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A rheological investigation of the behaviour of two Southern African platinum ores

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ABSTRACT

With the installation of ultrafine grinding on many platinum operations in southern Africa, there were concerns as to whether this would cause rheologically complex behaviour during the subsequent flotation of the ore. Rheologically complex behaviour refers to the non-Newtonian behaviour experienced by some suspensions, associated with exponential increases in yield stress and viscosity with increasing solids content. This is attributed to particle size and solids concentration effects, surface chemistry, and mineralogy. In this study, the rheological behaviour of two different platinum ores; a western limb UG2 ore and a Great Dyke platinum ore were investigated and compared with that of single mineral studies of the major gangue minerals of platinum ores (chromite, orthopyroxene, plagioclase and talc). The results show that Great Dyke ore is considerably more rheologically complex than UG2 ore. Great Dyke flotation concentrate shows high yield stress and viscosity at low solids concentrations (>20 vol.% solids). Should the ROM ore in a Great Dyke flotation operation suddenly show significant changes in ore mineralogy, the rheological properties of the slurry should be considered since they may be detrimental to the overall performance of the operation (e.g. loss of recovery through poor gas dispersion). In contrast, the rheological behaviour of UG2 flotation samples shows little cause for concern for the plant operator. Comparison of the pure mineral samples shows that the complex rheological behaviour of the Great Dyke ore may be attributed to the high degree of low temperature alteration and the formation of phyllosilicate minerals such as talc, more than particle size effects.

1. Introduction

1.1. Southern African platinum ores

The Bushveld Complex in South Africa and the Great Dyke in Zimbabwe are two of the primary sources of the platinum group elements (PGE – Pt, Pd, Ir, Ru, Ro, and Os). The global market for these precious metals includes a variety of applications such as the catalytic, electronic, automotive and even medical industries (Cawthorn, 2010). These precious metals occur in a host of platinum group minerals (PGM) that are often associated with the base metal sulfides (BMS) in three discrete reefs within the Bushveld Complex: namely the Merensky Reef, the UG2 Chromitite and the Platreef. Typically, the PGM in these three reefs are fine to very fine grained and only present in g/t concentrations (Holwell and Mc Donald, 2007; Kinloch, 1982; Mc Laren and De Villiers, 1982; Schouwstra et al., 2000). Similarly to the Bushveld Complex, the economic PGE mineralisation in the Great Dyke is stratabound and is found in the Main Sulfide Zone (MSZ) and the Lower Sulfide Zone (LSZ) (Oberthür et al., 2004).

In the last two to three decades, PGM concentrators have predominantly processed the Merensky Reef, which is a pegmatoidal pyroxenite ore with a base metal sulfide (BMS) content of ~1 wt.%. This is simpler to process than other platinum ores on account of the slightly coarser average grain size of the PGM, their strong association with the base metal sulfides (flotation recovery of PGM due to their association with floatable BMS) and the low chromite content of the ore (<5 wt.%). Since then, there has been a shift to process other PGM ores: UG2, Platreef and Great Dyke, all of which come with their own set of challenges (Rule, 2010). These include the liberation and flotation recovery of ultra-fine PGM particles (Rule and Schouwstra, 2011), processing of a dual density ore (e.g. UG2; Mainza et al., 2005), minimising the grade of Cr_2O_3 in the concentrate due to its detrimental effects on the smelter efficacy (Barnes and Newall, 2006) and minimising the amount of floatable gangue in the concentrate so as to increase smelter capacity (Mkhize and Andrews, 2011).

With the installation of stirred milling on many PGM operations, the issue of poor PGM liberation has essentially been addressed. A PGM flow sheet may use stirred milling in two

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applications: traditional ultra-fine grinding (UFG 80% < 20 μm) that seeks to improve concentrate grade in the cleaning stages and main stream inert grinding (MIG 80% < 45 μm) which seeks to liberate the valuable PGM locked in silicates (Rule, 2010). Several concerns have arisen with the installation of this technology on PGM ore. One of these is whether there will be an increase in the amount of naturally floating gangue (composite orthopyroxene and talc particles, Becker et al., 2009; Jasieniak and Smart, 2009) resulting in significant dilution of concentrate grade. This is particularly so for Great Dyke ores that show considerable low temperature, late stage alteration associated with the formation of hydrophobic talc (Li et al., 2008). Another concern is whether the decrease in average particle size associated with fine grinding will cause rheological problems in subsequent downstream ore processing. It has been well established that suspension rheology is strongly affected by the nominal particle size as well as the distribution of particle sizes in the mineral suspension (Boger, 1999; Farris, 1968; Tangsathitkulcahi, 2003).

1.2. Effects of rheology on processing

In general, ultrafine particles lead to rheological difficulties that may often manifest in complications during ore manageability and processing. Typical processing challenges associated with rheological complexities include the retardation of grinding within the ultrafine regime, due to viscosity effects (Shi and Napier-Munn, 2002). In flotation, high pulp viscosities can result in poor gas dispersion, increased turbulence damping, bubble coalescence and high gangue recovery, and can influence froth stability and mobility (Bakker et al., 2010; Farrokhpay, 2012; Genc et al., 2010; Schubert and Bischofberger, 1978). In the case of poor gas dispersion, the small bubbles generated within the vicinity of the impellor are not efficiently dispersed throughout the cell by bulk fluid flow due to the high (apparent) viscosity of the slurry. This inhibits bubble-particle contact, which is the fundamental mechanism of flotation. Cavern formation refers to the formation of a region of yielded fluid within the vicinity of the impeller of the flotation cell, whilst the rest of the slurry remains stagnant. Poor gas dispersion and cavern formation usually occur at high volumetric solids concentrations (Bakker et al., 2010; Shabalala et al., 2011). Dewatering operations are also highly sensitive to rheological factors as they affect both the settling rate and compressibility of the slurries, resulting in backfilling problems, instability and subsequent collapse of the tailings dams if not controlled (de Kretser et al., 1997; Nguyen and Boger, 1998).

The rheological properties of mineral slurries, simply defined as the suspension yield stress and viscosity, are of great practical importance in many mineral processing applications as they are useful indicators of the degree of aggregation and dispersion of particles within that suspension (Johnson et al., 2000; Lukham and Rossi, 1999). Although the distinction between these two parameters is often difficult in practice, they each represent different contributions towards overall suspension behaviour. For example, the design and operation of pumping systems of particulate suspensions is based on the viscosity and yield stress values. In such an application, knowledge of the yield stress is significant in ensuring the successful start-up of a pumping system from a static shut down condition, and the viscosity is an indication of the pumping requirements and ease of flow thereafter (de Kretser et al., 1997).

In addition to size effects on slurry rheology, rheological complexities may arise from the minerals themselves, i.e. from their surface charge distribution and morphologies. Studies linking the mineralogical content and rheological response have identified phyllosilicate gangue minerals as major contributors towards ore flow behaviour (Burdukova et al., 2008; Shabalala et al., 2011). This is supported by fundamental studies which have been conducted on pure phyllosilicate mineral suspensions, reporting significantly higher viscosities and yield stresses in the presence of phyllosilicate minerals (particularly swelling clays and serpentine minerals) compared to non-phyllosilicate mineral suspensions (e.g. quartz) (Ndlovu et al., 2011a,b). Often broadly classified as 'clays', this class of phyllosilicate minerals is closely associated with several processing issues such as reduced flotation rates (Ralston and Fornasero, 2006), complex tailings treatment (de Kretser et al., 1997) and pumping challenges (Dunn, 2004).

Non-Newtonian and rheologically complex behaviour in the processing of Platreef PGM ore has been attributed to the presence of phyllosilicate minerals such as talc and serpentine (Burdukova et al., 2008; Shabalala et al., 2011). These minerals generally form through low temperature alteration processes that convert anhydrous minerals such as orthopyroxene ($MgSiO_3$) to talc ($Mg_6Si_8O_{20}(OH)_4$)), or olivine (Mg_2SiO_4) to serpentine ($Mg_3Si_2O_5(OH)_4$). Little, however, is known about the rheology of other (non-phyllosilicate) minerals, specifically orthopyroxene (inosilicate), plagioclase (tectosilicate) and chromite (oxide) which are the major gangue constituents of UG2 ore.

1.3. Objective

The primary objective of this study is to compare the rheological behaviour of two different platinum ores, a western limb UG2 ore and the Great Dyke ore with that of the constituent minerals of the ores. In order to do so, rheological measurements of typical feed, concentrate and tailings of the two ores were performed to ascertain the changes in yield stress and viscosity with increasing percentage solids. In this paper, these measurements are compared with those of single mineral studies of orthopyroxene, plagioclase, chromite and talc to determine the effect the minerals have on the rheology. An additional objective is to identify streams which show complex rheology that may cause concern regarding any detrimental effects it will have on the performance of the flotation concentrator.

2. Analytical methods

The experimental programme comprised rheological analyses on plant samples and pure mineral samples as summarised in Table 1. UG2 ore samples were obtained from a miniplant campaign investigating ultrafine grinding (IsaMill) on a bulk sample of western limb UG2 ore, viz: primary rougher feed, rougher concentrate, final tailings. Great Dyke samples were obtained from the plant itself, viz: primary rougher feed, high grade concentrate, rougher tails and cleaner tails. The samples were dried and split into representative sub-samples for further rheological measurements. In each case, a wet size analysis was obtained using a Malvern Mastersizer (Malvern, UK).

Mineral samples of plagioclase, orthopyroxene and chromite were prepared from samples of Bushveld anorthosite, pyroxenite and chromitite respectively. Quartz and talc were also included for comparative purposes. Quartz was sourced from Kiln Contracts, W. Cape, South Africa in pre-ground form, whereas New York talc was derived from Wards Scientific. The mineral samples were further milled using a Ferguson ring pulverizer to less than 20 μm which is the particle size typical of ultra-fine grinding applications. The particle size distribution was determined using a Malvern Mastersizer.

The mineralogical composition of the UG2 flotation samples was determined using QEMSCAN (Fig. 1). Samples were wet screened, sized and prepared into vertical sections for bulk mineralogical analysis (BMA) with QEMSCAN on a LEO SEM at the Uni-