The development of ultra-fine grinding at Anglo Platinum

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Synopsis

Ongoing development work on ultra-fine grinding for various applications at the Group's concentrators has been conducted by Anglo Platinum over the last few years. Current potential applications for mainstream grinding and concentrate grinding are the subject of a group-wide research and development programme.

The first 10 000-litre 2.6 MW IsaMill was jointly developed by Anglo Platinum, Xstrata Technology and Netszch for installation at the Western Limb Tailings Re-treatment project in Rustenburg, South Africa. The unit was commissioned in late 2003/early 2004, and has operated in an intermediate concentrate regrind application successfully since. This paper describes the operational performance to date, as compared with the original duty specifications and objectives.

The first mainstream M10 000 IsaMill with a 3 MW drive will be operational in November 2006 at the Potgietersrus Platinum (PPL) 'Platreef' Sandsloot Concentrator in South Africa's Limpopo Province.

Keywords: Western Limb Tailings Re-treatment Plant, IsaMilling, Platreef, platinum, palladium, PGMs, tailings.

Introduction

Development of IsaMill technology at Anglo Platinum concentrators

The potential benefit of ultra-fine and fine grinding (UFG), has been identified for various applications at Anglo Platinum Concentrators over many years. An ongoing programme to investigate the technology has been running intensively for the last seven years. This programme comprises four major areas:

- laboratory-scale investigation of various plant samples using a 4-litre IsaMill
- pilot plant work at the Group's pilot facility near Rustenburg using 20-litre, 100-litre and 250-litre IsaMills
- on-site pilot work at various plants using a FCTR rig and the M20 20 litre IsaMill
- various studies on operating plant size by size composites, which have culminated in the implementation of a routine assay and mineralogical composite programme in early 2005.

The test work has identified that both mainstream and concentrate regrind applications are of significant potential. The identification of the ceramic medium MT1 as a mainstream, and concentrate regrind inert grinding medium has led to the implementation of projects in which five additional M 10 000 IsaMills will be installed in mainstream regrinding applications within the next two years (2006/2007).

The implementation of the IsaMill regrind circuit at each plant will apply to classified primary circuit tailings at the Waterval UG2 plant and on the secondary mill product streams at Potgietersrus Platinums (PPL).

Mineralogical and fractional assay data derived from many plant samples from sources throughout the Group have shown that considerable potential for better extraction efficiencies exists if a cost-efficient liberation methodology can be found. Not all ore types show the same potential improvement; it is a reflection of the liberation achieved at a particular plant and the inherent association and speciation characteristics of the ore being processed at that plant. However, it has been seen at several applications that the mineralogical potential for IsaMill regrinding by improving liberation is economically attractive. Middlings and locked platinum group metals (PGMs) in silicate composites are in preponderance in the coarser size fractions in these plants' final tailings.

A typical chart of flotation behaviour of a regrind stream compared with the unground stream is shown below in Figure 1. The benefits of improved liberation are clearly seen

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with the kinetic impact of flotation after regrinding to 90% -51 microns with the IsaMill. These data were generated from the on-site pilot plant programme of work.

The size distributions show the quantum of regrinding, as indicated in Table I.

Background

The installation of the M10 000 mill at the Western Limb Tailings Re-treatment (WLTR) plant near Rustenburg was the result of both:

- meeting the objective of the optimization of the metallurgy and hence project economics of the WLTR project
- the requirement for the development of an effective technology for achieving finer grinds that would be applicable to many other Anglo Platinum operations.

The WLTR project flow sheet development work was described in a paper presented in early 2004 at CMP in Winnipeg[1]. The strategic issues which guided the decision to include a world's first 10 000-litre IsaMill in the application was not discussed in the paper.

The R&D programme conducted by Anglo Platinum at its research and pilot facilities investigated the available ultra- and fine grinding technologies available in the marketplace. Through routine and extensive mineralogical work it was also recognized that this technology would have application for Anglo Platinum for a variety of potential projects if the correct operational and operating cost regime could be met.

Improvement in liberation was to be achived through finer grinding by minimizing deportment of non-floating middlings and locked values in plant tailings, and also by changing the grade-recovery relationships in the overall flotation plant. The drivers for aggressively pursuing the initiatives are obvious: better metal recoveries and higher concentrate grades, and the drop in costs required for handling and processing in the smelting operations downstream.

The development of a 'first unit' in any application is obviously a high-risk action. Generally, it is accepted that the 'pragmatic person', looking for a long career in the company and industry, would recommend the installation of the 'second' unit only, and allow the 'pioneer' to sort out the initial problems, start the learning curve and/or live with the risk of failure.

However, both Anglo Platinum and the platinum group metals (PGM) industry in general had the most to gain by developing a large ultra-fine and fine regrind mill, because Anglo Platinum is the PGM industry's leader. It has been engaged in a process of very significant and continuous production capacity expansion, which means that many new comminution facilities are to be built in the next few years.

Other compelling reasons for introducing fine grinding technology to improve recovery are economic advantage and 'plant fit'. Owing to the relatively high value of incremental recovery resulting from the relatively high metal prices of the principal revenue metals platinum, rhodium and palladium on world markets and the typical size and yield of the modern PGM Concentrator plant (typically modules and/or plants producing 200 000–600 000 tons per month of ROM ore) the group had sound economic reason to boost production.

It was also realized that regrind mills of ~ 3 - 5 MW (ball mill equivalent) capacity could be used for both mainstream and concentrate regrind applications in these plants without having to use multiples of small units.

The opportunity to demonstrate and develop an M 10 000 IsaMill fitted the WLTR project objectives. It was a relatively low-risk installation, as the project could meet its project financial hurdle rates without total dependence on the Isamill's meeting its objectives (that is, in the unlikely case of the mill being a total failure the project would still meet the investment 'hurdle').

The installation of mainstream IsaMilling was deferred in the first phase of the WLTR plant, subject to further work and potential trialling after commissioning in the concentrate regrind duty. This was mainly because no suitably economic grinding medium was available at the time.

Table I

Particle size distributions with UFG, typical ore sample

PSD	Before regrind	After regrind
P90 microns	105	51
P80 microns	69	34
P50 microns	26	12
P10 microns	5	4

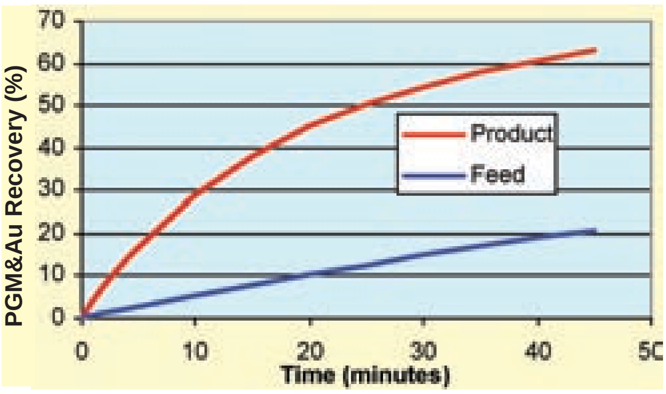

Figure 1—Primary circuit tails regrind vs. no regrind curve for a plant tailings sample

The flow sheet design allowed for the future testing of the mill as a mainstream regrind unit. This was a factor in the selection of the variable speed drive capability. The pilot plant test work demonstrated that grinding to a finer size distribution, nominally > 90% -75 micron, would improve overall recovery of value metals—see Figure 2.

While the flotation kinetics of PGMs in tailings streams are typically slow, it was significant that the rate of flotation increased with the finer grind. Mineralogical examination showed that the improved flotation performance at the finer grind was attributal to additional liberation of PGMs as well as the removal of iron oxide coatings from base metal sulphide surfaces by grinding in the inert media environment of the IsaMill.

The major reasons to defer the mainstream installation of the IsaMill at the time were:

- it minimized the capital risk for Anglo Platinum related to the introduction of a new technology—it was after all the first and hence the prototype 10 000-litre IsaMill
- it allowed the media issue to be addressed for mainstream feeds as opposed to flotation concentrate regrinds, from both the capacity and effective grinding energy perspectives and relative to the coarseness of potential feeds and their relative hardness compared with that of silica sand.

Since it was commissioned in early 2004 the IsaMill at WLTR has demonstrated in operations, to date that it has met all and, in some areas greatly exceeded, the original objectives targeted. It has met the metallurgical requirements of the project and (importantly) exceeded the design scale-up performance predicted by its manufacturers Netszch and technology developers, Xstrata Technology.

Owing to its successful development the machine has now begun to fulfil its originally conceived potential role in Anglo Platinum Concentrator plants for a number of projects. The first mainstream application, at the PPL plant at Sandsloot, Limpopo Province, is due for commissioning in November 2006.

A further four M10 000 IsaMills that will be installed for mainstream regrind duty have been ordered—two more mills at PPL and two at the Waterval UG2 Concentrator in Rustenburg. These four mills will commission in the third quarter of 2007.

The operational excellence of the M 10 000 IsaMill at WLTR

The WLTR project has been operational since late 2003 and by year-end 2005 had already processed in excess of 13.5 million tons, which included 4.349 million tons in 2004 and

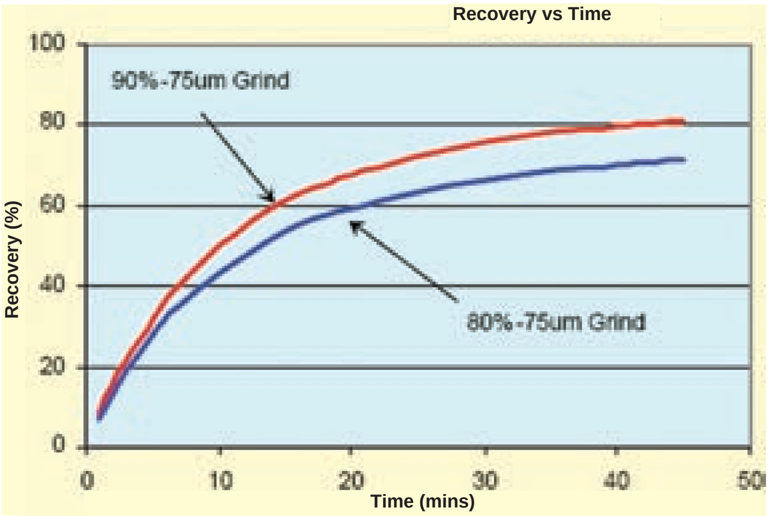

Figure 2—Rougher flotation recovery/time curve

Figure 3—WLTR site and IsaMill circuit area

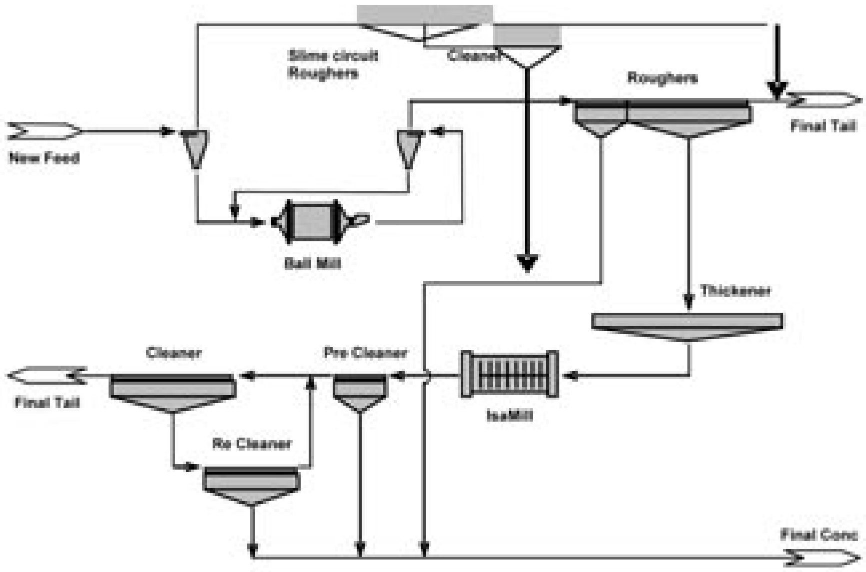

Figure 4—Simplified WLTR flow sheet

Table II

Representative comparison of bulk sample from Klipfontein central tailings dam

Sample origin	3E (g/t)	Pt (g/t)	Pd (g/t)	Cu (%)	Ni (%)
Resource estimate	1.05	0.80	0.19	0.028	0.076
Piloted bulk sample	1.17	0.73	0.33	0.027	0.076

5.577 million tons in 2005. This has resulted in production of final recovered platinum of 66 300 and 50 100 ounces troy respectively for the two years. The planned drop-off in production output is due to the initial mining of high grade areas on the old tailings dams. Interestingly, these dams were deposited at Klipfontein in the 1920s, before flotation was used in the PGM extraction processes. Gravity concentration was employed on a feedstock produced after ball milling. These dumps contained very fine oxidized PGMs—high grade but with a low recovery potential

Plant design

A simplified flow sheet for the Western Limb Tailings Retreatment Project (WLTR) is shown in Figure 4.

A staged approach was taken for the design and installation of the circuit to limit the capital exposure and project risk to the novel treatment of dormant PGM tailings. The project was divided into two phases, with the detailed design and installation of Phase 2 dependent upon the operating knowledge gained in Phase 1.

The Phase 1 WLTR concentrator was commissioned in the fourth quarter of 2003. The design is based on a production target of 400 000 tons per month (4.8 million tons per year), in a single grinding/flotation line. Much of the Phase 2 civil work was put in place during construction of Phase 1, making the addition of Phase 2 a relatively simple task. Phase 2 would basically add a duplicate grinding and flotation line to take capacity to 900 000 tons per month, or 10.8 million tons per year.

The WLTR operation, in its initial phase, processes the tailings resources at the Klipfontein tailings dams (which date back to the 1920s) and current UG2 tailings from the Klipfontein Concentrator plant.

Table II indicates the grade of the sample used for the major pilot work and also the resources contained at the Klipfontein tailings dam complex. The actual grade delivered to the plant is a composite of the tailings dam resource and the tailings from the operating plant, which treats roughly 110–120 000 tons per month with a 3E PGM tails grade of 0.7 to 0.8 g/t.

The circuit has been optimized based on operational experience since start-up and the capacity target has been raised, initially to 450 ktpm and subsequently to 540 ktpm.

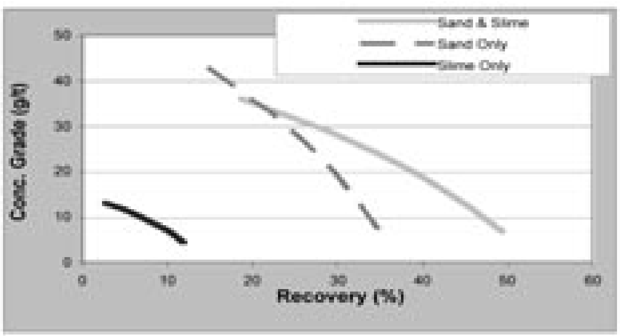

Figure 5—Klipfontein central sample—sand and slimes flotation

The original circuit design entailed removal of a 'slimes' fraction from the re-pulped tailings. This fraction is nominally 80% passing 15 mm and demonstrated poor flotation performance during laboratory tests (Figure 4). In the original design this was discarded to tailings. This stream, however, has double the head grade of the average plant feed. It is probably the most difficult stream in the PGM industry from which to achieve good recoveries because of the fineness of the size distribution and the degree of surface oxidation attributable to its deposition age.

Subsequently a flotation step was added on this stream to extract PGM values. Operational experience has shown that process instability arising mainly from the mining operation was reflected in variable feed conditions in the plant. Variations in slimes circuit feed grade and recovery potential drove this decision. This created the opportunity to separate out and investigate potential technology improvements on this ultra-fine and metallurgically very difficult stream. Test work has been conducted subsequently to investigate various technologies to improve performance. This will be ongoing in the project's life. Having such an extremely difficult processing extraction potential stream to work with is clearly an advantage.

Figure 6 shows the current cleaner and IsaMill circuit configuration, and indicates typical plant operating parameters.

With only two operating monitor guns in operation at the tailings dams being reclaimed at any one time, blending the feed into the plant is inherently not easy. Most of the tailings dams being mined have been deposited creating separate areas of coarse and fine slimes, following the typical deposition methods employed historically. Tailings streams were spigotdelivered around the periphery of the tailings impoundment, and the particles separated along the length of the slope on the deposition beach. The coarse particles dropped out first, and the fine and superfine particles were carried further and further down the beach. Clean water was typically reclaimed from the central and farthest point through a penstock arrangement.

Thus, periods of very different slurry particle size distributions and slurry density are fed to the plant. This variability is dampened by the density control thickener and surge tank but, unfortunately, does not produce a homogeneous feed at all times. Additionally, rain on the tailings area causes unavoidable variation in densities and massive volume influxes proportional to the degree of precipitation.

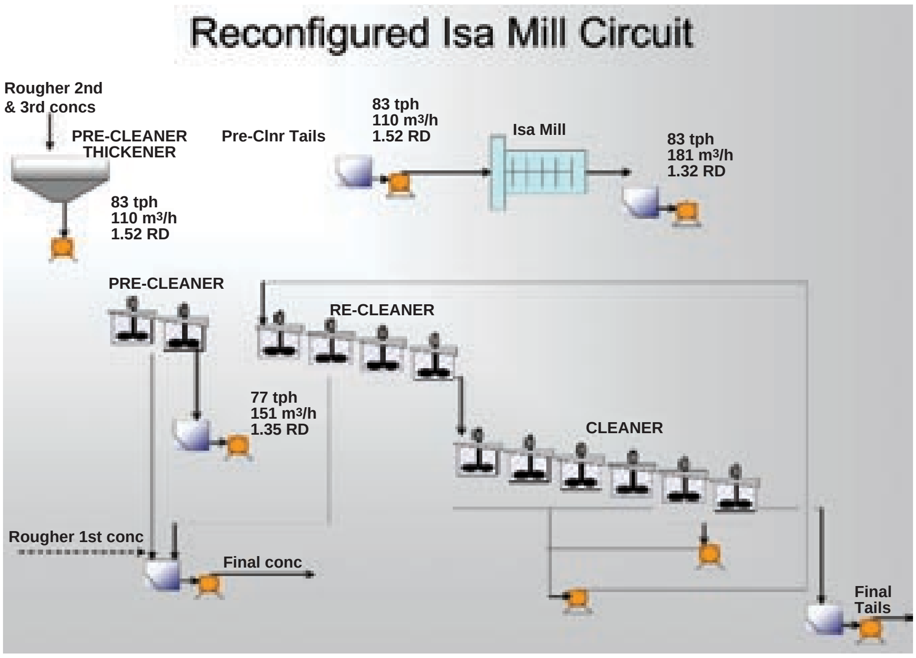

Figure 6—Schematic of current cleaner—IsaMilling circuit after optimization

Figure 7—In-flow to tailings dam pump station with tailings dams in background and view of the Klipfontein pump station and inlet area

The metallurgical difficulties evidenced in plant performance and low PGM metal recoveries, which were evident in the pilot work (see Figure 6) and confirmed in operation, present a 'test bed' that could potentially have spin-off benefits across the whole group. Every concentrator has a component of very fine and difficult material, even in most underground 'fresh' ore situations where it is in a relatively low proportion.

A particular issue with the slime stream material is the grade/recovery relationship—the slope is flat, not unexpectedly. See Figure 6 which shows results obtained during the project pilot plant and laboratory investigation programme.

The de-slime cyclone underflow reports to the single 24' 3 33', 10.5 MW (14 000 hp) ball mill in closed circuit with cyclones. The cyclone overflow feeds rougher flotation, which comprises 9 3 130 m^3 Outokumpu tank cells. Rougher tail reports to final tail. The first rougher concentrate is of final grade, and is sent to final concentrate. The remaining rougher concentrate is thickened prior to regrinding using ultra-fine grinding technology.

A single open-circuit 2.6 MW (3.500 hp) M10 000 IsaMill grinds the rougher concentrate using local silica sand as grinding medium. The IsaMill operates in open circuit and produces a narrow product particle size distribution because of the internal classification system this technology uses. The ground product is then sent to a three-stage cleaning circuit where final concentrate is produced. The cleaner tailings are discarded as final tailings or (as an option) recirculated to cell #7 of the roughers. This circuit comprises 2 3 10 m^3 pre-cleaners, 6 3 20 m^3 cleaners and 4 3 10 m^3 recleaners. All cells are Outokumpu tank cells.

The M10 000 IsaMill was installed with a 2.6 MW Siemens variable frequency 'Simovert MV' drive unit. The variable speed option was included in order to mitigate the scale-up design risk. The performance of the particle

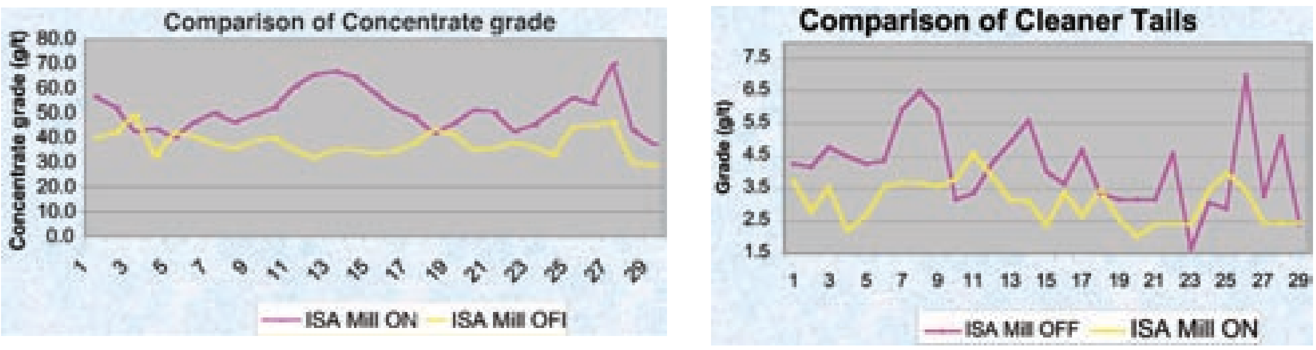

Figure 8—Typical operating data from 2005: comparison of IsaMill in/out of circuit

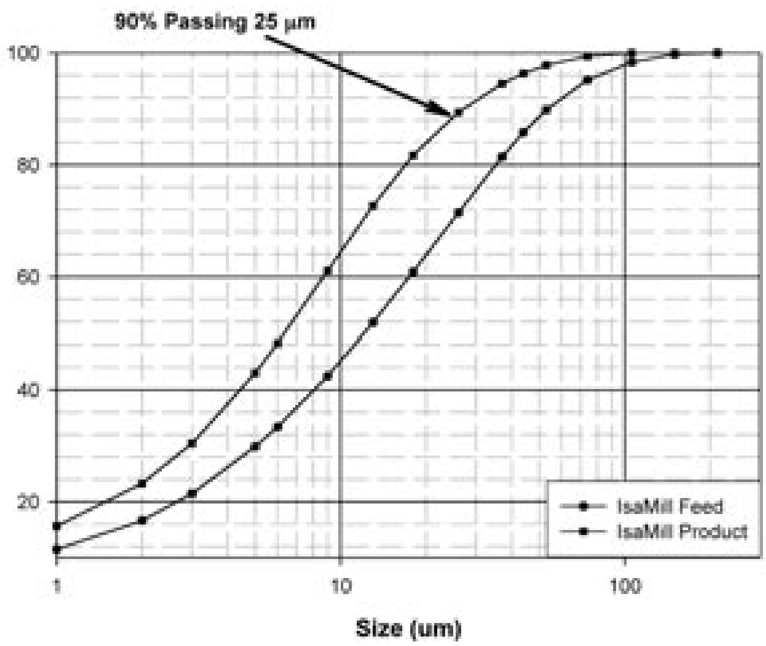

Figure 9—Typical grind data for feeds and products achieved at WLTR with the M 10 000

separator within the mill was expected to be a critical scale-up issue for the M 3000–10 000 units. The rotational speed of the product separator as well as its actual design contribute to the effectiveness of the separator. However, rotational speed influences the wear rates of the mill internals and also the performance of the mill as a grinding unit. Hence it was prudent to allow this important parameter to be varied in order to determine optimum separation and wear conditions during optimization.

A further motivation for the installation of the variable speed drive unit was the intention to test the application of the M 10 000 IsaMill on mainstream regrind on plant scale. This was deferred in the original project because a suitable grinding medium was not available. Subsequently ceramic media have been developed, and the mainstream applicability tests using them will be carried out in due course.

A total of five major downtime events have been experienced by the IsaMill circuit. Three events occurred owing to the failure of the VSD unit. The other two were the result of internal wear parts failures. These abnormal stoppage periods demonstrated the operational effectiveness of the IsaMill stage in the flow sheet. These downtime events are of interest because the M 10 000 IsaMill is the first unit of its size to be used by Anglo Plat.

Metallurgical performance

The two main expectations from the IsaMill are finer grinding, and subsequently better PGM flotation grade and recovery. Both of these objectives were met, as indicated in Figures 8 and 9.

The two graphs below show the typical metallurgical impact of the IsaMill circuit. This reflects periods before, during and after major stoppage events in 2004.

Advantage was taken of periods when major stoppages of the IsaMill circuit occurred (see the section on maintenance below) to analyse the metallurgical impact of the mill. Two studies were reported in the last 18 months. Both confirmed that the metallurgical impact is in line with the predicted benefits for the inclusion of the circuit in the project:

- ➤ improved recovery in the cleaner circuits
- ➤ improved concentrate grade due to enhanced liberation at the same recovery.

The analyses of the whole period of IsaMill downtime compared with normal operation when in circuit shows that cleaner circuit recovery improves by approximately 15%; i.e. typically from 45–50% to 55–60% recovered to final concentrate from cleaner circuit feed PGMs.

The impact on total circuit recovery was estimated at ~3% 3E PGM recovery.

Typical grind data shows that the IsaMill produces a significant size reduction.

Maintenance and circuit availability

Routine maintenance planning and scheduling was conducted with the assistance of the technology supplier, Xstrata Technology, from the commissioning period onwards, to ensure that the learning curve was as short as possible and that all data were collected. A priority was to establish the comparative operating performance of the M 10 000 unit relative to that of the M 3 000 units.

Five major failures have occurred in the 2.5–3 years of operation to date. The failures have all been fully analysed, both by the owners and by the suppliers of the equipment, Xstrata Technology and Siemens.

Figure 10—Photographs of the M 10 000 mill internals, showing the damaged discs and the discs after replacement following one of the internal failure incidents

Table III

Comparative normalized cost for M 10 000 and M 3 000 IsaMills, courtesy of Xstrata technology

IsaMill model	Normalized unit cost	
	/t milled	/kWh
M3000 (with 1100 kW motor)	1	1
M10000 (with 2600 kW motor)	0.33	0.55

Table IV

Maintenance scheduling for M 10 000 mill at WLTR

Event	Occurrence	Shutdown duration
Shuffle/rotate/change discs	Every 1 300 hours	6–8 hours

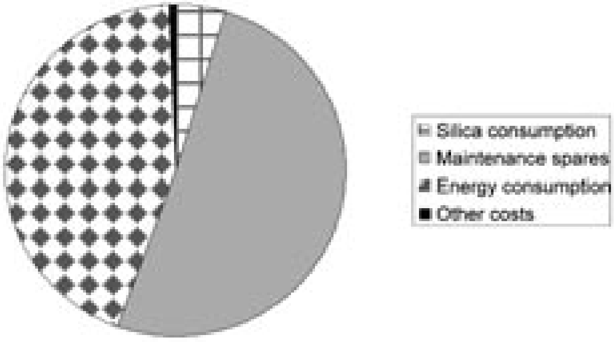

Figure 11—Pie chart of operating costs for period of 15 months January 2005–March 2006

Mill drive and electrics

The first major failure of the VSD unit occurred for two periods of two weeks each in May/July 2004. It was caused by the accumulation of insects and dirt in the drive building resulting in a local short circuit 'flash over' on HT equipment. The root cause was inferior filtering and insufficient VSD room atmosphere protection. This was addressed by installing both air conditioning and an upgraded filtration system on inlet air to the enclosure concurrently. Some problems had also arisen because of the very high ambient temperatures during hot periods in the summer.

A second major failure of the VSD occurred in September 2004, owing to problems in the HT circuitry. The third failure occurred in April 2006, which will require an 8–9 month repair to the unit. The transformer breaker unit failed because it was mechanically blocked and could therefore not open. (The main spring retaining bracket fitting worked loose, and prevented the operating rods from opening the contacts.) The failure of the breaker caused extensive damage to the drive equipment. A total replacement, with modifications, is required.

M10 000 milling unit

Failures of the internal wear parts of the unit occurred in June 2005 (downtime 21 days) and again in December 2005 (downtime 14 days).

In both cases the cause of failure was either poor maintenance practice (incorrect tightening of the discs/shaft after maintenance) or foreign particles (either oversize silica or debris in the bund area, e.g. discarded bolts/nuts), causing damage to the rubber internals and the separator polyurethane parts.

The WLTR M 10 000 unit's performance was compared with the average performance of M 3 000 IsaMills, which all operate on concentrate regrind. These mills are installed in the lead and zinc, gold and PGM (UG2) industries.

The maintenance scheduling for the WLTR mill was determined after the wear characteristics and maintenance schedule/planning for WLTR plant had been defined. The maintenance shutdowns of the IsaMill circuit can be conducted independently of the mainstream circuit, as it was designed to be switched in and out of the circuit as a side-stream processing step.

The mill is scheduled to be shut down for eight hours after every 1 300-hour running period (approximately every 7–8 weeks). All wear parts can be replaced during these shutdowns. The IsaMill circuit was designed to be shut down while the mainstream plant is operational.

Silica media consumption

The IsaMill uses local silica sand, which is mined in the nearby Magaliesburg quartzite. It is crushed and screened to – 4 mm +1.2 mm specification, and is of variable quality due to the characteristic variation of the rock in the mining area. Consumption averages 180 gpt of IsaMill circuit feed and a monthly consumption of 65 tons, and varies according to the quality and character of the media delivered to the plant.

Overall operating costs

The overall operating cost distribution for the M10 000 IsaMill at WLTR is shown in Figure 11. Note that operating and maintenance labour are excluded, as the scheduling of the maintenance and operation was designed such that no additional labour was employed specifically for the IsaMill circuit.

The operational costs principally comprise spares and electric power. The circuit treats between 8–10% of the mainstream tonnage, and has an operating cost of approximately 8–9.50 SAR per ton treated by the IsaMill circuit.

Conclusions

- The M 10 000 IsaMill at WLTR has achieved its designed metallurgical performance
- This has been achieved at lower than expected operating cost. Major failures have occurred, owing principally to faults on the variable speed drive unit. Otherwise plant availability has been very good
- The decision to scale up from M 3000 to M 10 000 has been vindicated, and is an example of rapid and effective joint development of a technology
- The success of the large M 10 000 IsaMill in regrind applications is a very important step in achieving better overall metallurgy and economic performance for PGM extraction at Anglo Platinum concentrator operations. The operating experience of the three PPL mills and the two Waterval UG2 mills will determine the progress of implementation of the technology

References

COPE, A.J. *et al.*, Tailings Re-treatment Project: Recovery Of 900 ktpm Tailings From Rustenburg Dormant Dams (Klipfontein and Waterval only) Process Technology Division, Anglo Platinum. 2002.

DURANT, A.C., BUYS, A.S., and KNOPJES, L.M. The Recovery Of Platinum Group Minerals From Dormant Tailings At RPM—Rustenburg Section. A Pilot Plant Study. Divisional Metallurgical Laboratory Report, Anglo Platinum. August 2002.

CURRY, D.C., CLARK, L.W., and RULE, C.M. Collaborative Technology Development—Design and Operation of the World's largest stirred mill. *Comminution*, Perth. 2005.

BEDESI, N. Comparison of IsaMill operation operating flotation grades data. Internal memorandum. 2004 .

BUYS, S., RULE, C.M., and CURRY, D.C. The application of large scale stirred milling to the re-treatment of Merensky Platinum Tailings. *37th CMP, Ottawa*. 2005.

JACOBS, J., ANYIMADU, A.A., BALRAM, A.K., and GAANAKGOMO, J. Operating data from the WLTR plant 2004–2006. Internal communication, Anglo Platinum.

PEASE, J.D., CURRY, D.C., BARNS, K.E., YOUNG, M.F., and RULE, C.M. Transforming flow sheet design with inert grinding—using the IsaMill. *38th CMP*, Winnipeg. 2006. ◆