED MILLING AT ANGLO AMERICAN PLATINUM

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ABSTRACT

This paper tells the story of the rapid commercial application of stirred milling technology at Anglo American Platinum's many Concentrators. The first stirred mill – a 10 000 litre IsaMill™, the largest at the time, was commissioned in late 2003. The project development work was presented at SAG 2001. This operation was “proof of concept” and vindicated the decision to scale up the technology; allowing a rapid and extensive roll-out of mainstream regrind mills as well as several further flotation concentrate regrind mills, over the next six years.

Currently 23 stirred mills are in operation with 64 MW of installed drive capacity – this paper describes the projects' roll-out and the significant results achieved to date. Many operational problems have been solved along the way, some of these will be described. The introduction of the technology has seen a step change in metallurgical results and progressively decreasing operating costs.

KEYWORDS

Process Mineralogy, PGM, Liberation, Plant Optimisation; UG2 reef, Merensky reef; Platreef; Stirred milling; Mainstream Inert grinding, MIG; Ultra Fine Grinding - UFG , Fine Grinding - FG

INTRODUCTION

The ore profile being mined at Anglo American Platinum has changed dramatically in the last two decades. Concurrently the production of PGMs has grown markedly. The ore sources have changed from being wholly based on the Merensky reef, in the 1980s, to the current split where UG2 makes up over 50% of ore treated in the fourteen managed Concentrator plants and is forecast at 16.7 million tonnes for 2011. Platreef at just under 11 million tonnes now ranks second with Merensky now only 4.5 million tonnes; total ore processed including other surface material is in excess of 41 million tonnes for 2011. See figure 1, which shows the profile change in the last 10 years.

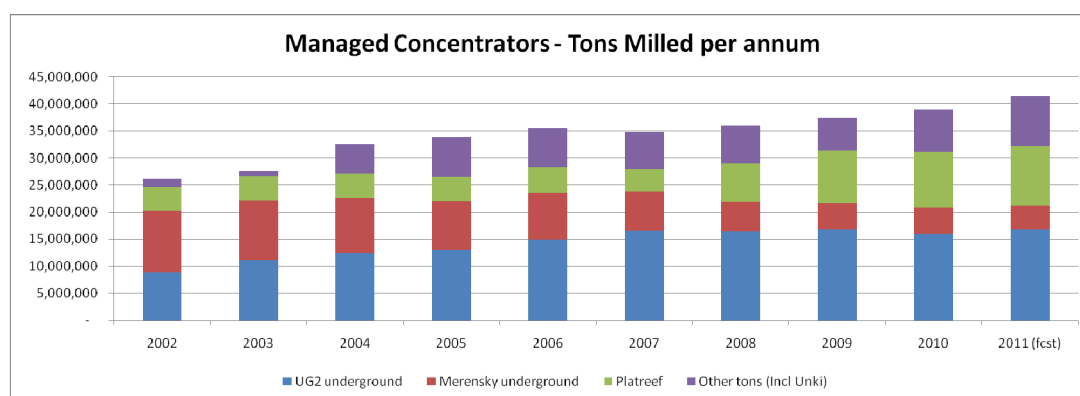


Figure 1: Ore milled over the last 10 years at Anglo American Platinum Managed Concentrators

The ore types have very different mineralogical characters which largely determine the metal extraction efficiencies. Unfortunately, the UG2 and Platreef are more mineralogically complex. They have smaller sized PGMs minerals and increasingly higher dissociation of PGM minerals from the larger and hence more easily floatable sulphide minerals; chalcopyrite, pentlandite and pyrrhotite. To compound the plant extraction challenge the head grades delivered have declined over the same time period. The

average feed grade has dropped from excess of 5.5 gpt combined PGMs, in 1999; to approximately 3.2 gpt in 2010.

Historically, AAP mining operations were mainly on the western Bushveld complex with the major operations at the Rustenburg, Amandelbult and Union section mining complexes. The Merensky reef mined there delivered grades often in excess of 6 gpt combined PGMs. See figure 2, for the location of the Anglo Platinum mining operations on the Bushveld complex and inset, a diagram of the Great Dyke in Zimbabwe.

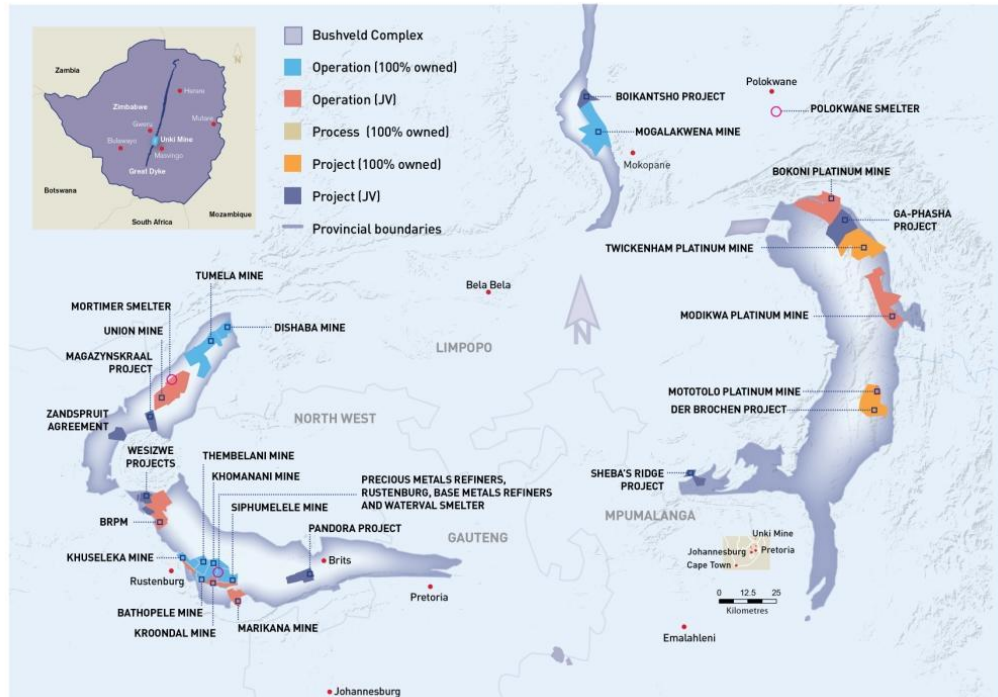


Figure 2: Bushveld Complex – this diagram shows the footprint of Anglo American Platinum’s operations on the Bushveld Complex in the northern provinces of South Africa and on the Great Dyke in Zimbabwe

Process mineralogy was recognized a fundamental capability that was required to facilitate a planned programme to address this declining trend in metals recovery. Investment in Anglo Research’s, (previously Anglo Platinum’s Research mineralogy section); has been considerable. (Schouwstra 2004)

In 2004, AAP’s Concentrator Technology function motivated to have a comprehensive programme for each plant’s monthly composites to be analysed by size fraction and further to submit selected samples to be analysed mineralogically. The volume of mineralogical work for twenty or so plants includes the non managed Concentrators; was enormous, so a priority process selected the reduced submissions for mineralogy. This priority rating was dictated by the plant’s relative ounce contribution and an ongoing assessment of the plant’s operational results at any time.

Anglo American Platinum has always had the capacity and desire to investigate potential beneficial new technologies. Investment in process mineralogy has been made bringing in the latest technology and hardware in the preceding years. The knowledge gained on the orebodies grew in line

with this investment and the intensive exploration programmes on the tenements held by the company on the Bushveld and Great Dyke PGM provinces. Plant troubleshooting studies had already shown the loss profile of the UG2 and Platreef operations was principally due to incomplete liberation and to losses of sub 10 micron liberated PGM minerals. The following illustrations; taken from the monthly composite programme results, illustrates this clearly.

Table 1: Mineralogical association data for typical monthly composites for MF2 UG2 plant samples, size fraction analyses shows potential for further liberation

Association	Feed	Concentrate	Tailings	Tailings -10	Tailings +10	Tailings +53
Liberated	49.2	53.1	31.3	82.3	18.5	2.4
Enclosed in BMS	23.6	15.8	4.7	4.1	9.7	1.8
Attached to BMS	7.9	12.7	0.3	0.4	0.6	-
PGM/BMS/Silicate*	5.6	8.0	7.7	-	5.6	16.5
Enclosed in silicate	7.5	8.4	36.0	2.7	44.3	57.0
Attached to silicate	0.6	2.7	9.3	3.5	13.9	6.8
Enclosed in oxide	4.8	1.3	7.6	4.3	6.0	11.7
Attached to oxide	0.8	-	3.1	2.7	1.4	5.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Middlings	7.2	14.8	7.0	8.3	14.8	-
Locked	43.6	32.1	61.7	9.4	66.7	97.6

*PGM/BMS/silicate associated refers to PGM particles which are associated with BMS which are then in turn associated with silicates.

Table 1 shows the potential for further grinding clearly, with the majority of losses of PGMs due to incomplete liberation, both locked and middlings particles in both the +10 micron and especially in the +53 micron fractions. The following illustrations shows the incomplete liberation in tabular form and in the false colour two dimensional images sourced from the MLA analyser.

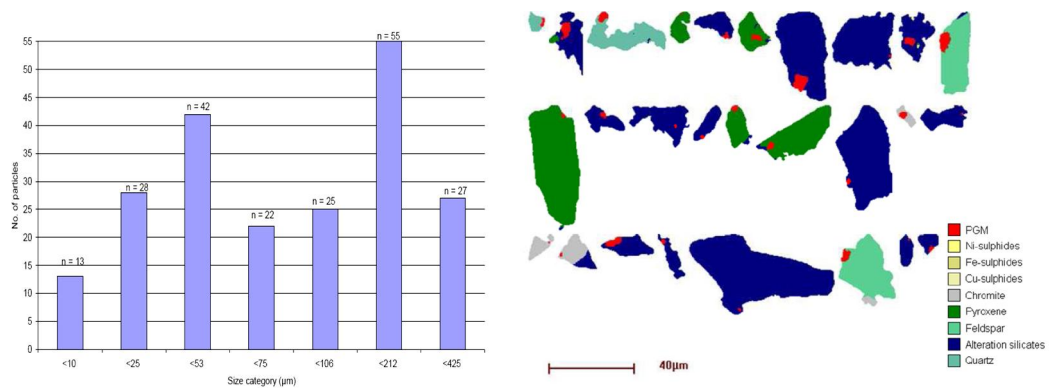


Figure 3: Number of composite particles containing PGMs by size fraction in a typical UG2 tailings sample. Particle map (false colour), showing the association of PGMs, (red), with mainly gangue minerals in a final tailing sample analysed from the plant composite programme

A history for each plant is built up for the sampled streams; in table 2 the average PGM liberation in tailings is seen at low levels of 20-35% and generally these are in the sub 10 micron fraction which are more difficult to float.

Clearly then an economic comminution technology that could improve PGM particle liberation economically and without generating large amounts of “super-fines” would potentially be a key to reaching much higher PGM recoveries. Stirred milling potentially was that technology.

Table 2: Typical UG2 Concentrator monthly composite plant tailings data – assay and mineralogy

	February 2008	December 2008	February 2009	December 2009	February 2010
Grade (4E) (g/t)	0.9	1.0	1.0	0.9	0.7
Tailings d50 (µm)	50	63	47	38	57
Alt. silicate (mass %)	2.4	2.5	3.3	3.3	2.1
BMS liberation (%)	56	60	59	72	69
PGM liberation (%)	24	27	33	33	24
PGM lib (%)>10µm	82	97	78	90	92

At the beginning of 2000, with the recent commercial availability of IsaMill™ stirred mill technology; a 4 litre bench scale mill was assessed at AAP’s research and development facilities along with other vertical stirred milling technology units. The three primary requirements for further regrinding in the PGM circuits were:

- Due to mainstream tonnages a large stirred mill was targeted; at that time the largest mills available were 1.1 MW 3000 litre for the IsaMill™ technology and for vertical stirred milling the 355 kW SMD. Multiple small units were not favoured,
- Inert or non steel media grinding was the preference due to potential surface chemistry and slurry chemistry issues with iron hydroxide precipitation and coatings on value minerals,
- The technology should be energy efficient and obviously must be economically viable with an expected recovery improvement potential of a further 2-5% PGM recovery.

Promising results lead to acquisition of larger units that could be used in pilot plant studies. Results at pilot scale led to the decision to use IsaMill™ technology in the new tailings re-treatment project, “WLTR” project, near Rustenburg. [5] The significant scale up decision, from a 3000 litre unit to a 10000 litre unit was made at that time by the author, thus facilitating the economic use of the technology for future mainstream applications and once a suitable ceramic media had been identified or developed. The initial mill was developed in a three party collaboration with Netzsch Feinmetall GmbH and Xstrata Technology; then known as MIM Technology. To mitigate the scale up risk a variable speed drive was chosen – the drive train was 2.6 MW due to the initial media being locally mined crushed and 2-5mm, screened silica sand

THE ISAMILL™ TECHNOLOGY ROLL-OUT PROGRAMME

The circuit applications identified as being the optimal circuit interventions are illustrated in the following block flow sheets, figure 4 and figure 5. The mainstream application – given the name “MIG” or mainstream inert grinding was added on regrind ball mill product ahead of scavenger rougher flotation; resulting in better mainstream PGM extraction. The “UFG” or ultra fine grinding application was targeted at modifying the typical plant grade/recovery relationships in the cleaning circuits for the mainstream flotation products and results in better product grades and higher circuit PGM recovery by regrinding composites and applying intensive surface attritioning. The two acronyms were created to prevent confusion and recognized the essential features; MIG - inert grinding using non steel media in mainstream applications, typically targeting 80% -53 micron products and UFG, concentrate regrind targeting 80% less than 20 microns. It would be more correct to call this application “FG” or fine grinding to differentiate from the very fine regrinding targeting products that are sub 10 micron common in lead/zinc production and in leaching applications.

This typical PGM Concentrator, “MF2” flow sheet shown in figure 4, incorporating the stirred milling technology is applicable to the Platreef and Merensky plant circuits.

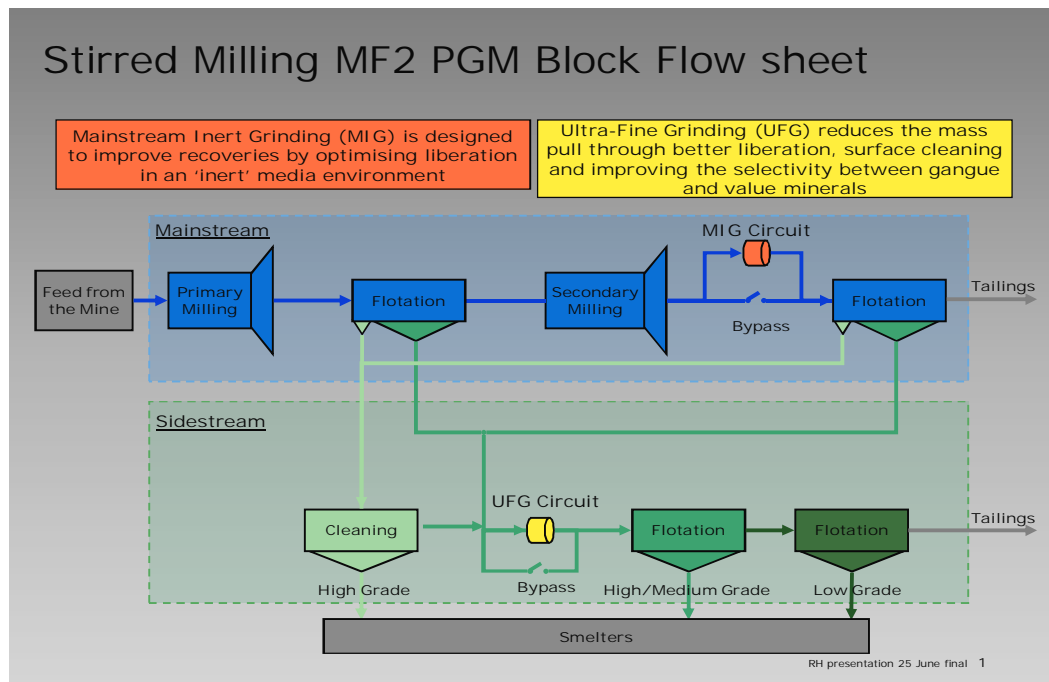


Figure 4: Process flow diagram of the application of stirred milling as 1) mainstream or MIG and 2) concentrate regrind or UFG is a typical PGM industry stage grinding and flotation, or MF2, circuit

For UG2 reef, due to its essentially bimodal form – a mix of silicate minerals and chrome spinel minerals in the chromitite reef; a variant of this MF2 circuit had been developed. The new circuit applied MIG stirred milling technology in the split regrind circuit. The primary rougher flotation tailings are split with a hydrocyclone cluster prior to further processing. This produces two streams; an underflow rich in higher specific gravity and coarse chromite spinel and the overflow enriched in lower specific gravity silicates and fines. The majority of PGMs follow the silicates; their occurrence in the in-situ ore is predominantly in the silicate minerals in between the chromite spinel crystals. Either the MIG IsaMill™ follows a regrind ball mill or it treats the cyclone overflow stream directly; dependant on the available milling units at the plant.

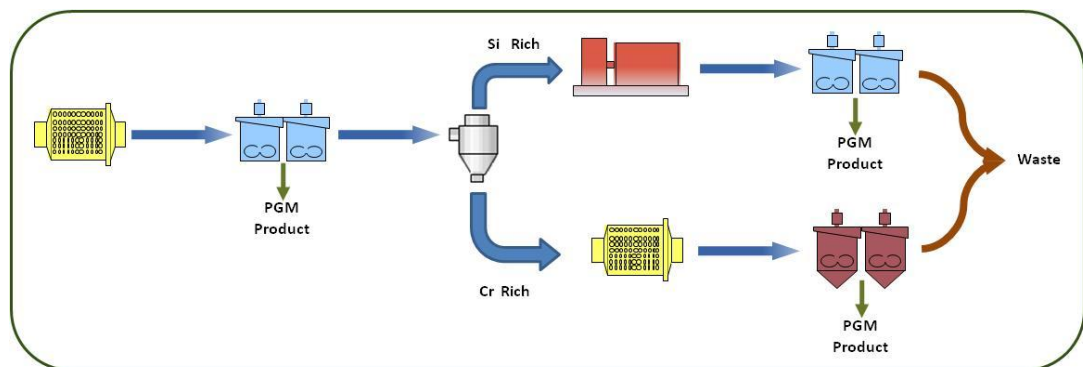


Figure 5: Process flow diagram for a split regrind MF2 circuit for UG2 ore treatment – shows the MIG IsaMill™ on the cyclone overflow and the open circuit ball mill on the cyclone underflow

The adoption of IsaMill™ stirred milling was a relatively fast adoption of a new technology. Key steps in this process can be listed:

- 2000/2001; scoping work carried out at AAP research facilities, “ARC”, at Germiston, east of Johannesburg and at the operational support centre, “DML” and pilot plant at Rustenburg. The pilot studies confirmed the potential for both mainstream stirred milling, “MIG” and concentrate regrind, “UFG” in mainstream flotation product cleaning,
- 2001; decision taken to use IsaMill™ stirred milling technology and to develop the first M10000 litre unit; development within a tripartite collaboration with Xstrata Technology, (then known as Mt Isa Mines Technology) and Netzsch Feinmetal GmbH. Key was the choice of scaled up unit; this was to allow future mainstream applications to be realized. Silica sand chosen as the grinding media in the absence of a proven ceramic media.
- 2001/2003; inclusion of UFG concentrate regrind M10000 IsaMill™ with variable speed 2.6 MW drive to mitigate design scale-up inaccuracy; in the tailings retreatment project, WLTR; at Rustenburg. Successfully commissioned in early 2004; proof of concept established. (Buys *et al.* 2004)

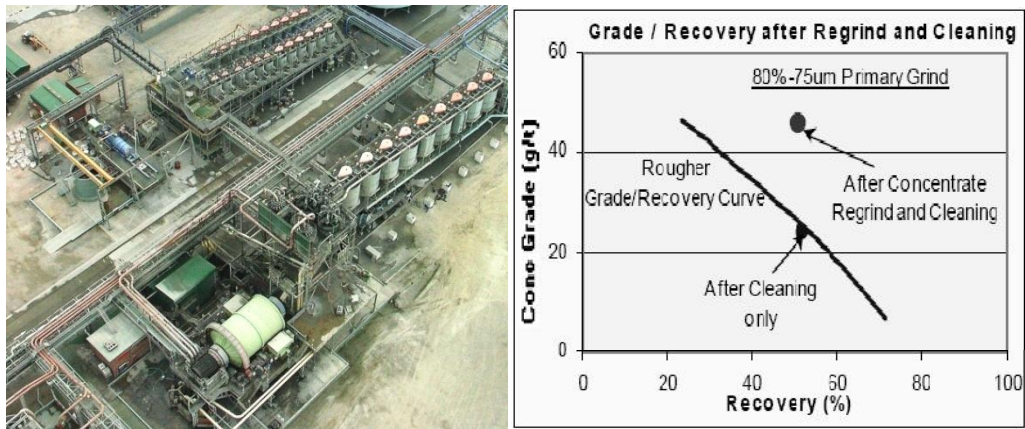


Figure 6: Aerial photograph showing the WLTR site and a graph showing the change in PGM grade/recovery potential by applying UFG stirred milling of mainstream flotation concentrates

- 2004/2005; initiation of a comprehensive off-site and on-site pilot programme with on-site piloting of various stream feeds using a M20 IsaMill™ unit and associated “FCTR” mini flotation rig. Initiation of the routine monthly composite plant sample programme. Fractional analyses and mineralogical analyses on plant feeds, plant flotation product and plant tailings. Realization of the economic viability and then definition of the priority for establishment of a wide scale roll-out of IsaMill™ technology for both mainstream MIG and concentrate regrind UFG applications at major AAP Concentrators. Identification of an economically viable ceramic grinding media for MIG applications. (Rule *et al.*, 2008)



Figure 7: Photographs of the test rig used to evaluate the potential of stirred milling – shown here at Mogalakwena South Concentrator in late 2004

- 2005/2006; the initiation of the ceramic media development programme. Silica sand, furnace slag and other natural medias could not be used in MIG applications due to the relative hardness of the ore and media. With the approval of the first MIG project at Mogalakwena South; the approving AAP body required that a multi-media ceramic supply base be put in place for the technology.



Figure 8: Grinding media used in IsaMill™ applications; in the left hand side photograph samples of furnace slag ex Mt Isa, Colorado River sand, screened ore particles and steel shot and in the right hand side photograph two samples of ceramic media

This was achieved by setting up a testing facility which included utilising both the 4 litre and 100 litre IsaMills at the Divisional Metallurgical Laboratory operational support facility in Rustenburg. A comprehensive test programme was established to allow assessment of the ceramic medias available in the world market. Simultaneously major suppliers were contacted and engaged with. Later in 2007, further QA/QC capability was established in order that ceramic media deliveries could be checked for adherence to specification. The programme to date has tested some 200 different medias from all the major ceramic media manufacturers and has led to the development of several improved formulations with various suppliers. A ceramic media manufacturing facility in South Africa was established by a third party in 2007. This proactive involvement has led to significant operating costs benefits and indeed the media consumable cost on a US\$ per kWhr consumed by the IsaMills has dropped by more than 2/3^{rds} from 2008 to 2011. (Bedesi et al, 2008)

- 2006; commissioning of the first mainstream or MIG IsaMill™ at Mogalakwena South Concentrator – C section project utilizing a 3MW M10000 unit; note the use of higher specific gravity media resulted in increase in drive train capacity. This mill installation proved the MIG concept was a workable technology and removed any risk constraint for the full roll-out of the technology throughout AAP operations.

- 2007/2008/2009; motivation, approval for execution and installation of a further 20 IsaMill™ units in MIG, (17 M1000 units) and UFG, (3 units, 2 M1000 and 1 M3000) duties at Bafokeng Rasimone, Waterval UG2, Waterval, Amandelbult Merensky, Amandelbult UG2 #1 and UG2 #2, Mogalakwena South A and B and Mogalakwena North Concentrators; (Rule *et al.* 2010)



Figure 9: IsaMill™ layout photographs, Waterval UG2, Amandelbult UG2#2 and Waterval Concentrators

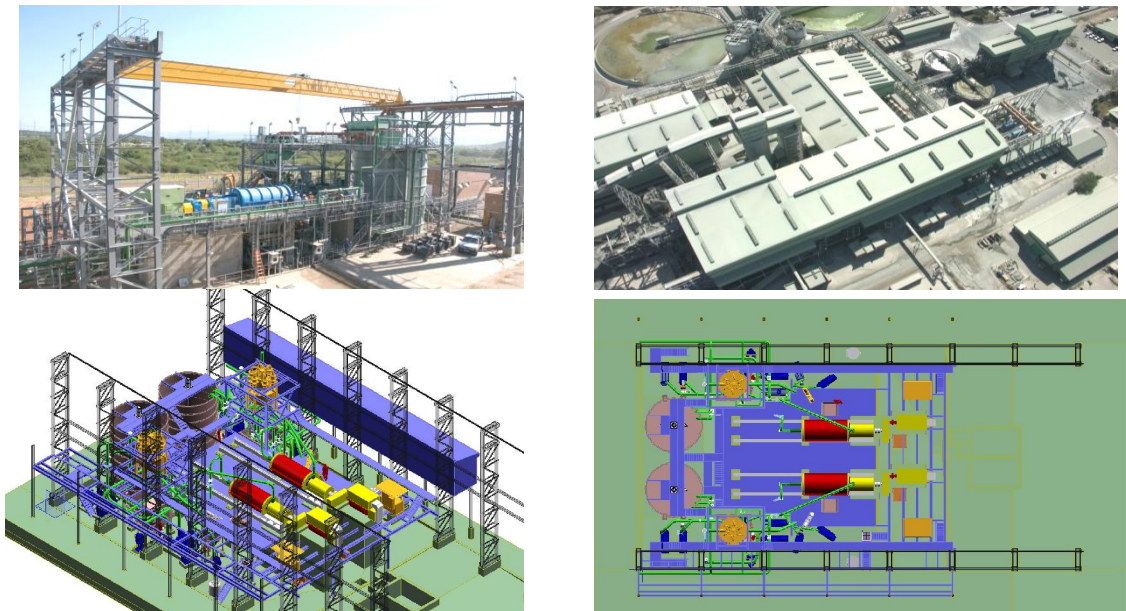


Figure 10: MIG installations at Bafokeng Rasimone, top left, shows the typical “wrap around” equipment in the circuit and on top the right hand side; Mogalakwena South Concentrator; A and B mills installed on far left hand side. Below these are the model drawings for A and B section IsaMills

OPERATING EXPERIENCE DURING THE EARLY PERIOD

There were remarkably few problems with the first M10000 installed at the WLTR Project in 2003. The scale up resulted in operational performance that was almost exactly as predicted; hence the variable speed drive unit is/was seldom utilized. Test work for future MIG application on tailings material in 2008 to 2010 was conducted and some work was done at variable speed regimes with varying media loads etc.

Following the first MIG milling application start up of the Mogalakwena C section mill in late 2006; the success resulted in the rapid approval of the next four MIG mills, two each at Mogalakwena South; A and B and at Waterval UG2 with commissioning by the end of 2007.

A major difficulty identified initially was the management of the position of the media load. Variability in mill feed volume and slurry density resulted in incidents of media compression at low flows and media loss at high flows. The media compression incidents resulted in the early modification of the internal wear discs configuration, with the disc in position 1, i.e. nearest the feed inlet; being removed totally, effectively creating a larger first milling compartment. Modifications to the dimensions of the feed end discs have been made with reduced diameter discs being successfully trialled. Too high feed slurry flows result in significant media loss – seen visually downstream and also measured in higher than expected media losses.

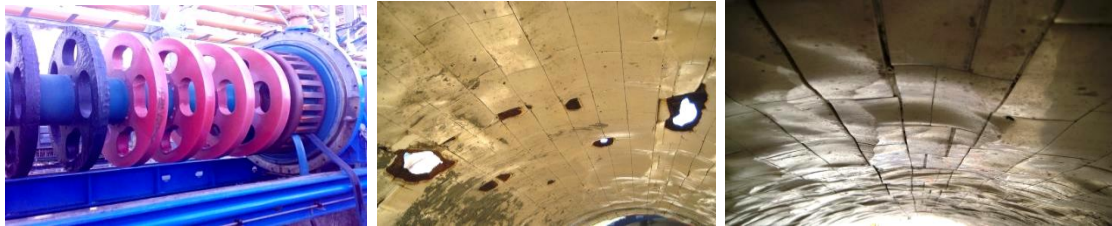


Figure 11: Photographs of grinding discs made of different rubber compounds and experimental ceramic tile shell liners after use

A number of materials of construction test runs have been conducted; figure 10 shows the mill internals of an M10000 and some ceramic shell liners using tiles that were unsuccessfully trialled.

A summary of issues that have been addressed to date between 2008 and 2009 follows:

- i) an inordinate number of drive train bearing over temperature trips were encountered on some of the mills – the bearing lubrication system was modified to a circulated/cooled oil rather than grease based system, before the modifications were completed the mills were run at lower power levels to reduce mill stoppage events
- ii) The incidence of damage from tramp material became a very significant cost and operating downtime issue for the MIG installations particularly from the middle of 2008; this included premature severe damage to internals from repeated ingress of steel ball fragments, nuts and bolts, ceramic wear tiles, (from upstream launders/still boxes etc) and coarse oversize excursions from upstream ball mills ahead of the IsaMill™.

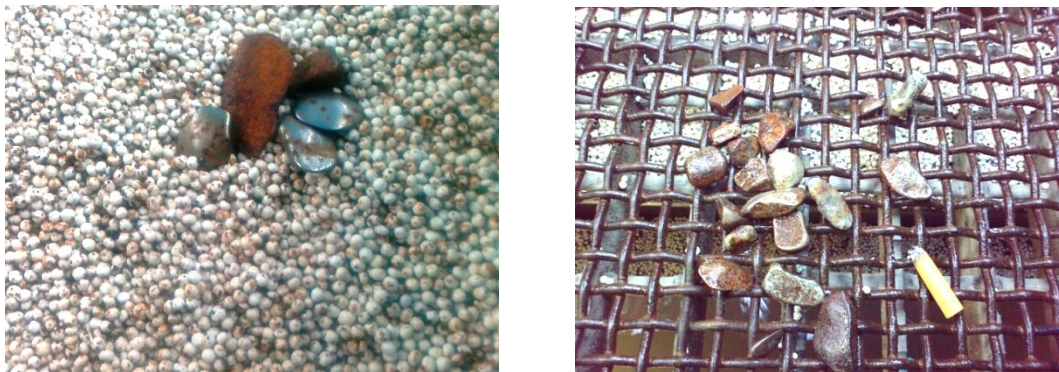


Figure 12: Photographs showing metal steel ball scats and “rust” on surface of some of the 3.5mm top size media in the dumped mill media and resting on the grating below the mill – damage to the rubber and polyurethane wear parts in the mill was severe and rapid!

- iii) At times poor judgement on the wear life of grinding discs led to disc collapse and severe damage to mill internals from the broken pieces.

Whilst these problems were analysed the MIG mills especially were run at lower loads and in the extreme case where multiple internal damage incidents occurred the mills were taken off-line at Waterval UG2 for 6 months at the end of 2008.

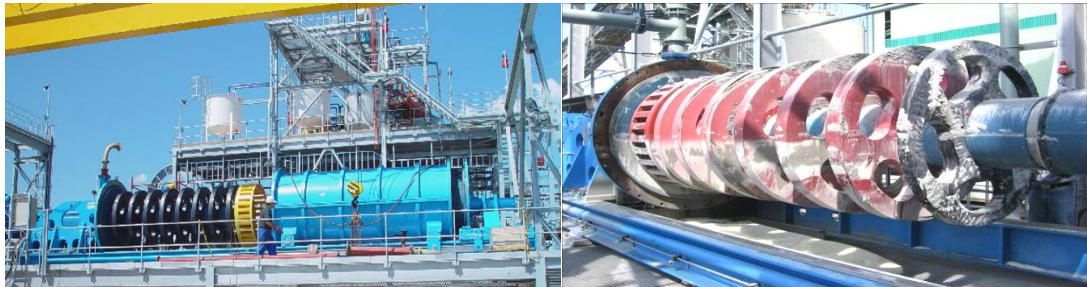


Figure 13: Internals of the IsaMill™, shows the grinding discs and separator with mill shell pulled back on the sliding rails – access position during maintenance

A rapid identification of root cause and development of solutions phase followed and in 2009 when the next 16 mills were commissioned the design fixes were auctioned during the installation and before commissioning; fixes were actioned including to the first 6 mills which were taken offline for modifications:

- a) Media position within the mill was controlled by modifying the existing slurry recycle stream allowing fixed volume flow set-point to be implemented in the control system; slurry density was controlled by optimizing the cyclone parameters upstream and optimization of the IsaMill™ feed circuit surge tank buffer control system, the 7 disc configuration was retained,
- b) A linear screen was installed on the circuit feed system ahead of the surge tank feeding the mill density controlling cyclone clusters – a physical barrier to oversize material greater than 2 mm was thus imposed on the circuit. An interesting finding during the analyses exercise at one of the sites was the occurrence of copious fragments of steel in the mill contents – this was discerned from analyses of the dumped media where “rusting” as well as large fragments “spalled” from the steel ball charge of the primary mill was seen. How large fragments >20mm were able to pass through the upstream primary circuit closing vibrating screens with decks panels of 850 microns aperture, travel through the primary rougher flotation and then enter the MIG IsaMill™ circuit via the densifying cyclone cluster fed from the surge tank pumps begs the question around operating and maintenance vigilance and control!
- c) Where ore quality processed varied another issue was apparent and is shown in the two photographs following, figure 14. The Mogalakwena South Concentrator occasionally treats extremely hard ore and during these periods the grind coarsens appreciably – exceeding the capacity of the FAG and ball mills ahead of the two A and B MIG IsaMills to provide a fine enough feed. Critical size build up results! The problem has been addressed by bringing back into the circuit the two redundant tertiary ball mills which now provide a further comminution step ahead of the MIGs.

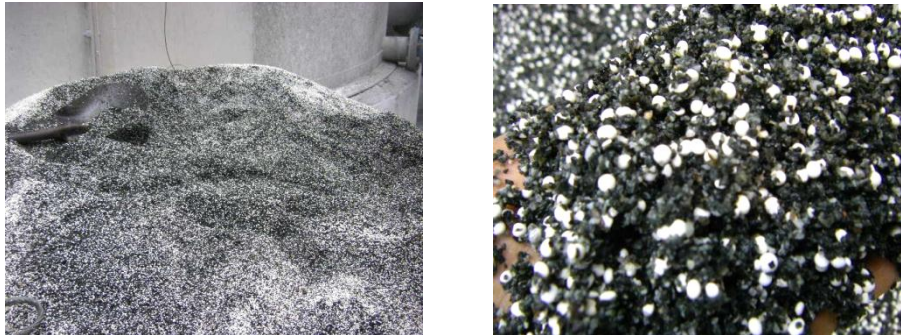


Figure 14: Photographs show severe critical size build up in the IsaMill™ at Mogalakwena South A and B sections; the media is white and the coarse feed particles are generally dark coloured

- d) Further more rigid operating recipe driven operation was rolled out across the sites – resulting in tighter control over all circuit parameters not just those impacting on “spikes” in volume and density flow through the circuit. A higher level of operating behaviour is now common place throughout the group Concentrators with benefits seen performance in all unit processes.
- e) The application of a comprehensive data collection from both the DCS system, remotely, to the group control centre in Rustenburg and maintenance supervision programme on all mills was put in place; data on media consumption and stock levels is also collated and reported. This comprehensive data set and reports has prevented the incidence of wear failures to be almost eliminated by 2010. A monthly report is generated to all sites and support personnel and in parallel the routine wear data is collected at each maintenance stop for all mills and analysed and reported co-currently. Note all the wear supervision is completed by Xstrata Technology personnel and is used routinely and for testing for mill component and circuit optimization

OPERATING RESULTS

The change in performance post MIG IsaMilling is well illustrated at the Mogalakwena South Concentrator, Waterval Concentrators and the Amandelbult Concentrators; the post commissioning period results at the Rustenburg and Amandelbult sites have been significantly better than predicted.

The initial evaluation for the Mogalakwena South Concentrator comparing the results post commissioning of AAP’s first MIG IsaMill™ on the “C” section ore processing line against the A and B section ore processing lines led to the rapid approval of further MIG mills at Waterval UG2 and for “A” and “B” sections. The statistical analyses conducted on the pre and post commissioning period concluded a PGM delta recovery increase of between 3.5 and 4%; due to MIG stirred milling in the mainstream circuit, refer figure 15.

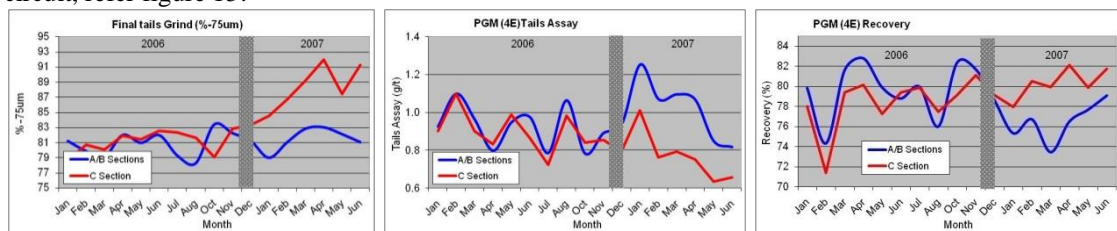


Figure 15: Results from Mogalakwena South after commissioning of the first MIG mill on “C” section compared to the other two lines, “A” and “B” operating with MIG IsaMilling – statistical analyses showed a 3-4% delta recovery improvement for the technology

Further assessment of the UG2 ore impact at the Waterval UG2 plant post commissioning in 2007 and through the early part of 2008 led to approval for the roll-out of the next phase of the technology's application on UG2 and Merensky/UG2 mixed ore Concentrators – taking the IsaMill™ fleet deployed to 22 units and 64 MW of installed drive train installed power.

Rustenburg and Amandelbult mining operations are AAP's biggest production units with roughly 2/3^{rds} of the 2010 total managed Concentrators' platinum output of 1.7 million troy ounces. Roughly 2/3^{rds} of the mined and processed tonnage in 2010, 10 million tonnes; was sourced from the UG2 reef.

Total site recovery at Waterval and Amandelbult - Pt %

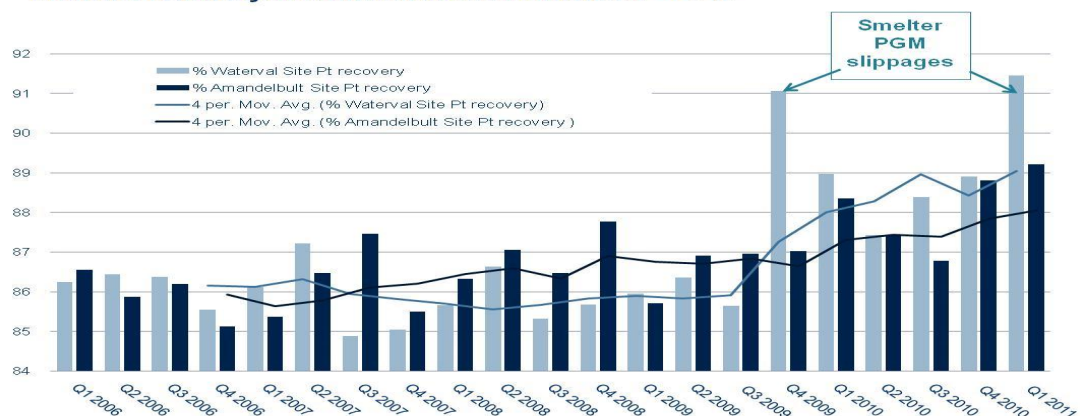


Figure 16: Waterval and Amandelbult Concentrator sites – platinum recovery including tailings scavenging operations, quarterly Q1 2006 to Q1 2011 MIG IsaMill™ commissioning 2Q to 4Q 2009

Figure 16 shows the impact on metals recovery since the commissioning period – an upward trend at both sites for platinum recovery. Tailings flotation scavenging achieves further metal recovery by allowing a lower grade product to be extracted from each site's combined tailings; before disposal to surface tailings dams.

Analyses of the performance of the two UG2 plants at Amandelbult shows the reduction in tailings grades from the two plants over time; the dramatic step reduction since MIG IsaMill™ commissioning stands out. Tailings grades are now at the lowest levels since Amandelbult mining operations began in the 1970s.

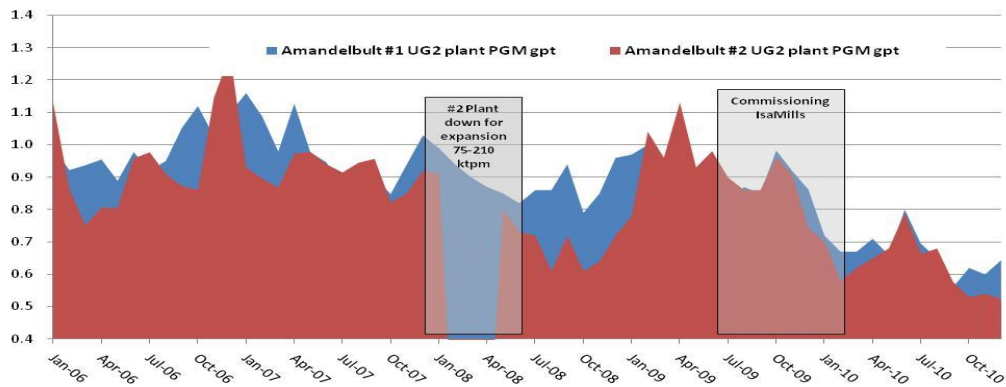


Figure 17: Comparison of the tailings values for the two Amandelbult UG2 Concentrators from 2006 to 2010; MIG IsaMills were commissioned in mid 2009 – a step change occurred with lowest ever tailings grades being achieved since the beginning of 2010

The graph shown in Figure 16 shows the comparison of PGM recovery values achieved for UG2 processing at the two mining sites at Amandelbult and its neighbour Union, some 30 kilometres away. Historically PGM metal recoveries at the Mortimer UG2 plant at Union have always been similar to that achieved at Amandelbult and averages around 80-82% extraction of PGMs. Since MIG IsaMill™ commissioning a strong divergent and upward trend is seen for the Amandelbult operation.

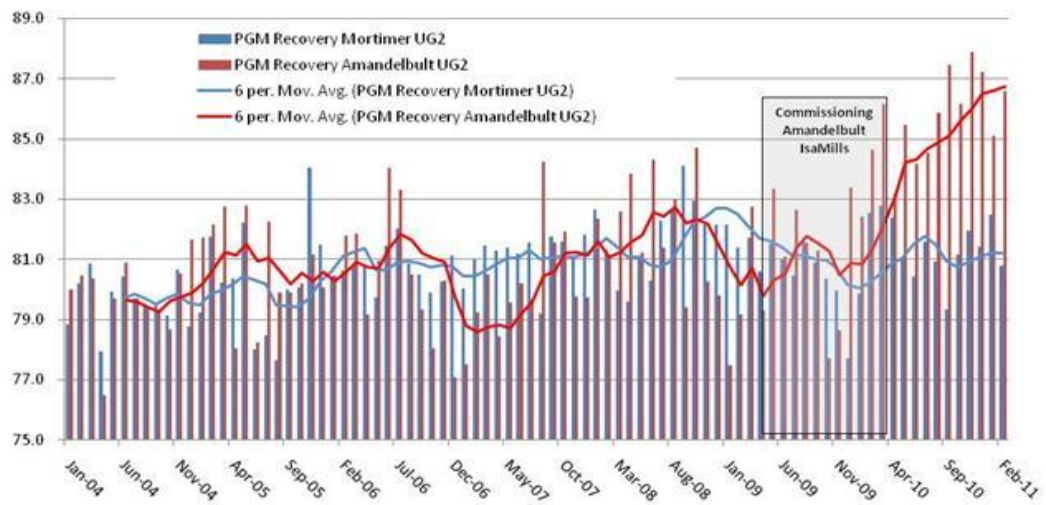


Figure 16: PGM recovery for the two UG2 Concentrator operations of the Amandelbult and Union mining operations – these were historically similar but post MIG commissioning at Amandelbult performance is now significantly superior

CONCLUSIONS

The journey to fully install stirred milling technology in AAP's Concentrator operations represents a very fast introduction of a new technology, by industry standards.

The economics of the recovery improvement potential at the plants is an overwhelming proposition due to the increasing value, with time, of the contained metal in the ROM ore. This justifies the level of investment in process mineralogy and a new comminution technology already made and continuing to be made at Anglo American Platinum. To illustrate this it is a sobering fact that an improvement of 1% in PGM recovery in the Concentrators at Anglo American Platinum is equivalent to >75 million US\$ for each year at today's metal prices and exchange rates.

Currently, further stirred mill installations are being motivated. Test work and circuit analyses has identified that further upside potential at existing operations remains to be achieved as the operations are optimised further.

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