HUMPHRIES, G., RULE, C., and WOLMARANS, E. The development of a process flowsheet for the new Anglo Platinum, PPRust north concentrator, incorporation HPGR technology. *International Platinum Conference 'Platinum Surges Ahead'*, The Southern African Institute of Mining and Metallurgy, 2006.

The development of a process flowsheet for the new Anglo Platinum, PPRust north concentrator, incorporating HPGR technology

G. HUMPHRIES*, C. RULE*, and E. WOLMARANS†
**Anglo Platinum Limited, South Africa*
†Dowding, Reynard and Associates, South Africa

The PPRust North project is an expansion of existing operations on the 'Platreef' orebody in the Limpopo Province of South Africa. Anglo Platinum has been mining and processing the Platreef since 1993 at the adjacent Sandsloot and Zwartfontein South open pits at a current rate of approximately 4.5 million tons per annum.

This paper describes the origin of the proposed process flow sheet. A comprehensive test work programme has been conducted evaluating the best process flow sheet for the very hard and variable ore in the proposed mining area. The selection of the comminution circuit is discussed where conventional crushing and SABC options were analysed based on both extensive test work and analyses of current operational data at the existing concentrator.

The application of the high pressure grinding roll technology has significant advantages—it replaces the 3rd and 4th stage crushing stages in a conventional circuit. This programme has been conducted over several years and has involved work done at site at pilot scale, internally at the company's research facilities and externally at various sites. The on-site pilot work was completed over a 7-month period at the existing concentrator facility using a ThyssenKrupp-Polysius, 'Polycom', 950 mm by 350 mm, high pressure grinding rolls (HPGR) machine. In excess of 185 000 tons of ore was processed through the unit during the trial period. This paper describes the test work programme and particularly the proposed application of high pressure grinding technology and its potential for further application in the platinum industry.

Introduction

The Platreef is a geological region of the Bushveld Complex—the largest source of primary platinum group metals, PGMs, in the world. PGM mineralization in the area was first reported by Dr Hans Merensky in 1924. The operation is part of the Anglo Platinum operations - Potgietersrust Platinums Limited, 'PPL', being a wholly owned subsidiary. The operations are situated on the Northern Limb of the Bushveld complex some 270 kilometres north of Johannesburg. The expansion project will lead to a new mining operation and new concentrator plant.

The Anglo Platinum mineral leases extend for a strike of over 15 kilometres on the Tweefontein and Tweefontein North properties—not currently mined; Sandsloot and Zwartfontein South properties—currently mined and the contiguous extension to the North—Zwartfontein North and Overysel properties, which will be mined in the new project. The Platreef is a thick package of partly 'footwall'contaminated pyroxenite rocks, which are currently defined as a separate intrusion of the Bushveld Complex. The orebody is the only Bushveld ore deposit that is mined using large-scale open-pit mining techniques. Limited, open-pit mining of sub outcrops of the UG2 and Merensky reefs is practised in the industry.

The Sandsloot operations commenced production in 1993 at a design throughput of 200 ktpm. This has subsequently been expanded to a current rated capacity of 385 ktpm. In the financial year, 2005, the PPL operation milled 4.5 million tons, producing 201 000 oz troy platinum and 214 000 oz troy palladium with byproduct base metals of 4 600 tons nickel and 2 700 tons copper.

The PPRust North project will increase the annual milling rate to 11.8 million tons adding a further 230–240 000 oz troy of platinum and 260–270 000 oz troy palladium to current production levels.

The 1993 Sandsloot flow sheet was defined after comprehensive laboratory, pilot plant testing and batch processing trials through a nearby plant. This included pilot scale milling on selected bulk samples through an AG Ball mill circuit, utilizing a 1.75 m inside liners AG mill.

On start-up it was soon evident that the chosen AG ball milling circuit was not ideal to cater for the variable ore rock characteristics and mine fragmentation. Periods of low throughput and reduced metals recovery resulted (the primary mills achieving only 90 tph versus design 145 tph).

Ore characteristics varied significantly in some areas of the orebody. A period of optimization and modification of the circuits began immediately. However, because the project was commercially very successful the opportunity arose to rectify the circuit deficiencies.

The circuit upgrades and expansions were sequentially:

- introduction of in-circuit crushing, 'ICC'
- optimization of available milling power, change in transfer size and introduction of flash flotation

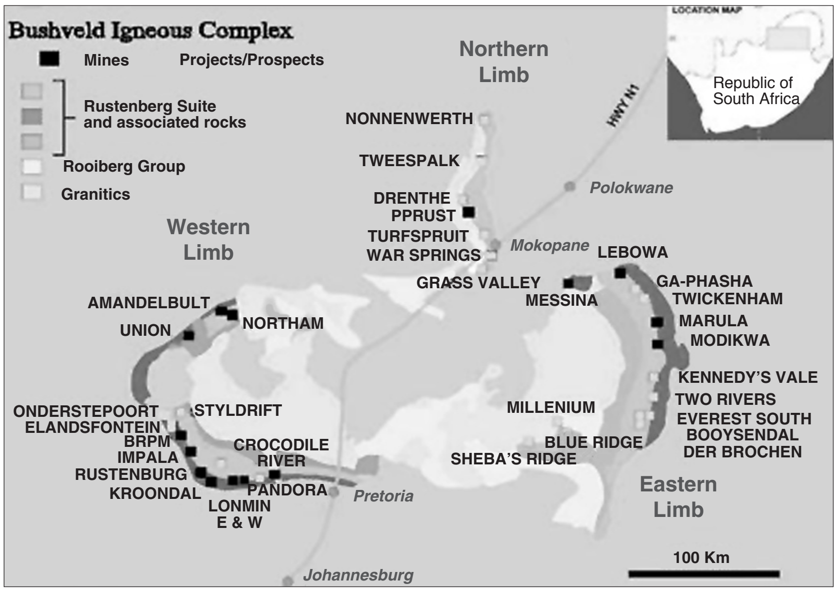
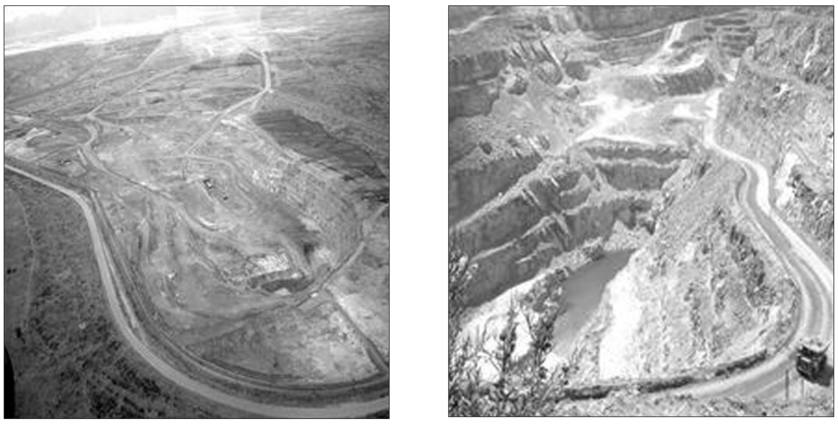


Figure 1. Location map with regional geology of the Bushveld Complex



Figures 2 and 3. Aerial views, Zwartfontein South Pit – mining commenced 2002, and Sandsloot pit – mining commenced 1993

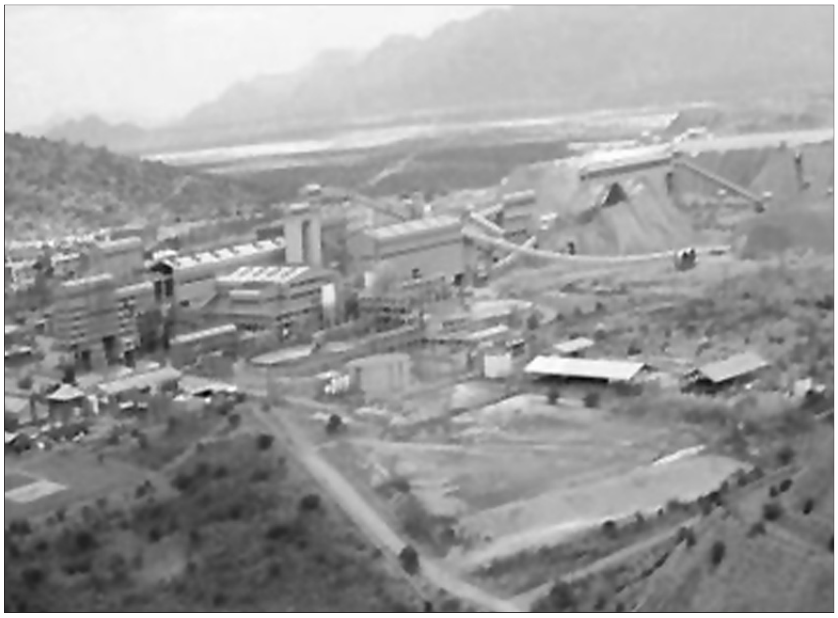


Figure 4. PPL Sandsloot metallurgical plant

- addition of new ball milling and flotation circuit, equipped with 9.75 MW in a mill-float-mill-float configuration, treating ICC product.

A detailed learning period on effects of ore type and mining fragmentation resulted. This contributed greatly to the knowledge base utilized for the PPRust North expansion project.

Thus, the flow sheet definition for the new project's processing facility considered the current operation's ore processing facility's historical and current performance.

The Sandsloot plant optimization and 'mine to mill' initiative have resulted in continuous improvement of Sandsloot plant's metallurgical performance. This has resulted in an extensive database of metallurgical and mineralogical information being generated for the Platreef orebody. This was utilized and referenced to the ore samples sourced from the drilling programme and subsequent modelling of the new Zwartfontein North and Overysel orebodies. The size of the plant was defined as 600 ktpm, mainly driven by constraints of available water within the framework of mine planning considerations and economic optimization of the project.

Geology and mineralogy of the orebody

The comminution influencing rock characteristics of the deposit have arisen due to the varied footwall geology and its interaction with primary ore magma during emplacement. The orebody that is economically exploitable

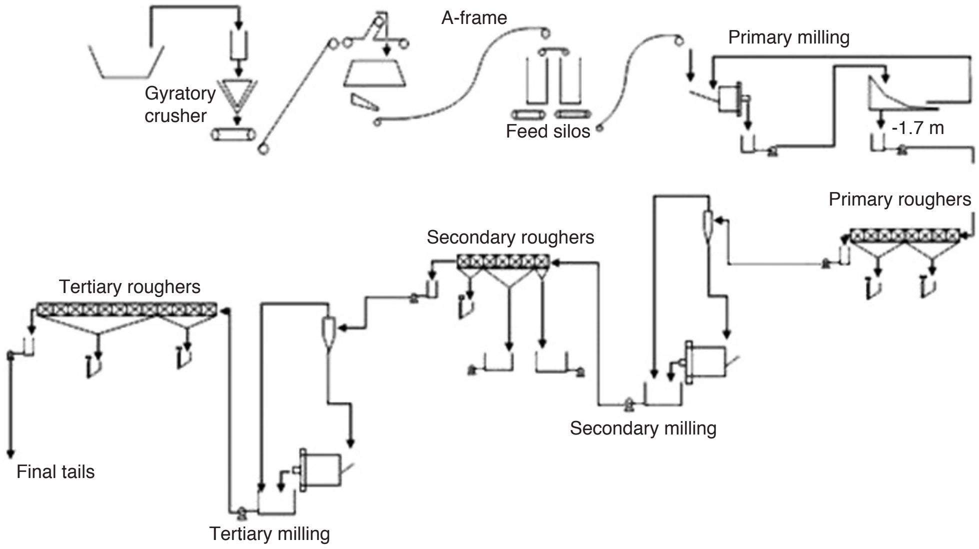


Figure 5. 200 ktpm—two parallel circuits; original flow sheet after start-up in 1993

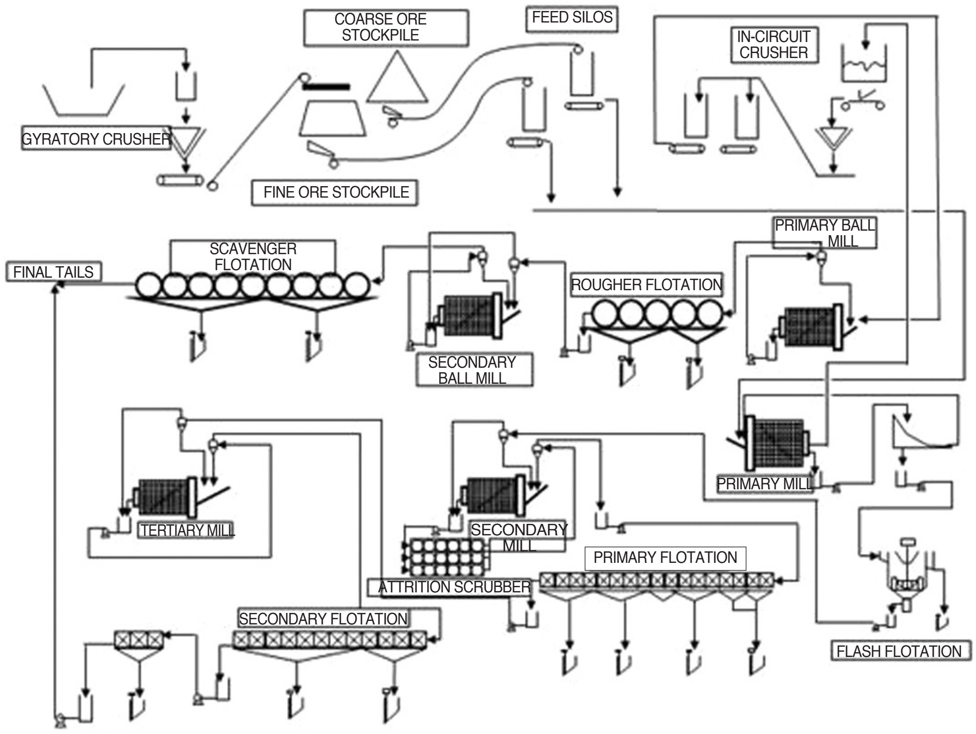


Figure 6. 385 ktpm - three integrated circuits with ICC; current flow sheet 2006

generally dips at 45°, is of an average economic thickness of 50 metres, and can be up to 200 metres thick in places—reflecting the mined reef package determined by the project cut-off grade.

As is the current practice, the rock types were classified throughout the potential ore zones: feldspathic pyroxenite, pegmatiodal pyroxenite and pyroxenite predominate, but significant localized occurrences of calc-silicates, para-pyroxenites and sepentinite occur. Footwall granofels is also often mineralized and will be included in the mined reef package in places.

The PGM and base metal sulphide mineralization is similar to that found in the existing operations. The metallurgical test work defined that a multi-stage, mill-float-mill-float circuit achieving a final product size of 80% -75 microns would be required to achieve the required recovery and grade of concentrates. Mineralogy is similar to the current orebody experience.

Due to the historical problems with comminution in the Sandsloot plant operations since 1993, a focus on the variability of the ore from a comminution perspective was maintained during the ore evaluation programme. Opportunity was taken to complete comparative work on the new orebody large diameter core samples and samples collected from ore being processed at the plant.

The ore characteristics of the orebody in the operating (two) pits and the proposed new pit area are variable. Rock characteristics for the ore zones show the variation in JK DWT (JK drop weight test parameters); UCS (unconfined compressive strength, Mpa) and BWI (bond work indices).

Tables I and II show data generated for 96 samples tested (JK DWT and BWI), for selected sections/rock pieces from bore cores or mill feed samples. The UCS data represents results from 268 tests.

The components of the reef package that will be exploited during mining will vary greatly throughout the life of the pit. Thus potentially the ore mix sent to the plant will vary significantly over the short-term throughout the life of the pit. This is the current experience at the Sandsloot operation even though batch metallurgical and grade definition is practised on 'bench' blasted and removed from the pit. All ore is stockpiled and scheduled into the plant in this way. This practically has the effect of causing significant variation in plant feed rock characteristics and operating instability frequently manifested as varying potentially monthly production levels and metallurgical performance.

Normal mine planning at PPL is currently done on grade rather than on optimization of metallurgy. Plant operating parameters are varied according to sample processing ahead of batches of ore being sent into the plant. This consideration was determined as a critical parameter in the choice of processing circuit and equipment for the new plant facility.

Processing option studies

The definition of the process flow sheet was completed after an exhaustive option trade-off study, which looked at various flow sheets. The major options considered in a detailed trade off were:

- primary crushing and SABC with either conventional crushing or HPGR in-circuit pebble crushing
- 3 and 4 stage conventional crushing followed by primary ball milling/flotation and regrind milling/flotation, the so called 'MF2' circuit
- 2 stage crushing with HPGR and MF2 circuit

HPGR technology was identified as favourable after a study of potential crushing options. It is interesting to note the initial discussions centred on using the HPGR as a replacement for conventional crushers in the in-circuit crushing, ICC, step of a conventional SABC circuit.

Table I
Typical rock characteristic data for the current and project lease areas showing variability in Bond work indices, JK DWT and UCS values

	BWI			JK DWT			UCS		
	Ave.	Range	Std.Dev.	Ave.	Range	Std.Dev.	Ave.	Range	Std.Dev.
Overysel	22.5	18.0-28.6	2.2	31.1	23.4-44.9	5.7	163.8	30.4-378.0	70.7
Zwartfontein	25.5	22.1-31.1	2.5	32.3	24.0-52.4	6.4	176.1	26.0-342.0	62.9
Sandsloot	23.9	17.8-29.5	2.1	32.6	21.6-53.8	6.6	177.7	76.7-361.0	54.2
Sandsloot (mill trial)				32.4	28.0-43.3	4.1			

Table II
Ore characteristics variation with rock type

Rock Type	A	b	Ax b	Ta	S.G.	BWI @74um (kWh/tonne)
Hanging Wall	73.72	0.39	28.7	0.20	3.04	26.5
Feldspathic Pyroxenite A-Reef	87.53	0.35	30.6	0.27	3.19	25.5
Feldspathic Pyroxenite B-Reef	60.78	0.51	31.0	0.31	3.20	26.7
Pyroxenite	55.49	0.64	35.5	0.43	3.14	23.8
Para-pyroxenite	67.58	0.40	27.0	0.27	3.04	27.5
Serpentinite	64.85	0.42	27.2	0.28	3.05	27.8
Calc-silicate	68.98	0.40	27.6	0.22	3.13	25.5

External consultants were used to model the options based on the data collected for the ore types expected. A higher risk of production variability was identified for the SABC option.

One criterion that Anglo Platinum has defined in its operations in recent years is the impact of process stability on metallurgical performance—principally in variation in mill circuit performance. The major variable influencing the mill product variation is mill feed size distribution and ore characteristics variation in the primary mill feed stream.

In the PGM industry the impact of metals recovery on project economics reflects the relatively high precious metals prices; decision making with respect to the process efficiency is influenced strongly by this factor. The metallurgical effect on recovery is sensitive to the grind. A target grind of 80%–75 microns for Platreef is the defined operating parameter for the current and the new operation. However, work is in progress to grind finer still, utilizing ultra fine grinding technology, with a target grind of 80%–53 micron showing economic benefit. Areas of poorer metallurgical performance in the orebody show increased proportions of very small composite silicate/PGM mineral assemblages, which require finer grinding to liberate for flotation recovery.

MF2 and MF3 circuits have found favour throughout the PGM industry in the last three decades due to their inherent ability to maximize metals recovery and meet concentrate specifications for smelting.

The main selection criteria were defined and after analyses of capital cost, operating costs, operational stability and metallurgical risk, it was identified that an optimal processing level of 600 ktpm employing a single module mill-float-mill float, MF2 flow sheet with primary ball mill feed preparation by three-stage comminution with HPGR as the third stage met the overall project criteria best.

On-site pilot operation of the HPGR

After an initial technology assessment of the technology it was decided that further work was necessary to ensure that it was well assessed. In order to seriously consider high pressure grinding rolls for application in the PPRust North project flow sheet, it was realized that a pilot campaign must be conducted. ThyssenKrupp-Polysius agreed to lease a machine for a six-month trial at the Sandsloot site.

The pilot campaign had as major objectives to:

- determine the suitability and reliability of HPGR technology for processing Platreef ores
- determine wear parameters and maintenance knowledge to apply within feasibility and applicability studies
- determine operability factors and familiarize operating and maintenance personnel with the technology
- ensure that all metallurgical and operational implications were understood to allow effective process engineering of the HPGR into the flow sheet design.

An approximately 1.5 million US$ project to trial the 900 mm/350 mm, twin 160 kW, Polycom Magro 09/3-0 unit was approved and construction commenced at PPL. The unit was built and operated on a continuous basis by the contractor under supervision of plant technical and management personnel. The technology suppliers provided the specialist operational and maintenance support. A technical assessment strategy was drawn up and agreed with the technology supplier.

The plant was commissioned in October 2004 and designed for 50 tph final product with testing at 25 and 35 mm feed sizes from the associated conventional crusher plant.

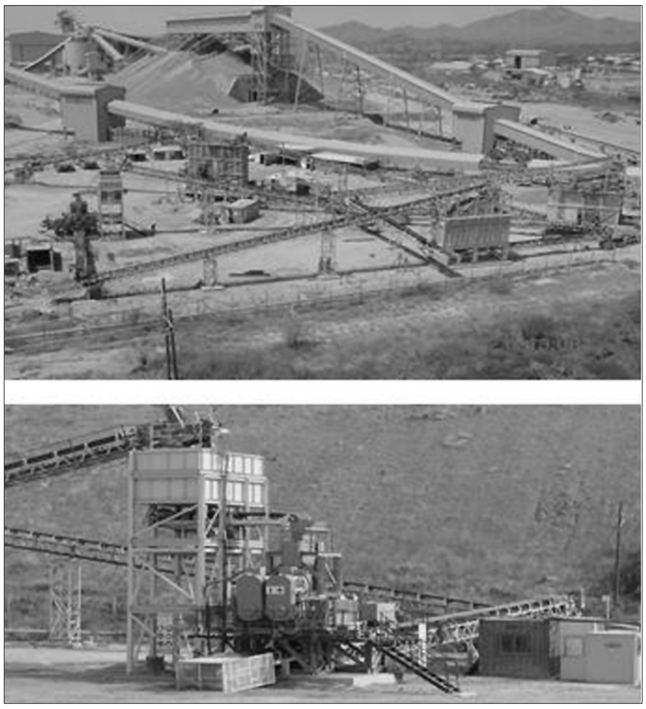
The plant eventually ran for seven months and crushed in excess of 185 000 tons of Platreef ore. The average throughput achieved was 60–70 tph of final product and with an 8 mm slotted polyurethane screen closing the circuit. The machine feed rate was on average 100 tph. The progressive wear rate on the rolls was measured routinely. Feed and product samples were taken and analysed. Additional samples were taken off site for testing at the Divisional Metallurgical Laboratories, 'DML' and Anglo Research, 'AR'.

A full metallurgical assessment at pilot scale 1–2 tph was conducted on feed samples generated by the crusher and HPGR plants. In addition a comprehensive laboratory scale assessment was undertaken. A scale-up exercise was conducted by AR personnel comparing the actual and predicted performance of the PPL unit using the laboratory 'Labwal' machine on the same ore sample.

At the end of the testing period 1 000 ton batches of UG2 ore and Merensky ore from the nearby (~100km), Lebowa platinum mine were processed to generate size distribution data and samples for off-site testing. The applicability of HPGR technology to other Anglo Platinum operations could then be assessed.

The test was very successful with the following major findings:

- Wear rates achieved on the tungsten carbide stud wear material on the rolls were relatively very low and for commercial application the predicted life is 20 000+ hours
- Reliability and operability were classified as excellent with high machine availability, > 95%, predicted
- Size distributions produced were significantly finer than obtained for conventional crushing of Platreef material



Figures 7 and 8: HPGR unit installed at PPL Sandsloot site

- Downstream primary ball mill operation would consume less power with HPGR for given mill product size distribution—due to comparative HPGR/crusher size distributions
- No problems were evident with cake breakage during screening and downstream material handling
- Potential further benefits in improved metallurgy and power consumption through micro-cracking were identified but not conclusively proven—no benefit assumed for the new plant design
- Operating and maintenance staff at PPL, after initial skepticism, are very supportive of HPGR technology use.

The circuit availability was very good—the lower monthly figures; see Figure 9, were due to three minor problems—the longish down times were due to the supplier's technician traveling to site from Johannesburg.

The wear profiles were measured weekly at several points across the face of both rolls using a purpose built jig.

The product size distributions were measured around the PPL circuit at various points—see Figure 13. The closed circuit product with 8 mm dry screening had a d50 of 1 mm (approximately).

This product size distribution is compared to conventional crusher products at PPL on the same ore sample processed.

The machine was operated over a range of pressure from 70 to 90 bar, an effective grinding force of between 3.8 and 5.3 N/mm^2 producing a overall average power consumption of between 2.5 and 3.13 kW/ton. There was no significant difference in particle size distribution found over the pressure range analysed on the plant test period. The variation in HPGR feed size distribution, however, may have masked any differences.

The unit operated at a fixed speed of 22 rpm, which gave a peripheral speed of 0.74 m/s. Detailed comparative data was generated from the site work and used in the modelling exercise conducted at AR. The samples used for the modelling work were taken at the same time as the plant testing programme was conducted.

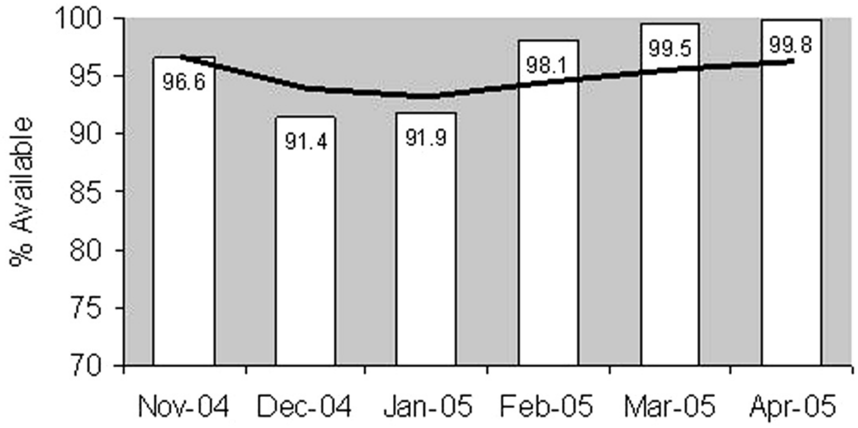


Figure 9. HPGR circuit availability

Figure 10. HPGR rolls at installation and during operation

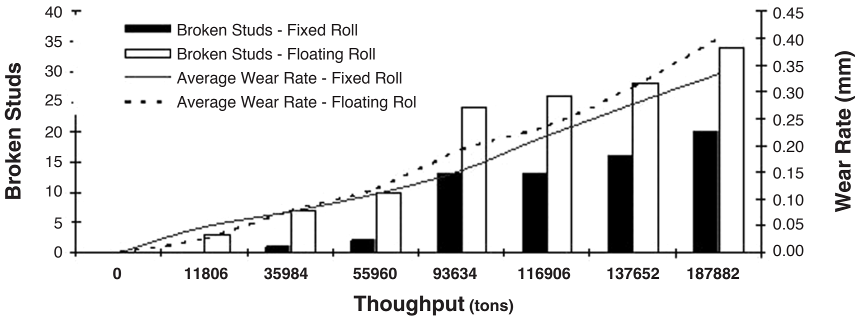


Figure 11. HPGR roll wear profiles during test period

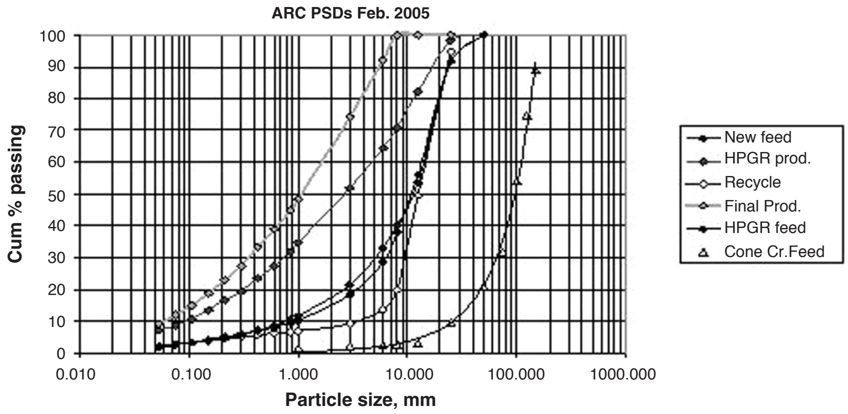


Figure 12. Typical particle size distributions around the HPGR circuit

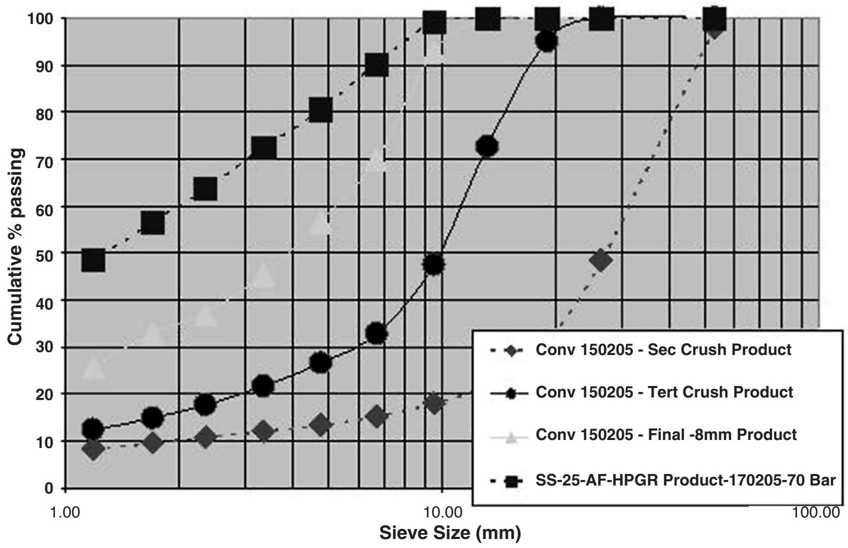


Figure 13. Comparative particle size distributions for HPGR product and conventional crushing

Cake stability did not appear to be an issue as the cake broke up on the vibrating screen deck fairly easily throughout the whole test period. The dust generation at each change of direction point and on the screen was identified as an important area to be considered in detail in the commercial scale design. The photographs, Figure 14, taken sequentially, show the operator able to break the cake easily by hand.

Off-site test work covered several key areas:

- modelling work as previously mentioned, that was conducted at AR using the Labwal machine and the Magro pilot unit for verification of the developed JK model
- investigation of the potential metallurgical benefits of HPGR product compared to conventionally crushed product after milling in flotation. This test programme was completed at the DML pilot plant with 500 ton bulk samples taken from the PPL circuit at the requisite point. The pilot plant circuit runs at approximately 2 tph.
- investigation, at the AR facilities, using the Labwal unit, of the effect of double pass HPGR processing on particle size and metallurgy
- investigation of potential Bond work index effects caused by HPGR comminution was done at AR
- laboratory-scale investigation of potential flotation benefits due to HPGR crushing compared to conventional crushing

Definition of the flow sheet for PPR North project

The overall circuit definition process was concluded after the test work and external studies were completed on the HPGR option. The HPGR product size distribution was important in the sizing of the milling equipment. Resolution was reached on the twin or single module(s) trade-off and risk assessment studies.

The circuit comprises vibrating grizzly and primary gyratory crusher—60/113 driven by a single 1 MW drive, delivering—175 mm product to a conical frame stockpile. The stockpile feeds a secondary crushing circuit in closed circuit producing a -65 mm product for the HPGR circuit feed. The secondary crusher circuit product is stored in silos with live capacity of 15 000 tons. The HPGR is a 2.5 m diameter by 1.7 m width unit driven by twin 2.6 MW drives. The HPGR circuit is closed by dry screening (10 mm slotted vibrating screens), the circuit product feeding a mill feed silo of 15 000 tons live capacity. This buffer capacity, before and after, the HPGR has been sized to ensure maximized milling and flotation circuit up-time and minimal stoppages.

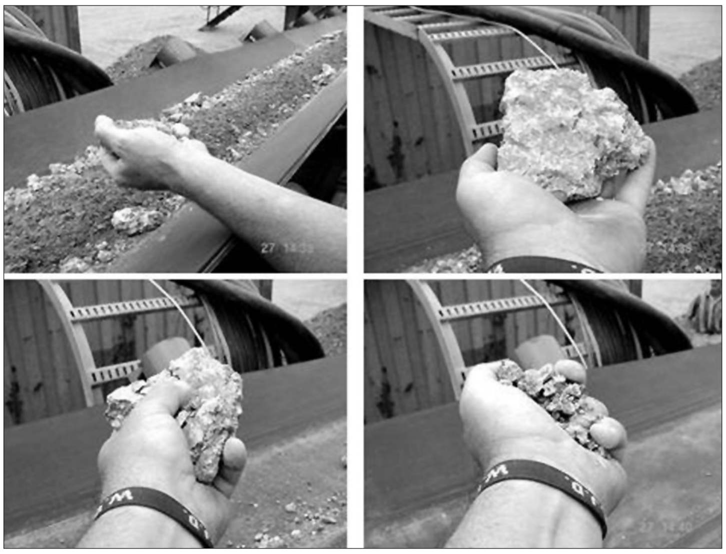


Figure 14 HPGR product cake stability demonstrated

The milling circuit comprises a 26′ diameter by 39′ EGL primary grate discharge ball mill in closed circuit with a cyclone cluster—designed to produce a 50%—75 micron primary rougher flotation feed. This circuit features the option to feed HPGR product to the mill inlet or to a wet screening stage ahead of the mill. Undersize material in HPGR product can thus be routed to the cyclone feed via the mill discharge sump. This allows flotation size particles to bypass milling directly to flotation. Cyclone overflow is gravity fed from the cyclone cluster to primary rougher flotation—14 100 m^3 flotation cells. Primary rougher tails are reground in a secondary overflow ball mill. This circuit will be equipped with a second 26′ diameter ball mill in closed circuit with cyclone cluster; mill product of 80% -75 microns is gravity fed to a secondary rougher stage comprised of 16 130 m^3 flotation cells. The primary and secondary ball mills will be driven by 17.5 MW gearless drives.

Concentrate cleaning is achieved in a three grade cleaning circuit where mainstream concentrates are fed according to kinetic ranking at the determined point in the circuit. Buffer capacity between mainstream and cleaning flotation is provided by surge tanks. Open circuit operation and future retrofit of ultra fine grinding of concentrates has been allowed for in the design.

The final concentrate is thickened and filtered in pressure filters for road dispatch to the group smelters at Polokwane, Mortimer or Waterval. Final tailings are pumped after thickening for deposition on a new tailings impoundment on the lease area. Paste thickening to maximize water use on the project is being evaluated currently.

Conclusion

The new PPR North concentrator facility has been designed to optimize metallurgy and project life cycle economics.

The circuit uses HPGR technology with conventional crushing feed preparation to ensure that circuit stability is enhanced. Feed stability, maximized milling/flotation circuit up-time, effective de-coupling of unit comminution processes for maintenance and steady flotation feed grind size distributions are major objectives that are met in the circuit design.

Energy savings and operating benefits will also be achieved compared to the other options considered.

Large, single module equipment has been installed with sufficient buffer between process steps to maximize plant up-time.

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