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Original Article

Binary modelling the milling of UG2 ore using a matrix approach

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ABSTRACT

The study reports a binary matrix modelling and simulation studies to improve the performance of the secondary grinding circuit of UG2 ores. The model developed was intended to help searching for optimal operating conditions of the secondary milling circuit so that the platinum group element (PGE) recovery is increased while reducing Cr_2O_3 entrainment in the subsequent flotation stage. A series of laboratory batch-scale tests was carried out in order to estimate the milling kinetics parameters of the chromite and non-chromite components. Finally, two alternatives circuit configurations for a better performance were evaluated using simulations. The optimal design consisted of a conventional ball mill in closed circuit with a hydrocyclone to separate the milling product into lights (non-chromite-rich) and heavies (chromite-rich) fractions followed by a vibrating screen to de-slime the cyclone underflow before it is returned to the mill for further grinding.

1. Introduction

Simulations of grinding circuits using mathematical models are increasingly used in comminution because of their low cost and their ability to consider many variables simultaneously [1,2]. Results from simulations can provide useful information on the effects of proposed changes on the circuit performance in terms of size distribution and material composition under various operating conditions. The size distribution and composition of materials in grinding circuits are often quantified by population balance models, more appropriately called size-mass balance models [3]. Many of these models are very complex that their simplified approaches are preferred to describe the steady-state and dynamic performance of grinding mills [4–8]. The aura of these models lies in that they are powerful frameworks that can be used to maintain the mass integrity and describe the output of equipment [7,9]. Their Achilles' heel is that they are limited to describing the behaviour of the size distribution and composition of material inside the mill in terms of input and output. They are not also suitable, in general to combine both size reduction

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model and liberation model in the same model framework. Further, population balance models do not describe in a very comprehensive way individual milling kinetics behaviours of multi-component ores. Some examples on the milling kinetics modelling of multi-component ores simulated using simplified population models are given hereinafter. Finch and Ramirez-Castro [5] used a simplified population balance model, referred to as the cumulative breakage rate function to describe the individual mineral grinding kinetics behaviours of some ores processed at Pine Point mines concentrator. A similar approach was later extended, by Laplante et al. [6] to describe the grinding mill circuit of multiple classes of composite particles. More recently, Hinde and Kalala [8] adopted the same approach to reconcile the behaviour of chromite and silicates in the closed circuit milling of UG2 platinum ores. A simplistic way of representing grinding population balances is by use of matrices [1]. The transformation matrix approach can be very useful in describing individual milling kinetics parameters (Selection, Breakage, Discharge and Partition curve Functions) of multi-component ores during grinding circuit simulations. The matrix modelling approach was successfully used by Choi et al. [10] to estimate the individual milling parameters of ZnS and gangue of a sphalerite ore. A similar approach was used by Herbst et al. [11] to develop a multi-component-multi-size liberation model of a copper ore.

The aim of the study was to develop a binary matrix model that adequately describes the grinding kinetics behaviour of chromite and non-chromite components during ball milling in a closed circuit with a hydrocyclone and a screen, and to investigate the effects of the proposed circuit configuration on the minimization of chromite content in downstream processes using simulations.

2. Contextualization

Platinum concentrators in South Africa experience significant losses of valuable platinum group metals (PGM) in their secondary milling circuits due to insufficient liberation of platinum-bearing minerals. In fact, the interlocked texture between chromite and the valuable minerals predisposes the PGM ores to an inefficient froth flotation. Studies on the froth flotation of PGM ores abound (Mailula et al. [12], Hay [13], Hay and Roy [14]) and highlighted the problem brought by a high proportion of chromite in the PGM concentrates. Entrainment mechanism of fine chromite has been recognized to be the main responsible for the contamination of the PGM concentrates. The problem of chromite in PGM concentrates is very critical. Chromite belongs to the spinel group which forms stable compounds at temperatures approaching 2000 °C [15]. A high chromite content in the concentrate impacts negatively on the smelting efficiency. For this reason, the chromite level in the final concentrate has to be kept as low as possible. PGMs in the UG2 are known to be tiny inclusions of an average size of 2–4 μm and maximum size of 25 μm in the PGM ores [16]. This requires a very fine grinding to liberate all the PGMs locked in the silicates, which would lead consequently to the chromite being ground even finer. The current standard circuit design to concentrate PGMs from the UG2 ore consists of a mill-float/mill-float approach designated under the acronym MF2. The motivation behind this approach is to perform a first flotation while keeping chromite as coarse as possible. The tailings from the primary flotation are thickened and separated in a hydrocyclone, and the hydrocyclone underflow is fed to the secondary open circuit ball mill. The feed to the secondary ball mill usually comprises of large amounts of liberated chromite and silicate-rich particles containing the bulk of the PGMs in a locked state [17,18]. However, the efficiency of secondary grinding of UG2 ore is currently limited by the use of open-circuit grinding in many plants, which is inherently inefficient, due to short-circuiting of coarse particles and possible segregation by gravity in the mill. It should be noted that the use of hydrocyclones results in wasting energy and increasing chromite entrainment whilst not effectively allowing for the grinding of silicates to liberate the PGMs and base metals [18]. The fine chromite present in the underflow stream is sent back to the grinding circuit resulting in over-grinding of barren chromite [19]. Hinde and Kalala [8] conducted optimization tests on secondary milling circuits for UG2 ore and found that through the use of fine screening technology, it was evident that the chromite was effectively liberated and virtually barren of PGM. The majority of the PGMs were associated with and locked in the silicate minerals. Hinde and Kalala [8] also noted that the liberated chromite has a much higher density than the silicates and reports preferentially to the hydrocyclone underflow whereas the lighter silicates containing the locked PGM have a tendency to report to the hydrocyclone overflow and therefore do not undergo secondary milling. This clearly highlights the problem of the inefficiencies in the hydrocyclone circuit. Many attempts have been made over the years to replace hydrocyclones with vibrating screens in UG2 concentrators [8]. Although the energy saving benefit was noted in many cases, the changes were not practical based on current technology. It was noted that a considerable breakthrough was achieved with the introduction of new fine screening technology with the introduction of the Stacksizer by Derrick Corporation in the USA. These screens were non-blinding with high open areas and with a high lifespan as compared with conventional wire mesh screens. This does indicate that using hydrocyclones and screens in closed circuit with ball mills would be a good solution since the separation relies on both particle size and particle density.

3. Theoretical background

3.1. *Breakage and Selection Functions: theoretical background*

The conventional ball mill model is based on the so-called “Modern Theory of Comminution”. In this theory the comminution operation, such as ball milling, is regarded as the sum of many repetitive individual comminution events [20,21] and calls up two probabilistic sets of parameters: the Selection Function S and the Breakage Function B. The former, also called grindability refers to the grinding kinetics of each independent particle. The latter, also called distribution of primary fragments characterizes the size distribution of the resulting fragments following the breakage events.