THE APPLICATION OF LARGE SCALE STIRRED MILLING TO THE RETREATMENT OF MERENSKY PLATINUM TAILINGS

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ABSTRACT

The use of fine grinding (FG) in mineral processing is well established. The application of FG in the South African platinum industry is more recent and it's use in the recovery of PGM's from dormant tailings dams is unique. Anglo Platinum uses IsaMill FG technology at their Western Limb Tailings Retreatment project (WLTR) near Rustenburg in the North West Province of South Africa.

In December 2003, Anglo Platinum commissioned the first purpose built tailings re-treatment facility for PGM recovery in South Africa. The concentrator re-treats Merensky ore tailings from concentrators that operated early last century. The WLTR facility takes advantage of modern technology, such as FG, to economically recover PGM's from material historically considered as waste. The WLTR concentrator has a capacity of 4.8 Mtpa, and has been designed to easily expand to 10.8 Mtpa. The flow sheet includes recovery of tailings by high pressure water monitoring, ball milling, rougher flotation, rougher concentrate regrinding and cleaner /recleaner flotation.

The rougher concentrate is reground in an IsaMill, which is a stirred mill that operates with inert silica sand grinding media. For this project, Anglo Platinum required a stirred mill of a unit size not previously available. Xstrata Technology and Anglo Platinum collaboratively developed the largest wet, fine grinding mill available; the M10,000, 2.6 MW IsaMill.

The use of IsaMill technology was enabling for the WLTR project, as it allowed smeltable concentrate grades to be produced from the oxidised, slow floating tailings. The economics and practicality of fine grinding has fundamentally changed with the M10,000 IsaMill. Flotation is transformed by high intensity attritioning in the inert media environment, and the narrow size distribution of product in open circuit configuration. The use of conventional steel media grinding to improve fine particle flotation is limited due to the oxidation of liberated mineral surfaces inherent in these environments.

INTRODUCTION

During 2000 and 2001, Anglo Platinum conducted metallurgical and geological investigations into the retreatment of dormant tailings dams in the Rustenburg area. At the current market value of platinum and palladium, the concentration of PGM minerals in the dams represented a possible economic resource. Metallurgical test work identified a significant proportion of these minerals that could be recovered via fine grinding and flotation.

A pilot plant program was developed to confirm the effectiveness of fine grinding with respect to flotation recovery. The results from the program assisted with the proposed concentrator process design and samples were generated for vendor test work of critical equipment.

A collaborative design project between Anglo Platinum and Xstrata (then MIM – Mt Isa Mines) was initiated to run in parallel with the pilot plant tests and plant design. This project required a detailed design for a fine grinding IsaMill of 2,600 kW (3500 hp) capacity, to maximise economies of scale with this unit process.

METALLURGICAL TEST PROGRAM

Bulk Sample Collection

The Klipfontein Central tailings dam was selected to provide the bulk sample for pilot testing. A total of 56 holes were drilled, producing approximately 424 tonnes of sample. The resource for the Rustenburg section was calculated to be 186 Mt at 1.08 g/t PGM + Au. Over 4 Moz of platinum were contained within this resource. The Klipfontein Central bulk sample was representative of the total Rustenburg resource.

Test Program Detail

Using previous laboratory scale results in conjunction with certain process design criteria, the pilot scale program was developed to confirm the integrity of the concepts identified previously. Four campaigns were designed to provide the necessary information. The grinding circuits are summarised in Table 2.

Table 1 : Grinding Targets and Mill Type

Pilot Run #	Primary Grinding		Rougher Conc Regrind	
	Mill Type	% -75 μm	Mill Type	% -25 μm
1	1^0 Ball, 2^0 Ball	80	-	-
2	1^0 Ball, 2^0 Ball, 3^0 IsaMill	90	-	-
3	1^0 Ball, 2^0 Ball	80	IsaMill	90
4	1^0 Ball, 2^0 Ball, 3^0 IsaMill	90	IsaMill	90

A nominal grind of 80 % passing 75 μm was achieved by using a primary and a secondary ball mill (secondary mill in closed circuit with cyclone) for Runs 1 and 3. An IsaMill was used in open circuit to grind the cyclone product to 90 % passing 75 μm for Runs 2 and 4. All tests used rougher flotation with a residence time of 45 minutes. A cleaning /recleaning stage was used to increase the rougher concentrate grade to 50 g/t (final concentrate target). An IsaMill was used in open circuit to regrind the rougher concentrate to 90 % passing 25 μm prior to cleaning for Runs 3 and 4. The rougher and cleaner bank flotation tails reported to final tails. The recleaner tail reported to the cleaner feed. Reagent selection, addition rates and locations were based on results from laboratory scale test work.

Head Assay Analysis

The bulk sample was mixed prior to being fed to the pilot plant. The statistics in Table 2 indicate that this mixing process was effective, as very little variation in grade is evident. Samples were collected over three one-hour periods for each Run.

Table 2 : Head Assay Analysis

	3E (g/t)	Cu (%)	Ni (%)
Mean	1.17	0.027	0.076
Standard Deviation	0.04	0.003	0.010
% RSD	3.45	9.49	13.86

Pilot Plant Results

A summary of the flotation results, with respect to PGM, for each run is presented in figure 1. The overall recovery achieved for the four runs were similar with runs 1 and 3 achieving slightly better results. Final concentrate grade improves significantly by introducing a finer product to the cleaner flotation circuit.

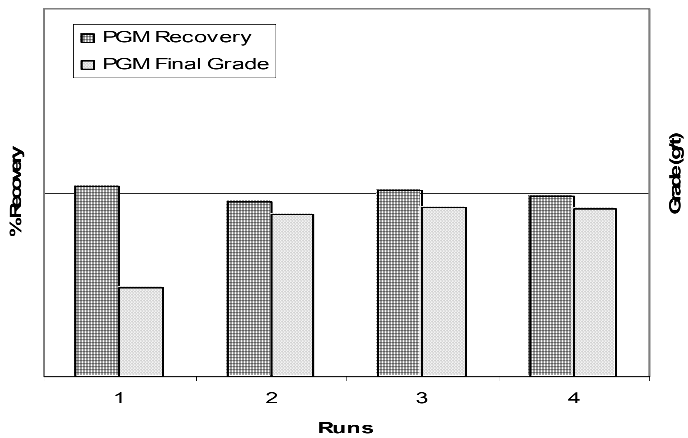

Figure 1 : Final PGM Recovery and Concentrate Grade

The final concentrate grade is dependent upon grind size. Table 3 demonstrates the particle sizes of the rougher and cleaner concentrate streams.

Table 3 : Rougher and Cleaner Stream Sizings

Run #	Rougher Feed	Cleaner Feed	Rougher Conc Regrind
	% Passing 75 μm	% Passing 25 μm	
1	77.0	50.3	No
2	93.4	85.4	No
3	76.6	83.4	Yes
4	94.6	88.1	Yes

The cleaner feed size distributions were similar for Runs 2, 3 and 4. Despite Run 2 not having a rougher concentrate regrind stage, the finer primary grind (rougher feed) resulted in a similar cleaner feed size as Runs 3 and 4 where regrinding was used.

Rougher Flotation

Figure 1 confirmed the laboratory scale observations that the recovery of PGM's from the tailings dams was highly dependent upon fineness of grind. At equivalent concentrate grade, PGM recovery was approximately 10 % higher with a primary grind of 90 % passing 75 μm, than with 80 % passing 75 μm.

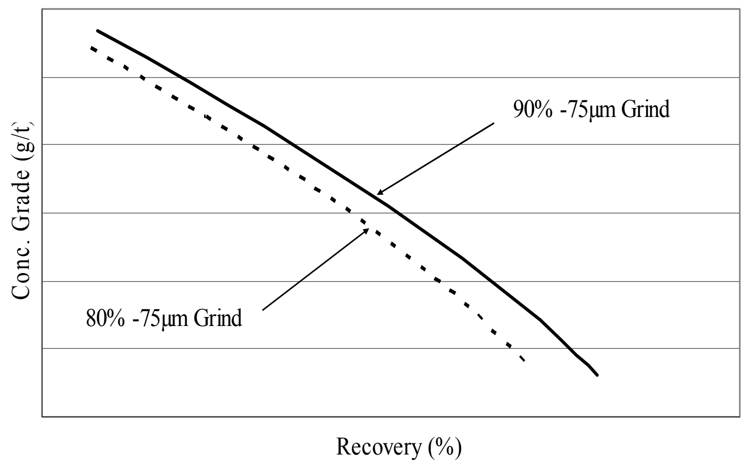

Figure 2: Rougher Flotation Grade /Recovery Curve

Whilst the flotation kinetics of PGM's 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 due to additional liberation of PGM's as well as the removal of iron oxide layers from base metal sulphide surfaces by grinding in the inert media environment of the IsaMill.

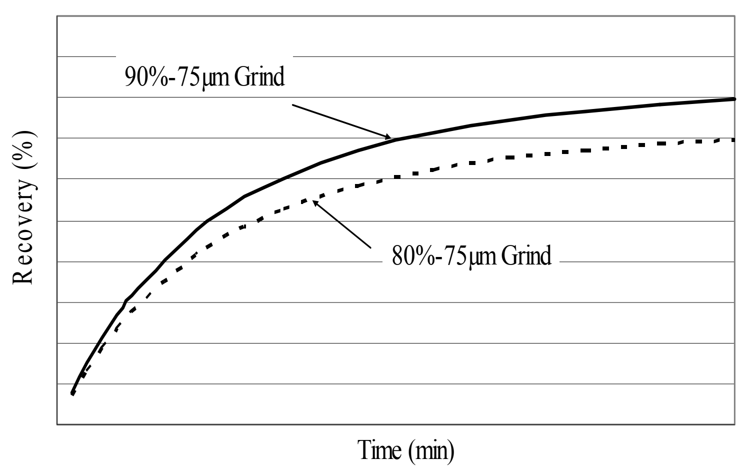

Figure 3 : Rougher Flotation Recovery /Time Curve

Cleaner Flotation

It was anticipated that the use of a conventional cleaner /recleaner circuit would enhance the grade of the rougher concentrate with minimal loss in recovery. However, it was not possible to shift the grade /recovery curve for Run 1 (80% passing 75 µm primary grind) as shown in Figure 4. As shown in Table 3, the cleaner feed size distribution was the coarsest of all Runs (50.3 % passing 25 µm). Limited success came from additional laboratory investigation to identify methods of upgrading the rougher concentrate using alternative reagents, pH modification and novel chemistry techniques. However, mineralogical examination showed that poor liberation and iron oxide coating of base metal sulphide surfaces were responsible for the poor upgrade potential of the rougher concentrate. Regrinding of the concentrate was required to improve PGM liberation and freshen-up the heavily oxidised mineral surfaces.

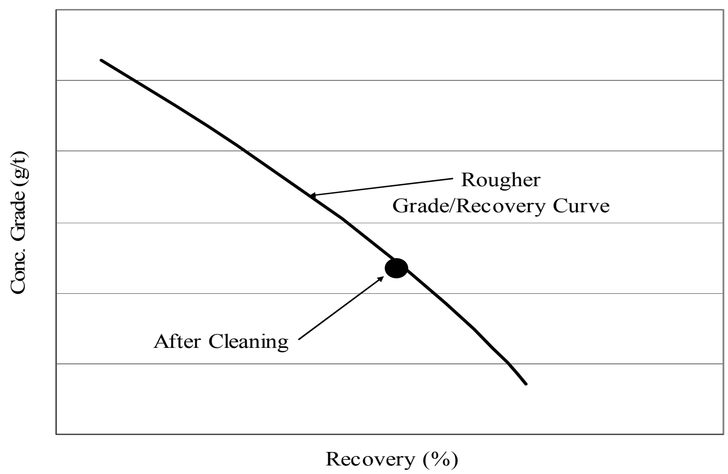

Figure 4 : Run 1 – Grade /Recovery for 80%-75µm Primary Grind

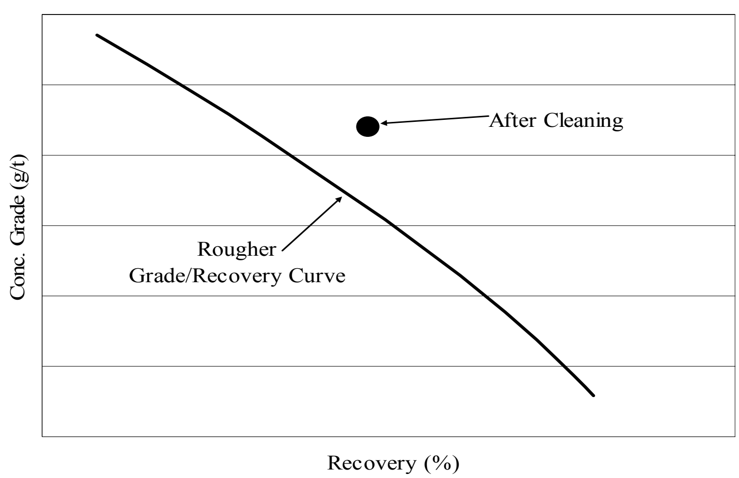

Figure 5 : Run 2 – Grade /Recovery for 90%-75µm Primary Grind

Run 2 adopted a finer primary grind of 90% passing 75 µm. The benefit of this to rougher recovery has been discussed, but the additional liberation and removal of base metal sulphide oxide surface coatings permitted significant upgrading in the cleaners. Figure 5 shows the shift of the grade /recovery curve.

Runs 3 and 4 used an IsaMill rougher concentrate regrind stage to test what improvements in cleaning could be gleaned from additional liberation and particle surface cleaning. With the coarse rougher concentrate size distribution produced in Run 1, it was expected that regrinding prior to cleaning would have the greatest benefit for this case. Figure 6 confirms this, with the grade /recovery curve shifted to the right of the rougher plot.

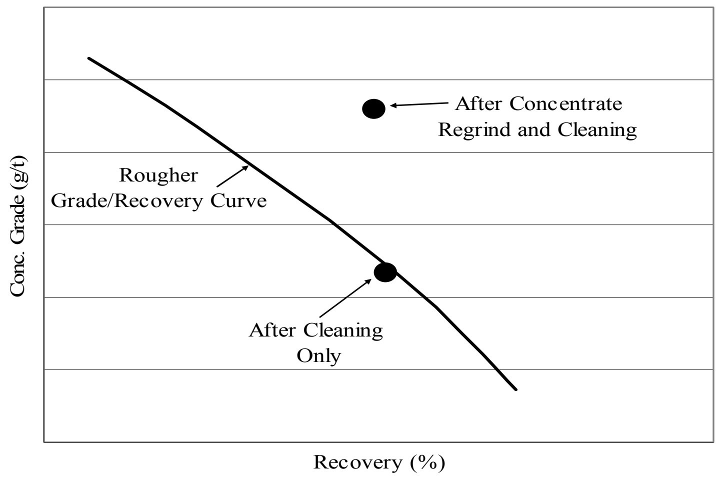

Figure 6 : Run 3 – Grade /Recovery After Rougher Concentrate Regrind at 80%-75 Primary Grind

The cleaner feed size after regrinding in Run 3 was 83.4 % passing 25 µm. This compares well to the cleaner feed size in Run 2 (finer primary grind) of 85.4 % passing 25 µm. As Run 2 and Run 3 both involved a stage of inert media grinding in an IsaMill (clean mineral surfaces), and possess similar size distributions it was expected that the overall flotation performance of these two cases would be similar. Figure 1 shows Run 3 exhibiting a marginally better final concentrate grade and recovery, despite having a lower feed grade and slightly coarser cleaner feed size distribution than Run 4. It is hypothesised that the better performance of Run 3 was due to IsaMilling applied immediately before cleaning, rather than before roughing (to produce a finer primary grind) in Run 2. It is likely that the clean, reactive mineral surfaces produced by the inert IsaMill environment oxidise during the 45 minute rougher flotation period. Application of IsaMilling after roughing as performed in Run 3, produces fresh mineral surfaces which are likely to be responsible for better cleaner flotation performance.

Run 4 used IsaMilling to produce a primary grind of 90 % passing 75 µm, and for regrinding the rougher concentrate. The cleaner feed size of Run 2 (finer primary grind only) was 85.4 % passing 25 µm, compared to 88.1 % passing 25 µm in Run 4. Only a small increase in fineness was produced by regrinding the rougher concentrate, but the flotation performance improved, showing that the cleaning potential is sensitive to rougher concentrate particle size distribution and mineral surface condition.

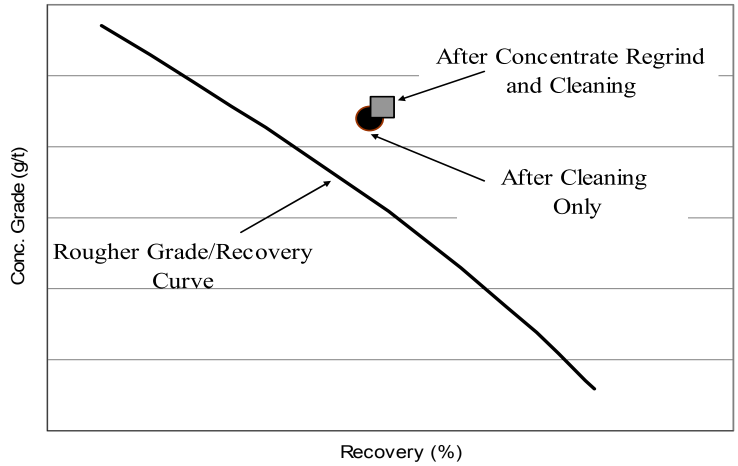

Figure 7 : Run 4 – Grade /Recovery After Rougher Conc Regrind at 90%-75µm Primary Grind

Pilot Plant Test Conclusions

The following conclusions were made from the pilot plant tests:

- The PGM grade and recovery targets can be met with the use of conventional flotation and IsaMill inert grinding.
- A primary grind of no less than 80 % passing 75 µm, and rougher concentrate regrind of no less than 85 % passing 25 µm is required to meet the grade /recovery targets.
- A finer rougher concentrate regrind is likely to improve cleaner flotation – flotation is sensitive to grind size.

Most importantly, the combination of improved liberation and inert media grinding is required to maximise flotation potential. The impact of changes in mineral surface chemistry (such as oxidation from iron in grinding media) to flotation recovery is generally much larger than the effect due to liberation alone (refer to AMIRA P336, Report P336/26). There are examples where the actual change in recovery due to increased liberation from grinding is much lower than predicted due to the negative impact of mineral surface oxidation. It is even possible that the overall flotation recovery decreases after regrinding due to surface chemistry changes, despite increasing mineral liberation (Frew, Davey and Glen, 1994).

PLANT DESIGN

The Western Limb Tailings Retreatment Project (WLTRP) simplified flow sheet is shown in Figure 8. A staged approach was taken with 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 of Phase 1.

The Phase 1 WLTR concentrator was commissioned in the fourth quarter of 2003. The design is based on 400,000 tonnes per month (4.8 Mtpa), 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 /flotation line to take capacity to 900,000 tonnes per month, or 10.8 Mtpa.

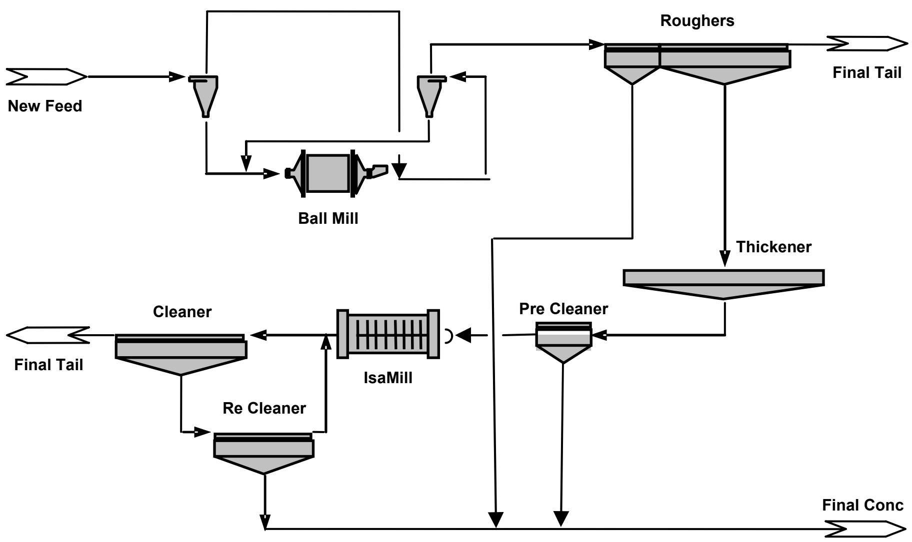

Figure 8 : Simplified WLTRP Flow Sheet

The deslime cyclone under flow reports to the single 7.3m x 10.06m, 10.5 MW (14,000 hp) ball mill in closed circuit with cyclones. The cyclone over flow feeds rougher flotation, which comprises 9 x 130 m^3 tank cells. Rougher tail reports to final tail. The first rougher concentrate is of smeltable grade, and is sent to final concentrate. The remaining rougher concentrate is thickened and then floated in a pre-cleaner prior to regrinding.

A single, open circuit, 2.6 MW (3,500 hp) M10,000 IsaMill grinds the rougher concentrate to a P_{90} of 25μm using local silica sand as grinding media. The IsaMill operates in open circuit and produce a narrow product particle size distribution, because of the internal classification system this technology uses. The ground product is then sent to a two stage cleaning circuit where final concentrate is produced, and cleaner tailings are discarded as final tailings. The cleaner circuit comprises of 2 x 10 m^3 pre-cleaners, 6 x 20 m^3 cleaners and 4 x 10 m^3 re-cleaners.

IsaMill Design and Scale-Up

The WLTRP design required grinding of a nominal 53 th^{-1} and maximum 65 th^{-1}. Test work demonstrated that a reduction of F_{80} = 75 μm to P_{90} = 25 μm required 35 $kWht^{-1}$ using -5 +3 mm silica sand grinding media from a local quarry. As grinding media, the local sand was extremely low cost and demonstrated a consumption rate of 50 g/kWh (1.75 kg/t). The purpose of the scale-up project was to use only one IsaMill. Considering the maximum duty, a 2.6 MW IsaMill with

10,000 litre grinding chamber was designed. This would be the largest fine grinding mill available to the minerals processing industry.

The design represented a significant challenge, as the scale-up of absorbed grinding power was more than 2.5 times the existing design. Historically, the scale-up process of the IsaMill to the 1.1 MW (M3000) model was based on conservation of power intensity. At the 2.6 MW scale, the media agitator (grinding disc) tip velocity would be excessive using this method. A 'constant tip velocity' method was developed which proved more complex than power intensity models, as power does not scale-up linearly with volume.

A variable frequency drive was designed for the first M10,000 installation to reduce process risk and permit testing with fine (regrind duty) and coarse (secondary grinding duty) media types, important to Phase 2 of the WLTR Project.

Component and materials selection was critical, and importantly the disc surface abrasion rate was kept within 3 % of the 1.1 MW mill's rate. As the M10,000 disc design was larger in diameter and thickness, the increased volume of rubber would mean a longer disc life than in the 1.1 MW mill, as abrasion rates are a function of area.

The larger diameter of the M10,000 required modifications to the design of the Product Separator; a centrifuging /pumping device that classifies the mill product (and retains grinding media). As centripetal acceleration decreases with increasing diameter (at constant tip speed), and pumping efficiency decreases with lower radial velocity, both the centrifuging and pumping actions of the Separator had to be re-designed. The new design focused on improving efficiency of the rotor suction region, rotor pump finger shape and product classification efficiency.

The disc tip velocity and power calculations have proven to be accurate. Figure 9 shows the correlation between calculated power draw, and observed power draw at different disc tip speeds during commissioning. Higher tip speed (and power draw) was not required, as the grinding efficiency was high and product size specification was met. Operation of the new Product Separator was successful above 76 % motor speed. Classification efficiency was poor at this speed, however the minimum operating design speed for the M10,000 was 20.5 ms^{-1} or 81 % output. Figure 11 shows how the product particle size distribution of the IsaMill is narrower than that of the feed. This is due to the classification effect of the Product Separator. The IsaMill was operating at 80 % output, or 20 ms^{-1} tip speed at the time of that survey.

Tip Speed m/s	Calculated Power kW	Observed Power kW	Motor Output %
19	1500	1400	76
20	1750	1700	80
21	2026	2000	84
22	2329	N/A	88

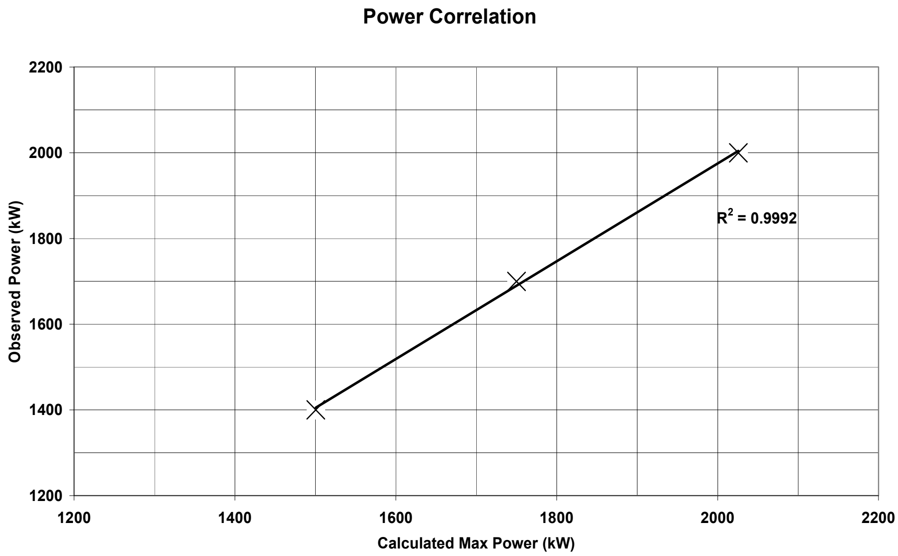

Figure 9 : Power Scale-Up For M10,000 IsaMill

Figure 10 : WLTRP Site And IsaMill

FINE GRINDING AND FLOTATION CIRCUIT OPERATION

Commissioning

The IsaMill circuit was commissioned late December 2003, and began operation in early February 2004 once steady rougher concentrate feed was available. Figure 11 shows the first size survey data across the mill during commissioning. At this time, the feed sizing was finer than design (low primary mill feed tonnage) and of lower pulp density (1.13 kg/L, 17 % solids). As the IsaMill can operate successfully with low density feed, the product specification could still be met (P_{90} = 25 µm). Notably, the product particle size distribution is significantly narrower than the feed, which is a function of the internal classification of this type of mill.

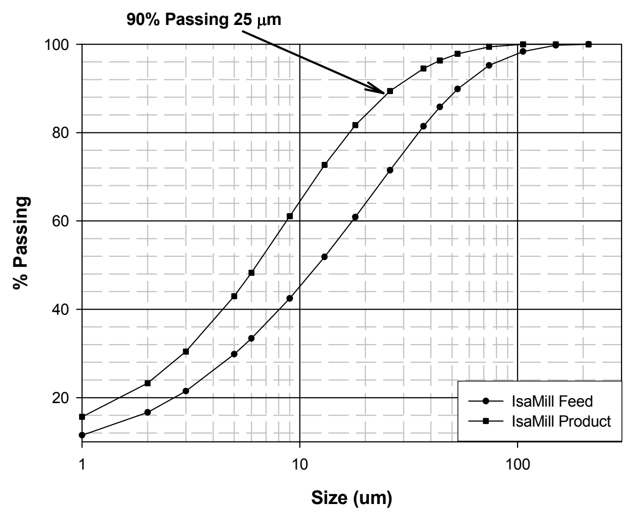

Figure 11 : IsaMill Size Distributions – Commissioning

The cleaner flotation banks had already been commissioned, so a qualitative comparison of froth characteristics before and after IsaMilling could be made. Figure 12 shows the observed difference between the recleaner froths. Without regrinding, the froth was pale, watery and barren; stability was poor and mass pull was very low. After regrinding, the froth was dark grey and heavy in mineralisation. Mass pull was higher and froth stability better.

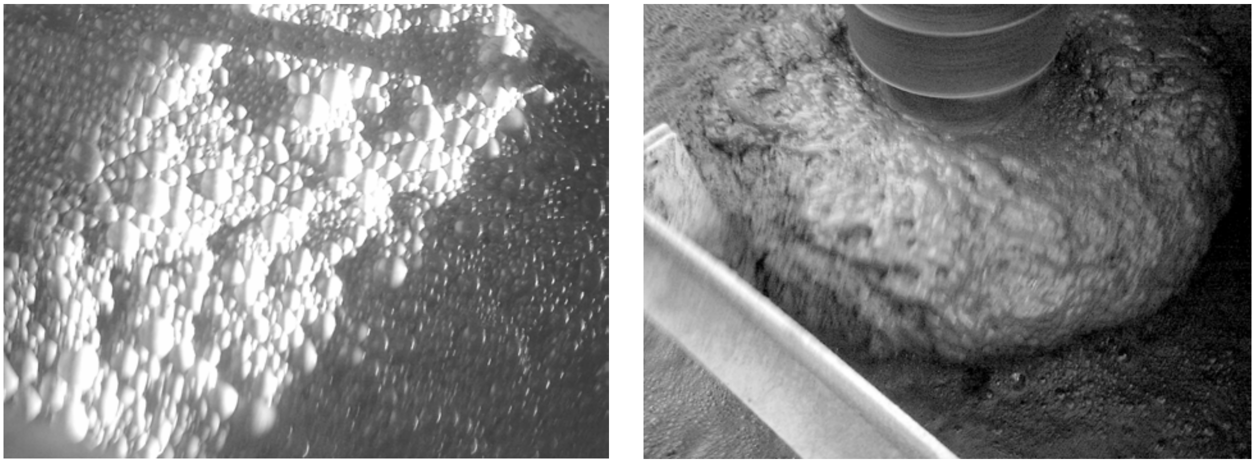

Figure 12 : Froth Appearance Without (Left) and With (Right) Regrind

Current Operation

The main focus after the commissioning of the newly built WLTRP was the optimisation of the main stream circuit as this is the key to ensure optimum PGM recovery from the recovered tailings material. Optimisation of the IsaMill and cleaner flotation circuit will be in full swing when the first phase is completed.

Operational data generated from the IsaMill and cleaner circuit has revealed that the unit is producing a P_{90} of 40µm compared to the design P_{90} of 25µm. The optimisation of this circuit is currently in progress. The first obvious change in the circuit was the increase in mass pull from the rougher circuit from a design of 8% to a current mass pull of between 10 to 12%. This is a 50% increase in feed tonnage to the unit. Consequently, the energy input is 14.5 kWh/t compared to design of 35 kWh/t which explains the coarser grind. Increasing the power draw and specific energy of grinding will form part of the cleaner circuit optimisation program.

Figure 1 indicates the average of the feed and product size distributions taken over a week period. The IsaMill produced a reduction ration of 1.6 from a F_{80} of 40µm to a P_{80} of 25µm. The current feed to the mill is much finer than originally anticipated, so the use of a finer grinding media (to increase efficiency) will also be investigated.

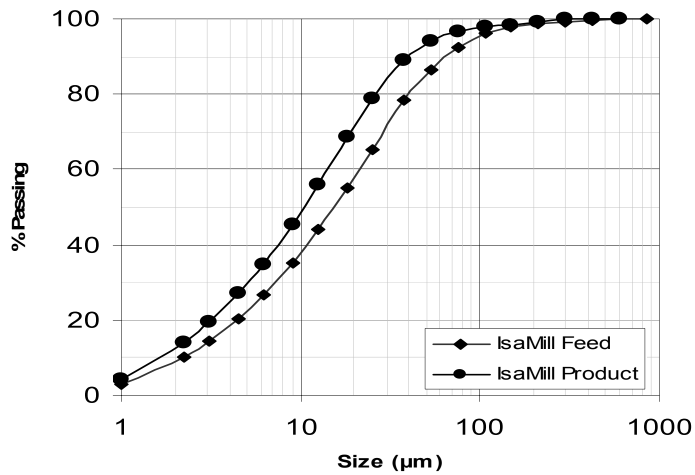

Figure 13: IsaMill Size Distribution

Fine grinding is a new and relatively unexplored field in the platinum industry and optimisation of PGM flotation after fine grinding will be the key to success. Anglo Research Laboratories has initiated several projects to investigate the optimisation of the flotation parameters to ensure maximum benefit from the IsaMill installation.

CONCLUSIONS

- The use of IsaMill technology was enabling for the WLTR project, as it allowed smeltable concentrate grades to be produced from the oxidised, slow floating tailings.
- The collaborative IsaMill design project between Anglo Platinum and Xstrata was successful and is a sound model for technology development.
- Flotation kinetics increased after IsaMilling. The improved flotation performance was due to additional liberation plus the removal of iron oxide surface coatings by grinding in an inert media environment.
- Rougher concentrate IsaMilling was required for the WLTRP, to liberate PGM's and clean-up heavily oxidised base metal sulphide surfaces.
- A staged approach was taken with the WLTRP design to limit capital exposure and minimise risk associated with the novel treatment of dormant PGM tailings.
- The design PGM grade and recovery targets were met using conventional flotation and IsaMill inert grinding technology.
- The IsaMill M10,000 scale-up (from 1.1MW to 2.6MW) was successful.

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