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Understanding the influence of HPGR on PGM flotation behavior using mineralogy

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ABSTRACT

Due to the very fine grained nature and complexity of the platinum bearing ores from the Bushveld Complex in South Africa, numerous processing operations have investigated alternate comminution devices that can be used to liberate the platinum group minerals of the Merensky and UG2 ores at a coarser grind, at reduced energy consumption and increased throughput. In this study, the mineralogy and flotation performance of product from the high pressure grinding rolls (HPGR) was evaluated and compared to a conventional ball mill product with the aim of determining whether the HPGR product could be used for flotation without any further grinding. Results show that for both the Merensky and UG2 platinum ores, the HPGR product showed more fines and less coarse content compared to the ball mill product. No conclusive evidence of preferential liberation was observed for samples prepared by particle bed breakage. The best flotation results were obtained from the ball mill product. The results from this study have shown the definite need for an integrated approach for the interpretation of the results that extends beyond just measurements of valuable mineral liberation.

1. Introduction

The Bushveld Complex in South Africa is one of the largest layered intrusions in the world and hosts economic deposits of chromium, vanadium and the platinum group elements (PGEs) (Clarke et al., 2009). The platinum group minerals (PGMs) are exploited from three major reefs in the deposit, the Merensky, UG2 and Platreef. Copper and nickel base metal sulfide (BMS) minerals are exploited as by-products in the process. These three reefs account for up to 80% of the world's reserves of the platinum group elements (PGE, Liddell et al., 1986). The total platinum group element (PGE) abundance of these reefs ranges between 4 and 8 g/t and is sometimes lower (1–3 g/t) with PGM grain sizes ranging from less than 10 μm up to 350 μm (Cabri, 2004; Schouwstra et al., 2000). The major BMS present in the reefs include chalcopyrite ($CuFeS_2$), pyrrhotite ($Fe_{1-x}S$), pentlandite ($(Fe,Ni)_9S_8$) and pyrite (FeS_2). The Merensky reef is richer in the BMS (~1 wt.%) than the UG2 reef (~0.1 wt.%). In general, the majority of the PGM are associated with the BMS (Lee, 1996).

The extraction of the valuable minerals from the Merensky and UG2 ore is a highly energy intensive process. This is due to the significant energy used in the grinding and liberation of the very fine grained PGMs (Cramer, 2001; Liddell et al., 1986). Conventional comminution devices such as the ball mill are well known for their energy inefficiency (Fuerstenau et al., 1999; Tromans, 2008). Therefore, in a climate where energy costs are rapidly increasing, the mineral processing industry has investigated alternate, more energy efficient comminution methods. This has occurred in conjunction with the need to improve capacity, recovery and reduce operating costs in the beneficiation stage (Rule, 2008). The high pressure grinding rolls (HPGR), developed by Schönert in the 1970s (Schönert, 1988) is one such possible device that may satisfy these requirements.

Several possible applications of the HPGR in comminution circuits include the following (Brachthauser and Kellerwessel, 1988); one step comminution in the fine crushing to coarse grinding size range, pre-treatment of the feed of a conventional tumbling mill in open or closed circuit, or production of the final product in closed circuit. In these configurations, the attractiveness of the HPGR is the 20–50% reduction in energy consumption, the 20–30% increase in throughput, as well as the significant reduction in operating costs compared to conventional circuits AG/SAG mills in primary grinding applications (Daniel, 2007).

One of the further potential advantages of the HPGR are the reports of preferential weakening and or/liberation of particles. Tavares (2005) argued that due to the inter particle bed breakage that occurs when the compressive forces from rotating rolls such as the HPGR transmit energy through layers of particles, a preferential weakening of the coarser particles occurs. This may in turn result in preferential liberation, such as has been reported by authors such as Celik and Oner (2006) or Apling and Bwalya (1997).

Recent systematic studies on BMS ores, such as Wightman et al. (2008) and Vizcarra et al. (2010), showed that for a particular size class of particles less than 150 μm, the degree of liberation

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achieved was independent of the comminution device. In the PGM ore context, Daniel (2007) found no enhancement of liberated material with the HPGR. Palm et al. (2010a) also found no improvement in liberation of the PGM with the use of the HPGR, although the BMS showed improved liberation.

The effect of the HPGR on downstream processes however, is of key interest when assessing its value. Esna-Ashari and Kellerwessel (1988) reported increased mineral recovery in leaching due to the presence of the micro-cracks that increase the porosity of the ore, and allow the leach fluid to efficiently percolate through large particles. Palm et al. (2010b) also found an improvement in Zn grade and recovery with the use of the HPGR on the flotation of a sphalerite ore. Some studies have shown no significant improvement in mineral recovery with the application of the HPGR compared to the ball mill, particularly for fine feeds (Dunne et al., 1996; Shi et al., 2006). It has also been shown that for a PGM ore, the use of the HPGR prior to rod milling was actually to the detriment of the flotation performance (Palm et al., 2010a).

The focus of this study on platinum ores is to determine whether the product of the HPGR is sufficiently comminuted for the primary flotation circuit, without any subsequent grinding requirements. In order to assess this, the flotation performance in terms of PGE recovery of the Merensky and UG2 platinum ores will be evaluated. Given that there are also several different HPGR operational and design variables that have significant effects on energy consumption and the degree of mineral liberation (Lim et al., 1996, 1997), three different operating conditions will be investigated and compared to a ball mill product. The detailed analysis of the effects of these operating conditions on energy efficiency, throughput and reduction ratios are given in Solomon et al. (2010). Numerous studies have also shown that the effect of comminution on flotation behavior cannot be truly assessed without consideration of the mineralogy of the ore (Becker et al., 2008; Johnson and Munro, 2008; Nel et al., 2005; Triffett and Bradshaw, 2008). Consequently, the results of this study are interpreted within the perspective of the effect of the mineralogy on the process and vice versa.

2. Experimental details

Bulk samples of both Merensky and UG2 platinum ore were sourced from the Lonmin Platinum mines as run of mine ore from the Western Limb of the Bushveld Complex. The bulk samples were crushed to feed top sizes of 12 mm and 6 mm, blended and then split into 500 kg samples for the HPGR and ball mill tests.

2.1. HPGR tests

A Krupp Polysius LABWAL HPGR located at Mintek in Johannesburg with 250 mm rolls diameter, 100 mm rolls width and a roll speed of 0.5 m/s was used in this study. Three different operational conditions were investigated to generate HPGR product with a grind suitable for flotation tests. An operating pressure of 150 bar corresponding to the specific press force of 7.5 N/mm^2 was used and the material underwent four passes for all HPGR tests. Different HPGR operating gaps were used on each of the 500 kg bulk samples. Table 1 summarises the different experimental conditions used in generating the HPGR product. Further details of the energy consumption and throughput associated for the different experimental conditions are given in Solomon et al. (2010). The final HPGR product was then screened on a 1 mm sieve. The −1 mm sub-sample was split into either 1 kg samples (Merensky ore) or 1.2 kg samples (UG2 ore) in preparation for flotation, sizing and mineralogical analysis. Just prior to flotation, the dry sub-samples were made into slurry and transferred to the flotation cell where the volume was made up with synthetic plant water to ensure a solids concentration of ∼35 wt.%.

2.2. Ball mill tests

A Pilot scale ball mill with a 700 kg/h capacity located at Lonmin Platinum was used. A 6 mm feed size was used, and milling conducted at 78 wt.% solids. The ball mill product was discharged onto a 1 mm screen where water was added to ensure that the screen undersize had a solids concentration of ∼35 wt.%. Six 3 L samples were collected at the screen undersize for flotation, sizing and mineralogical analyses.

2.3. Flotation tests

A 3 L Leeds batch flotation cell was used for the flotation tests. The cell was fitted with an impeller whose speed was manually maintained at 1200 rpm. Flotation reagents were added to the cell and allowed to condition for absorption onto the mineral surfaces (Table 2). The air supply was then switched on and concentrates were collected after 2, 6, 12 and 20 min of flotation by scraping froth into a collecting pan every 15 s. The pulp level was kept constant by manually adding synthetic plant water made according to

Table 1
Summary of the experimental conditions used to produce the three different HPGR samples.

Test	Feed top size (mm)	Operating gap (mm)	Pressure (bar)	Number of passes
1	12	1.5	150	4
2	12	3.0	150	4
3	6	1.5	150	4

Table 2
Reagent dosages used in the batch flotation tests.

Reagents	Merensky reef		UG2 reef	
	Type	Dosage (g/t)	Type	Dosage (g/t)
Activator	$CuSO_4$	55	$CuSO_4$	170
Collector	SNPX	200	SNPX	155
Depressant	Dep 267	220	KU11	80
Frother	DOW200	40	DOW200	40

Table 3
Quantitative mineralogy of the Merensky and UG2 platinum ore samples.

Mineral (wt.%)	Merensky reef	UG2 reef
Pentlandite	0.6	<0.1
Pyrrhotite	0.4	<0.1
Pyrite	0.2	<0.1
Chalcopyrite	0.3	<0.1
Other sulfides	<0.01	<0.01
Orthopyroxene	45.9	12.8
Clinopyroxene	7.8	0.9
Olivine	0.6	0.2
Talc	0.1	0.3
Serpentine	1.2	1.6
Amphibole	0.7	0.2
Chlorite	1.5	2.8
Plagioclase	33.4	14.5
Mica	0.7	0.7
Chromite	5.0	62.1
Quartz	0.5	0.3
Oxides	0.6	1.1
Calcite	0.2	0.2
Other	0.6	2.3