RULE, C.M., MINNAAR, D.M., and SAUERMANN, G.M. HPGR—revolution in platinum? *Third International Platinum Conference 'Platinum in Transformation',* The Southern African Institute of Mining and Metallurgy, 2008.

HPGR—revolution in Platinum?

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High pressure grinding rolls (HPGR) technology has come a long way in its application for comminution duty in hard rock mineral processing in the last three years. Several major projects in copper, nickel, gold, molybdenum, platinum, and iron ore have opted for this technology. Advances in wear abatement technology have established the HPGR as a reliable machine with the required high utilization and availability.

The HPGR captures the imagination as the next step change improvement in ore processing, based on the following benefits:

- Energy efficiency (potentially 10–30% more efficient)—very topical in an increasingly 'green' society, and in times of rapidly increasing energy costs and availability concerns. 2008 has shown this to be especially important in Southern Africa
- High (and stable) throughput with a relatively small footprint
- Lower operation cost
- Liberation benefits
- Creative 'mine-to-metal' system improvements made possible by HPGR.

The platinum industry, renowned for its historically conservative approach, has not been left behind with two significant new HPGR installations, one in Platreef application and one in UG2 application, commissioned in 2008. While the decision for the Platreef application was driven primarily by comminution circuit capacity and design imperatives, the UG2 application seeks to develop a flowsheet that will have a significant recovery benefit in addition to capacity increase and reduced operating cost. The Platreef application of HPGR also provides the opportunity to introduce a novel comminution flow sheet and to demonstrate exceptionally low wear rates treating very hard, abrasive and variable ore types.

The HPGR lends itself for inclusion in existing SABC circuits to increase the capacity of the plant and mills. With current PGM prices many operations are attracted to the HPGR technology benefits. The HPGR clearly has the potential to transform entrenched opinion and provide decision makers with significant alternative comminution options.

This paper aims to provide an overview of the current applications and to speculate on the transforming stimulus that the HPGR exerts on industry.

Introduction

'Acceptance of the HPGR in the hard rock sector has been slow and cautious, but has come to maturity in the successful commissioning of the Cerro Verde project'. (Morley C, 2008)

High pressure grinding roll (HPGR) technology has been the subject of many technical presentations in the minerals comminution fraternity ever since the technology was first introduced as an energy efficient comminution device that revolutionized cement grinding plants.

HPGR was quickly accepted in the minerals realm for diamond processing in various flowsheet positions. Since the first installation in 1986 HPGR also revolutionized kimberlite treatment plants. Avoiding the breakage of large diamonds in the size reduction process provides very persuasive driving force.

From the mid-nineties HPGR revolutionized iron ore concentrate and pellet feed filter cake treatment plants to the point that it is now considered standard equipment.

Twenty-one years after the first installation, the Polycom HPGR has come of age, having developed appropriate roll wear abatement technology (Figure 1), and proved itself as an alternative comminution device for 'hard rock' applications offering (amongst others) reduced operating cost (energy and wear efficiency). The Cerro Verde (copper/molybdenum), Freeport Indonesia (copper) and Boddington (gold/copper) projects selected HPGR as preferred technology.

Anglo Platinum embraced the technology for its Mogalakwena Mine (previously Potgietersrust Platinums Limited Mine) after conducting diligent studies and investigations. Similarly, Northam Platinum recognized the potential of the Polycom HPGR for its UG2 plant. The question is whether these two successful installations will also initiate a revolution in the platinum industry's approach to comminution as has occurred in several other sectors.

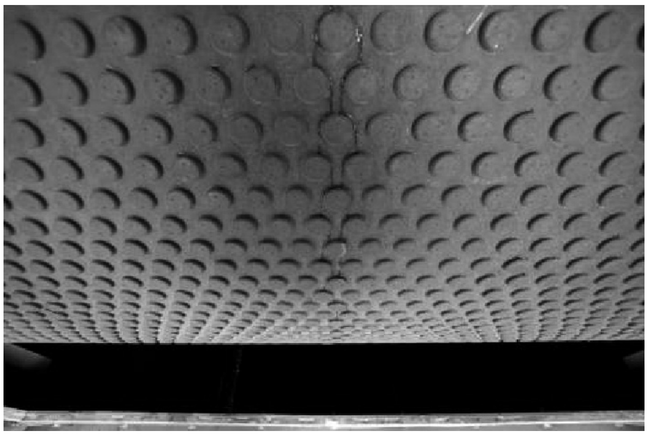

Figure 1. Roll wear abatement technology

High pressure grinding roll—an overview

Operating principle—interparticle breaking

The HPGR consists of a pair of horizontally-opposed counter-rotating rolls, one fixed and the other floating. Feed is introduced to the gap in between the rolls and is crushed by the mechanism of interparticle breakage. The grinding force applied to the crushing zone is controlled by a hydro-pneumatic spring on the floating (movable) roll. When the feed enters the gap between the rolls, the pressure in the crushing zone increases until it exceeds the preset pressure in the hydropneumatic systems. At this point the floating roll moves against the pistons, increasing the gap between the rolls. The movement compresses the nitrogen in the piston accumulator, increasing the total hydraulic system pressure. Eventually the hydraulic system pressure equals the pressure in the crushing zone and the floating roll maintains it position. At this point the working gap is reached. Energy is thus transferred to the feed material through pressure in the material bed and not primarily through the gap between the rolls.

The speed of the rolls is also adjustable (VSD) to obtain optimum grinding conditions.

Ores most amenable to HPGR comminution

The 'amenability' of an ore or process to HPGR treatment should be considered relative to the driving factors that influence the decision in favour of installing HPGR. These factors include the following:

- Liberation/recovery benefit through selective comminution of softer components of the ore and breaking along grain boundaries. This is clearly seen and intuitively accepted in the recovery of diamonds, which accounts for the quick acceptance of the HPGR in this sector. Refer Figure 3
- Energy efficiency achieved through the inherently more efficient energy transfer mechanism in the HPGR than in tumbling mills. While the degree of energy savings is ore specific and has to be tested individually, it is common to find 10 to 30% reduction in comminution energy. In cement where energy is a significant cost driver, the HPGR has been assimilated very quickly. In hard rock minerals wear-related issues had to be addressed before this advantage could be realized. The larger the amount of work performed in the HPGR, the greater the energy savings
- In existing installations the most compelling reason for installing HPGR is the necessity to increase production and reduce operating cost. The larger amount of fines produced by the HPGR holds the potential for increasing the throughput in downstream ball milling by 30–50%. This is achieved with relatively small machine footprint
- HPGRs also offer the potential to reduce operating wear costs. Recently HPGRs have been justified on savings in grinding media alone
- For new installations, the main reasons given for considering HPGRs as an alternative to SAG mills are large capacities, low head grades, high energy requirements, and high pebble recycle rates. Proven high availability and utilization of HPGR means that it can be combined in the flowsheet with small or no buffer capacity with the downstream 'wet plant'.

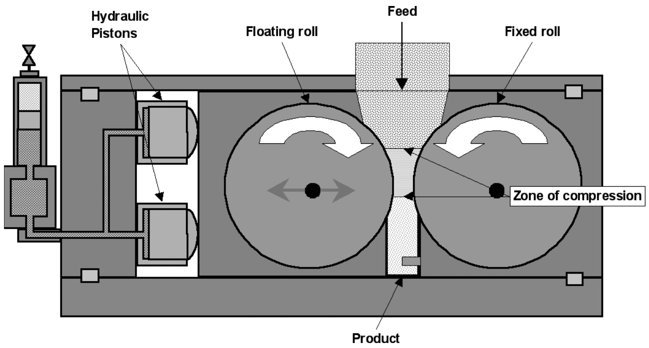

Figure 2. Schematic cross-section of HPGR

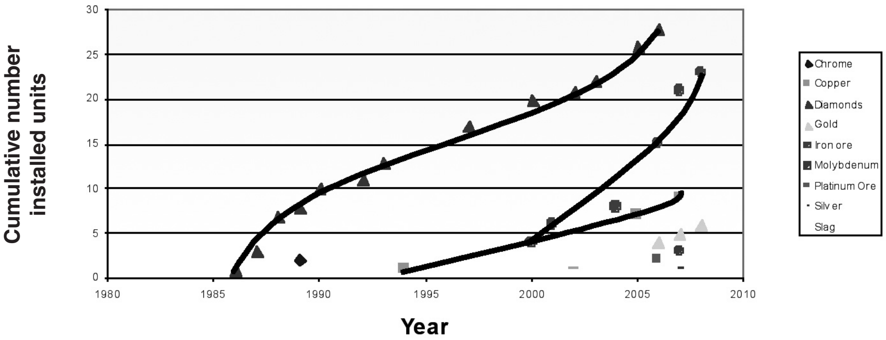

Figure 3. Growth rate of HPGR installation in minerals

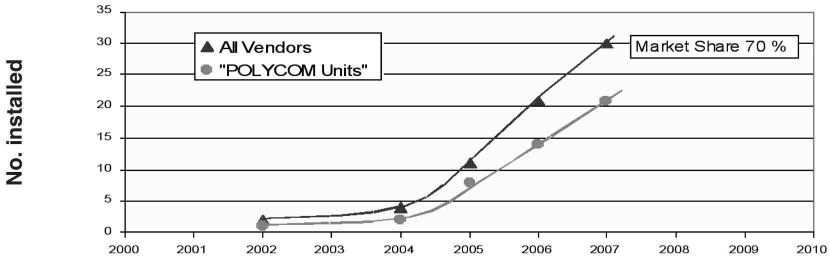

Figure 4 . Growth rate of HPGR installation in hard rock industry

- Faster start-up to full production, i.e. HPGR typically achieves full production in 2–3 months or less.
- Fewer operating parameters (pressure, roll speed), but more efficient control
- The fact that HPGRs maintain production rate even as the rolls wear
- No decrease in production after liner change out which occurs in the case of SAG mills.

In general hard brittle ores with low to medium abrasiveness (in an HPGR) are most suitable to comminution in an HPGR.

The larger the benefit, the easier the decision can be made in favour of a 'new' (higher risk) technology. The growth of HPGR in minerals applications clearly shows this phenomenon. The case for HPGR in hard rock applications is a combination of the above factors. The perceived risk of installing HPGR is fast diminishing with more and more successful installations.

Polycom HPGR installations in minerals applications

The Polycom HPGR can be engineered for roll diameter, roll width, roll speed and hydraulic and bearing size to cater for any specific throughput requirement but standard size machines emerge. A summary of machines installed in the minerals sectors highlights this.

The machine model is designated as PC 17/12-4, meaning roll diameter 1.7 m, roll width 1.2 m and frame size 4. See Tables I–III

Installation in platinum comminution circuits

Two significant installations pioneered the use of HPGR in platinum comminution circuits in 2008. One installation is in a greenfield Platreef application whereas the other is a retrofit in a UG2 plant. The two installations and their relevant business cases are discussed in more detail below.

Anglo Platinum Mogalakwena North concentrator

The new Mogalakwena North, formerly PPL, concentrator began commissioning in late 2007 with first ore processed towards the end of first quarter 2008. The flow sheet employs the first HPGR in the PGM industry at a design throughput of 7 million tons per year through a single machine.

Careful study of various flowsheet options resulted in the selection of HPGR as a tertiary crusher ahead of an 'MF2' ball milling and flotation circuit shown in Figure 7. The following options were considered:

- 4-stage conventional crushing followed by MF2 ball milling
- 2-stage conventional crushing, HPGR in closed circuit followed by MF2 ball milling
- Primary crushing, SABC, incorporating pebble crushing (conventional and HPGR).

Particular attention was paid to the following:

- Flowsheet operability and process stability
- Capital and operating risk
- Benefits and risk
- Metallurgical performance
- Recommended investigations and testwork.

Since PPL already had more than 10 years, experience operating an SABC plant with in-circuit crushers, the study sought to gain an appreciation for the salient operational requirements of an HPGR. To this end tests were conducted at Polysius Research Centre, Anglo Platinum Divisional Metallurgical Laboratories (DML), Anglo Research Centre and JK Minerals Research Centre.

Table I
Kimberlite installations

Quantity	Machine model	Installed power (kW)
3	PC 28/05 B	2 x 600
1	PC 20/10-5	2 x 730
1	PC 19/15-6	2 x 1 350
8	PC 17/08-6	2 x 825
8	PC 17/12-4	2 x 720
1	PC 14/08-2	2 x 400

Table II
Iron ore installations

Quantity	Machine model	Installed power (kW)
1	PC 11/08-1	2 x 200
1	PC 14/08-2	2 x 500
1	PC 14/08-4	2 x 500
1	PC 14/10-4	2 x 615
4	PC 17/12-5	2 x 1 200
2	PC 17/14-5	2 x 1 320
6	PC 20/15-6	2 x 1 650
1	PC 22/15-9	2 x 1 800
5	PC 24/17-8	2 x 2 300

Table III
Hard rock installations

Quantity	Machine model	Installed power (kW)
1	PC 09/06-0	2 x 220
1	PC 17/09-5	2 x 800
1	PC 22/16-8	2 x 2 800
11	PC 24/17-8	2 x 2 500–2 800

Figure 5. HPGR Polycom 22/16- 8 at Mogalakwena plant

At the Polysius Research Centre Atwal wear (HPGR with 100 mm roll diameter) and Regro (HPGR with 720 mm roll diameter) reliability tests were conducted. The results of these test indicated that Platreef ore is very amenable to HPGR comminution, having high specific throughput rates, creating high percentage of fines (29–33% passing 250 µm) in final product with specific energy ranging between 1.2 and 1.6 kwh/t at an optimum specific grinding force between 3 and 4 N/mm^2. The Atwal wear index further indicated wear rates to be among the lowest encountered to date by Polysius for 'hard rock' applications. This is particularly interesting since Platreef ore is considered to be a medium to high wear rate ore in conventional circuits.

Pilot-scale testing was conducted at the DML to compare milling and flotation response between conventional crusher and HPGR product.

The Anglo Research centre conducted 'bulk sample' Labwal tests on an HPGR with 250 mm roll diameter and 100 mm roll width. The aim was to perform bench-scale flotation evaluation.

JKMRC conducted Labwal batch tests with the aim of quantifying the potential energy benefit of employing the HPGR and developing a simulation model for Platreef.

The positive results of the laboratory-scale tests paved the way for large-scale HPGR testing over a period of 6 months on Platreef ore at site in 2004/2005. The aim of this 75 tph (fresh feed) test was to obtain an accurate measure of actual wear rate, reliability, availability and operating cost and at the same time introduce HPGR technology to the operating and maintenance personnel at the site. This test showed that low roll wear and a favourable ball mill feed particle size distribution was achievable on the hard and variable ore types mined at the PPL and PPRust North pits.

This intensive large-scale test was self-funding due to the increased production provided by the HPGR in a comminution constrained operation.

The decision in favour of the HPGR technology at Mogalakwena was enabled by:

- The fine HPGR particle size distribution, 'psd', which allowed the circuit to be designed for the required tonnage employing single module ball mills in the standard MF2 configuration
- The energy requirement for the overall circuit was reduced due to HPGR incorporation
- Wear rate and operating cost savings—an HPGR roll tyre wear life of 12 000 hours is conservatively expected

Figure 6. The pilot facility at Mogalakwena South

Table IV
Summary of the JKMRC work carried out on Platreef samples illustrating the energy savings achieved using HPGR versus conventional comminution

Target grind size (µm)	300	150	106	75	45
Stage 1—HPGR energy (kWh/t)	3.3	3.3	3.3	3.3	3.3
Ball milling of HPGR product (kWh/t)	16.2	25.6	32.8	57.7	53.7
Total HPGR route energy (kWh/t)	19.5	28.9	36.1	61.0	56.9
Stage 1—Jaw crushing energy (kWh/t)	2.4	2.4	2.4	2.4	2.4
Stage 2—Rolls crushing energy (kWh/t)	0.9	0.9	0.9	0.9	0.9
Jaw + Rolls crushing energy (kWh/t)	3.3	3.3	3.3	3.3	3.3
Ball milling for conventional product (kWh/t)	23.6	33.7	40.0	63.0	70.0
Total conventional route energy (kWh/t)	26.9	37.0	43.3	66.3	73.3
Net energy saving for HPGR route (kWh/t)	7.4	8.1	7.2	5.3	16.4
Energy saving (%)	27.6	22.0	16.7	8.0	22.3
Average energy saving (%)			19		

- While not statistically representative, the test indicated a potential upside for metallurgical improvement
- Operating and maintenance staff accepted the 'new' technology
- The HPGR had 96% availability during the 6-month test period
- Ore characteristics and plant feed variability were major risks for FAG/SAG operation.

Mogalakwena North comminution flowsheet

The Mogalakwena North flowsheet consists of

- 2-stage conventional crushing—60/113 primary gyratory with 1 MW power, plus three H8800 secondary crushers
- HPGR – PC 22/16-8 with 2 x 2,800kW motors
- MF2 ball milling—two 26' Ø ball mills each with 17.5 MW gearless drives
- Allowance is made for future mainstream inert regrinding (MIG) and concentrate regrind (UFG)
- Twin parallel flotation equipped for 'head to head' testing—feeds, tails and concentrates sampling points.

HPGR statistics

Model number	:	Polycom® 22/16-8
Roll diameter	:	2200 mm
Roll width	:	1600 mm
Installed power	:	2 x 2800 kW
Throughput	:	2 160 tph
Feed size	:	< 65 mm
Product size	:	< 8 mm (~ 50%–1 mm)
Machine weight	:	345 tons

Performance of Mogalakwena North concentrator

The total design circuit rate is specified at 900 tph, with the HPGR circuit specified at 1 200 tph, allowing for 'catch up' to fill the mill feed silos facilitating optimum overall plant uptime around major maintenance downtime.

Hot commissioning of the plant started in March 2008. As at end of July 2008, the plant has been running at full design capacity consistently and it has been seen already that there is much capacity upside in the overall circuit. At the time of paper submission the plant was reaching the end of the planned production ramp-up phase and there has only recently been an opportunity to perform a survey of the circuit. The data are still being processed. It is therefore too early to report on the performance of the HPGR on the particle size distribution, wear rate of the rolls, energy balance and overall metallurgical performance. The early indication of the full-scale HPGR is however, encouraging. The current performance suggests that the plant design throughput would be exceeded. The observed circulating load is in the order of 96 to 118%, which is somewhat higher than that expected based on results of the demonstration plant. Much opportunity remains for optimization.

Table V provides a comparison of the initial operating parameters of the HPGR with that of the demonstration and pilot plant units.

The HPGR unit at Mogalakwena North has already shown the benefit of enhancing downstream circuit stability in the early operational period. The comminution circuit provides a very steady particle size distribution despite variations in ore quality coming into the plant.

Commissioning issues

As with commissioning any new circuit, a number of operational and design issues were identified during the start-up of the circuit of the Mogalakwena HPGR circuit.

Feed presentation and roll skewing

Two variable speed driven, 'VSD', belt feeders are used to feed onto a fixed speed conveyor belt that feeds the HPGR. During the detailed design process the length of the feed bin to HPGR conveyor link was increased beyond the original design criterion. Thus the control action was compromised. Early commissioning problems were experienced with the feed presentation of the belt feeders onto this belt. This resulted in roll skewing and necessitated modifications to the chutes below the feed silo.

It has proven difficult to achieve a desired level in the HPGR feed hopper. Since the HPGR unit is not fitted with VSD drives, it was realized that the speed of the feed conveyor has to be increased in order to obtain a level in the HPGR hopper. A VSD will be retrofitted on this conveyor that will enable the HPGR to achieve and maintain level in the feed bin. HPGR works best when choke fed.

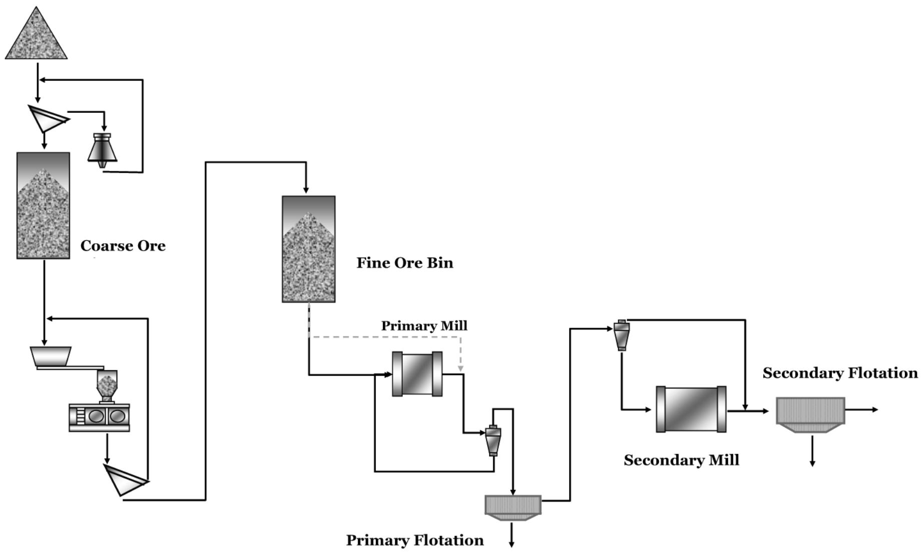

Figure 7. Mogalakwena North flowsheet

Table V
Comparison of full scale HPGR and demonstration and pilot plant scale units

Unit		Mogalakwena				PPL MAGRO	AR Labwal
		19–Apr	28–Apr	15–May	Design		
Ore type						Sandsloot	Sandsloot
Feed size	mm	0–45	0–45	0–45	0–45	0–25	0–12
Nitrogen pressure	bar	70	55	55	70	40	17
Preset pressure	bar	100	100	100		90	91
Working pressure	bar	100	140	140	155	121	–
Zero gap	mm	30	30	30		12	4.5
Floating roll power (gross)	kW					130	6.7
Fixed roll power (gross)	kW					125	2.7
Total roll power (gross)	kW	4 000	3 000	3 374	4 400	255	9.4
Total no load power (for both rolls)	kW	150	150	150	150	20	4.77
Roll speed	rpm	20.5	20.5	20.5	20.5	22	22
Average operating gap	mm	42	52	56	60	21	5.3
Net spec energy cons (total HPGR feed)	kWh/t	2.26	1.38	1.34	1.97	2.40	2.39
Net spec energy cons (final product)	kWh/t	7.70	2.71	2.93		3.13	–
Specific grinding force	N/mm^2	2.88	4.03	4.03	4.49	5.3	5.4
Specific throughput rate	t/m^{3}h			241	280	270	269
Measured axe flake thickness (stud to stud)	mm						
Measured axe flake thickness (high to high)	mm			60		30.75	9.27
Measured flake density (PPL samples)	t/m^3			2.64	2.55	2.42	2.77
Measured mass flow rates							
Circuit fresh feed rate	tph	500	1 050	1 100		75	1.95
HPGR total fee	tph	1 700	2 060	2 400	2 160	98	1.95
Screen oversize	tph	1 200	1 010	1 300		23	
Screen undersize	tph	500	1 050	1 100		75	

Figure 8. Fine product on mill feed belt

Excessive wear in the feed hopper

The fact that level is not achieved in the feed hopper results in continuous ore impact on the feed hopper, which leads to excessive wear in the feed chute. This is addressed through temporary means but it is imperative that level is achieved in the feed hopper – awaiting VSD installation on the feed belt drive.

Dust suppression

A consequence of the inherent feature of the HPGR to create large amounts of fines, together with the dry processing of the material, means that dust generation is to be expected. The plant design opted for dust suppression rather than dust extraction. This suppression system proved to be problematic in that the material processed can be hygroscopic and tends to 'cake-up' on contact with even low amounts of moisture. This resulted in a number of flow problems in chutes, transfer points and screens. A long-term solution is being investigated and is likely to be the replacement of the current dust suppression system with a multiple and localized dust removal system.

Bearing temperatures

Higher than expected roll bearing temperatures (>80 degrees C) were experienced shortly after start-up as the volume through the machine was ramped up. This caused the machine to trip. A closed circuit water cooler will be added to the bearing cooling system of the HPGR.

Northam Platinum UG2 plant

The HPGR installation in the Northam UG2 plant is the first installation in a PGM UG2 concentrator. It is also the first brownfield upgrade project in a platinum concentrator where an HPGR is installed with the aim to increase the plant capacity while simultaneously reducing operating cost, increasing PGM recovery and reducing chrome in final concentrate.

The original Northam UG2 plant did not achieve its designed primary grind. This MF2 circuit employed a primary rod mill to grind the secondary crusher minus 20 mm product.

The plant suffers of a high rod wear rate (2 kg per ton treated) requiring 0.5 hour delays every second day to charge new rods. In addition the rods are expensive at R5 600/ton and available from a sole supplier only.

Objectives of the project

- Increase plant throughput from 75 000 tpm to 100 000 tpm

Figure 9. Northam UG2 Plant Polycom 09/06-0

- Reduce operating cost
- Reduce energy consumption
- Increase PGM recovery
- Reduce chrome content in concentrate
- Secondary crusher
- HPGR PC 09/06-0
- Re-pulper
- Flash flotation
- Convert rod mill into ball mill with low ball charge (15%)
- Primary flotation
- Secondary mill
- Secondary flotation

HPGR statistics

Model number	:	Polycom® 09/06-0
Roll diameter	:	950 mm
Roll width	:	650 mm
Installed power	:	2 x 200 kW
Throughput	:	160–200 tph
Feed size	:	< 32 mm
Product size	:	75% passing 1 mm)
Machine weight	:	32 tons

Commissioning experience

The HPGR was hot commissioned at the beginning of June 2008. The event went without incident and except for some minor software adjustments there were no delays in getting the plant started up. The rod mill was operated for another two weeks after starting the HPGR to compare the HPGR/rod mill circuit with the HPGR/ball mill circuit and to ensure that all was well before the rod mill was converted to a ball mill.

Initial results

The plant has been running for approximately one month at the time of submitting this paper and has not yet been optimized. The total impact of the conversion is still being evaluated. Preliminary observations and measurements are extremely promising.

- Throughput of 160 tph exceeds the project's design specification of 150 tph with further upside potential already evident
- Total energy consumption is 20 to 30% lower referred to the comparative grinds achieved. Refer to Table VI, which shown the reduction in work index to create 75 μm product
- Achieve 42% passing 75 μm after the converted ball mill (original rod mill). This is 100% improvement on the best case 22% passing 75 μm in the original plant
- Total 4E PGM (fire assay) based recovery of 84% is being achieved. This is an improvement of 4% on average preproject plant performance. Refer Table VII.
- Low (1.9%) chrome, (as Cr_2O_3) content in final flotation concentrate
- Availability and utilization of plant higher than original plant—no stoppage for rod charging.

Plant optimization and detailed quantification of the total effects of the upgrade project is ongoing.

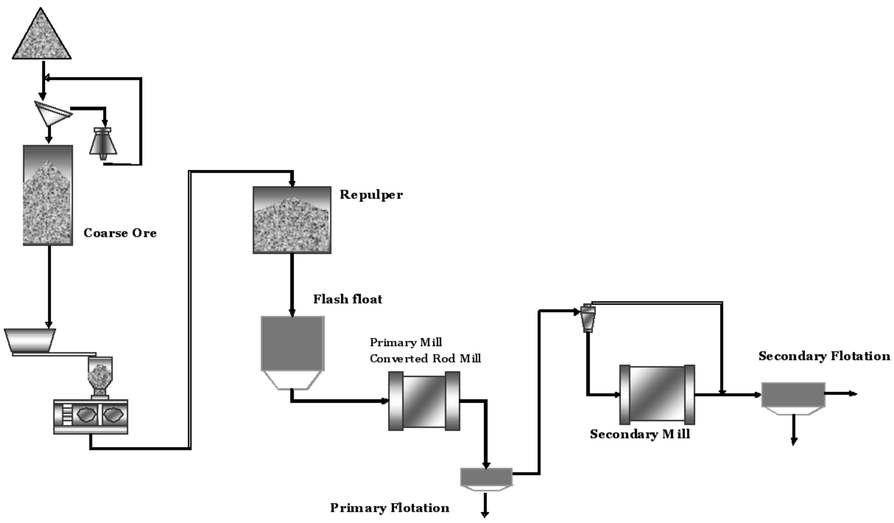

Figure 10. Northam UG2 concentrator comminution flowsheet

Table VI
Comparison of progressive flowsheet development at Northam

	Throughput (tons/h) dry	Operating work index (kWh/ton)	Work index (kWh/ton -75 μm PRF)	PRF % –75 μm	PRF % –106 μm	Mill SG
Design rod mill	115	9.9	28.3	35	–	–
Rod mill	140	9.62	54.6	17.64	32.33	2.26
HPGR and rod mill	151	9.64	37.51	25.69	34.27	1.65
HPGR and ball mill	156	7.86	20.97	37.49	49.80	1.60

Table VII
Comparison of progressive improvement of primary flotation recovery at Northam

	Rod mill	HPGR Rod mill	HPGR Ball mill
Primary flotation revovery (%)	72.5	77.8	81.6

Conclusion

HPGR technology has matured and is now accepted in the minerals industry as a viable alternative comminution technology. In many cases HPGR provides significant benefits to the operation. This has resulted in an increase in interest, in numerous potential future projects with HPGR applications and extensive discussions at international gatherings of mineral processing professionals. Most importantly the number of actual HPGR installations in worldwide operations is increasing exponentially.

Will HPGR revolutionize the platinum ore processing industry? Every operation is uniquely driven by various factors including ore comminution characteristics, existing flowsheets and different mining rates and there is thus more or less opportunity for improvement at various existing plants. Given these considerations, HPGR technology can be expected to play a significant role in the future of platinum processing.

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He qualified as a mechanical engineer from the University of Pretoria in 1989. In 1997 he received an MBL from the University of South Africa.

He has served the mining industry in various capacities since 1997. He was responsible for the industrialisation for South African production of crushers and mills for a leading supplier, has experience in product testing, plant commissioning and product support. He has extensive experience in advising industry in the field of comminution, ranging from crushing (primary through tertiary), milling and grinding.

He played a leading role in establishing the 'preferential mill' technology which has been adopted as the standard flow sheet by De Beers Marine and others with specialised requirements. He counts this as one of his proudest achievements.

Since 2004 he focused his efforts in establishing the HPGR in hard rock applications (i.e. gold, copper, Platinum, etc.) in his capacity as product manager and marketing manager.

He currently represents Polysius as Manager, Minerals.