How to Use Hard Ore Components as Grinding Media

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ABSTRACT

The commonly used SAB, SABC and run-of-mine (ROM) ball mill circuits can achieve high throughputs with good operating stability. However, these circuits consume a substantial amount of grinding media, which can have a substantial impact on the OPEX and the 'carbon footprint', specifically when viewed as an 'embodied' energy input.

On the other hand, fully autogenous (AG) circuits can operate at much lower operating costs, but with limited throughput. The control of AG mills, fed by ores with hard and soft components, can also be challenging, due to the sensitivity of the mill to the ratio of hard to soft components.

In this paper, a multi-component modelling approach was used to demonstrate that the harder component should be used as grinding media, and its use should be kept to a minimum to avoid reduction in the mill throughput. There is an optimal blend of hard to soft, and any optimal blending condition is both ore-dependent and mill-specific. Establishing this blend is challenging, and consequently discourages the use of autogenous mills. The new modelling approach addresses this challenge by providing a quantitative prediction of the influence of blending soft and hard components in a mill. This prediction can then be used to establish the required blend for maintaining a stable and efficient operation in autogenous grinding mode.

INTRODUCTION

UG2 platinum ore has a friable mineral-bearing seam composed predominantly of chromite. Hanging- and foot-walls predominate with reasonably competent silicate. The ore is, in theory, well-suited to autogenous grinding and this has been successfully practiced. However, if the fraction of hard waste is too low, the mill throughput decreases. This challenge has driven operations to switch to high ball load ROM milling. However, their hope is to return to the more economic AG milling, but clear operating limits are required to assess the longer-term viability in relation to their various ore-bodies and mining techniques.

Therefore, a pilot plant campaign was planned and conducted to test mixtures of UG2 ore (silicate and chromite) and hard waste silicate, using an AG mill in open circuit (Bueno *et al*, 2011). Three tests were conducted at the following feeding conditions:

1. 20 per cent UG2 +60 mm: 80 per cent UG2 -60 mm
2. 20 per cent waste +60 mm : 80 per cent UG2 -60 mm
3. ten per cent waste +60 mm : 90 per cent UG2 -60 mm.

The data from the pilot tests show clear effects of the multi-component feed on AG mill performance:

- The hard component accumulated in the mill load and trommel oversize, due to its slow breakdown characteristics, and was retained in the coarser size fractions.
- The proportion of coarse particles in the AG mill feed was necessary to maintain good AG performance, as the coarse particles act as grinding media. A lack of coarse particles lead to the AG mill 'sanding up', resulting in decreased throughput and reduced energy efficiency.
- As the soft component increased in the feed, the mill throughput increased but the mill product became coarser.
- There is an optimal blend of multi-component feed, based on a balance between the ratios of the hard to soft and the coarse to fine.

UG2 ore and waste characterisation

Samples of UG2 and waste mill feed, collected during the pilot campaign, were used in a comprehensive ore composition and breakage characterisation program. The density distribution for each feed material is presented in Figure 1. The results of component specific breakage characterisation tests, conducted using the JKDWT and Bond tests (Napier-Munn *et al*, 2005), are show in Table 1.

The density distribution data indicated three classes of components for UG2 ore, but the JKDWT results show that there is almost no difference in UG2 low and mid density particles. The data also show that chromite rocks are not competent, as indicated by the high A × b figures, and that low-density silicate rocks in the UG2 ore are less competent than in specific waste samples.

Multi-component autogenous/semi-autogenous grinding model

The current JKSimMet models (Napier-Munn *et al*, 2005) assume a uniform feed, and describe it using a single set

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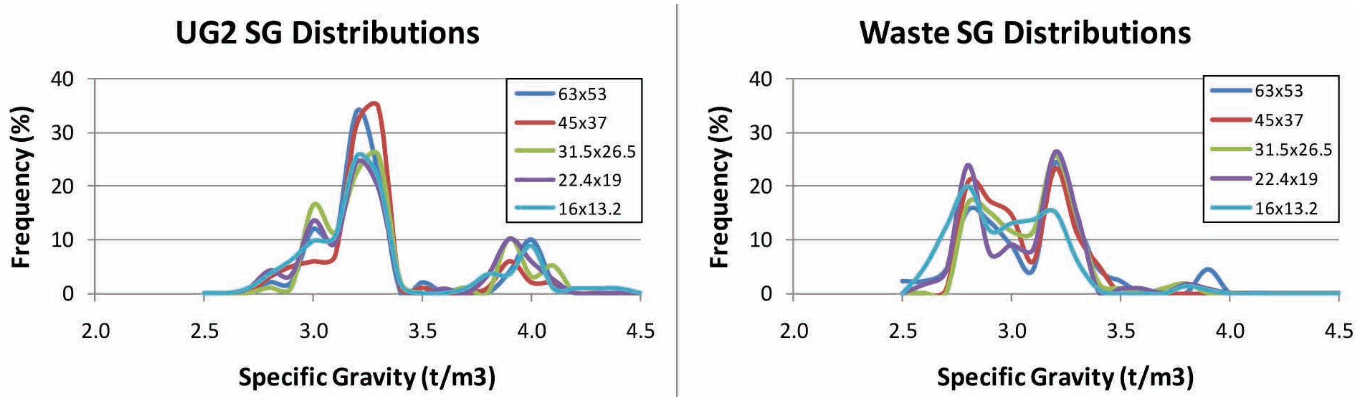

FIG 1 - UG2 and waste particle density distributions.

TABLE 1
Breakage testing data.

Sample	SG	Standard deviation SG	A	B	A × b	ta	Wi
UG2 low-density	3.0	0.1	73.9	1.66	123	0.51	19.5
UG2 mid-density	3.3	0.1	73.3	1.66	122	0.61	20.4
UG2 high-density	4.0	0.1	81.4	4.29	349	2.38	16.8
Waste low-density	2.9	0.1	71.5	0.86	62	0.34	19.2
Waste mid-density	3.3	0.1	73.1	1.07	78	0.34	19.8

of average ore breakage function parameters (A, b and t_a). Consequently these models cannot describe the effects of a varying ratio of hard and soft components on the mill performance.

The JKMRC has recently upgraded the current JKSimMet 1D model structure to a 2D data format, allowing for the specification of the feed on a component by size basis. Based on this framework, a new simple and robust multi-component model has been developed (Bueno et al, in press). The model relies on independent breakage and discharge rates for each component. The components are then combined to allow the model to match the underlying discharge rate of the bulk solids and water. The major features of the model are captured in Figure 2 and are listed below:

- more accurate calculation of specific comminution energy (Ecs)
- independent breakage functions (A, b and ta) for each component
- independent breakage and discharge rates for each component
- accounts for the effect of blending in the mill power draw calculation.

MULTI-COMPONENT MODELLING

The tests results and ore characterisation data were fitted to the new multi-component model which was then used to simulate the effect of adding coarse waste to the mill feed.

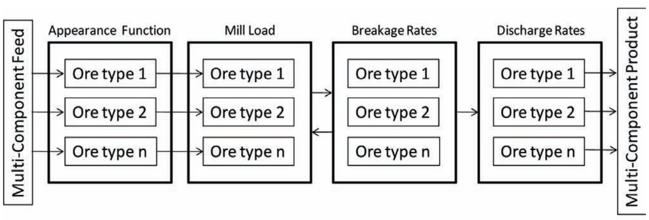

FIG 2 - Multi-component autogenous/semi-autogenous mill model structure.

A total of six parameters were fitted for each component: fine size (Xm) and breakage rates at knots 1 to 5 (R1, R2, R3, R4 and R5). The breakage rates calculated for two different feeding conditions are plotted in Figure 3, and it is clear that chromite has higher breakage rates than silicate in most sizes and in both conditions.

The breakage rates of the individual components were affected by feed composition, as shown in Figure 4. With hard waste in the +60 mm feed, the breakage rates at fine sizes increased for both materials. At coarse sizes, rates for chromite decreased, while there was no change in the silicate breakage rates.

Once the model was calibrated, it was possible to accurately reproduce the experimental data in terms of particle size distribution and composition by size, in both mill load and product, as shown in Figures 5 and 6. The build up of hard silicate in the mill load was also captured by the model, as shown in Table 2.

SIMULATING THE USE OF HARD WASTE

For any given mill, there is an optimal feed blend of hard and soft components and coarse and fine materials. The optimal blending conditions are ore-dependent and mill-specific. However, simulations, using the model calibrated with the pilot plant data, can provide a guideline for selecting a blended feed for AG milling.

The new model was used to simulate different additions of hard silicate waste in the coarse feed (+60 mm) and to identify the blending responses. The simulations were run at a constant feed size distribution, starting with pure UG2 ore (ie zero addition of waste) and then for increasing increments of hard waste in the +60 mm feed size. Figure 7 illustrates the simulated mill throughput, energy consumption, product size and dilution in platinum grade, as well as the recommended minimum and maximum additions of waste as dashed lines.

The suggested optimum range for blending is theoretical, specific to the tested ore and presented only as a guideline.

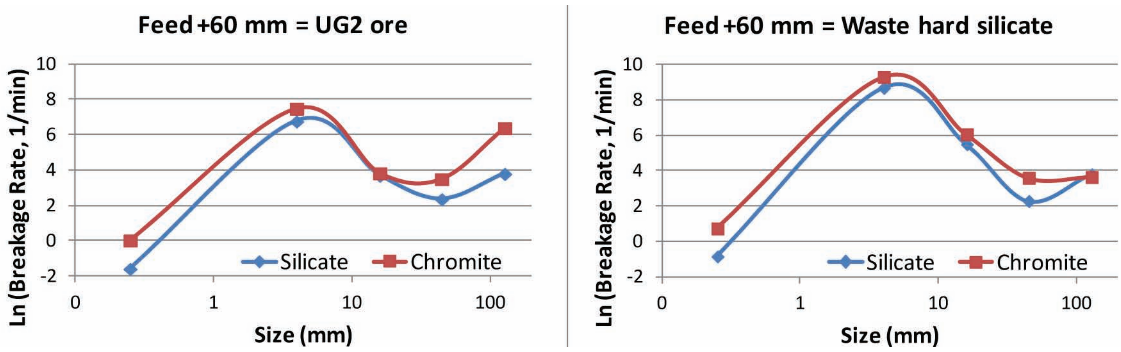

FIG 3 - Chromite and silicate breakage rates, fitted to pilot plant data.

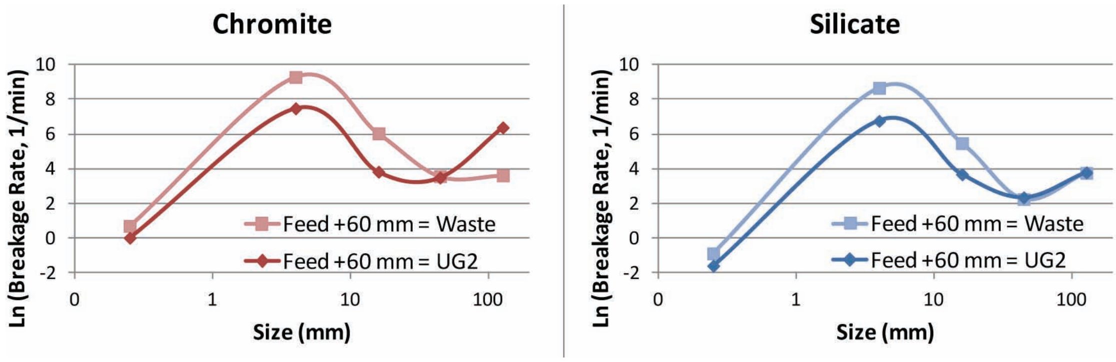

FIG 4 - The effect of feed composition on chromite and silicate breakage rates.

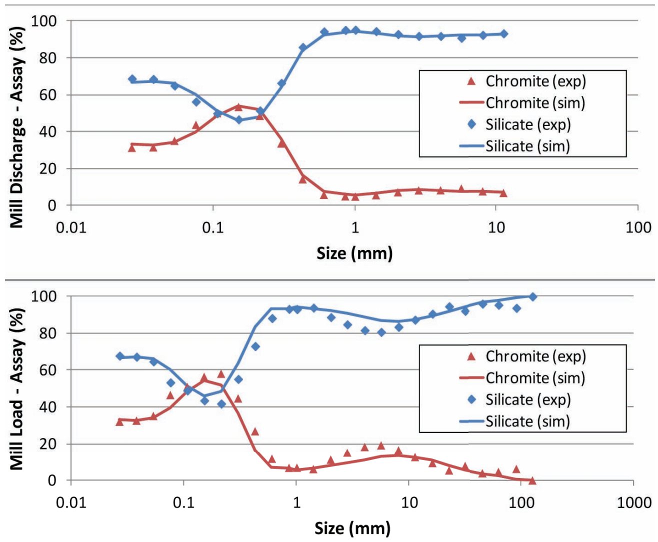

FIG 5 - Measured and simulated assay-by-size data for mill discharge and load.

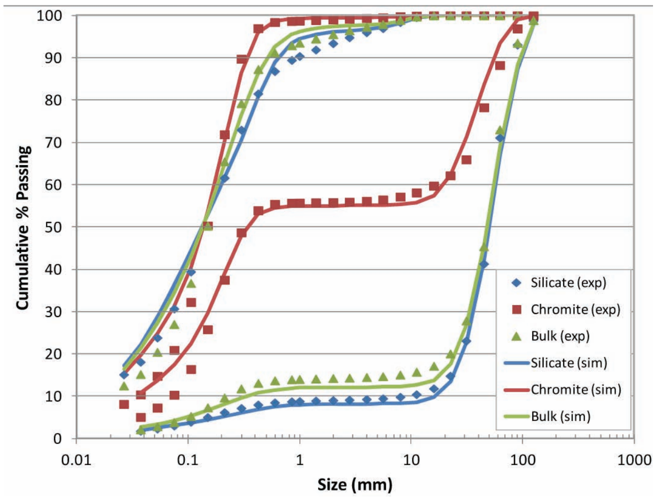

FIG 6 - Measured and simulated mill discharge and load particle size distributions.

This range depends on ore characteristics and both upstream and downstream limitations (eg mine capacities, flow sheet, installed mill power, required grind size, flotation constraints, etc). Once the objectives and limitations have been established, the new model can assist in determining an optimum blend for a particular application.

In order to assess these effects on a real circuit with recycle loads and downstream processes, a multi-component flow sheet simulator with other processing unit models is required. This simulation capability is currently being developed using the Excel-based Model Developer's Kit (MDK) by the JKMRC, under the AMIRA P9P project (Andrusiewicz *et al*, 2011), and it will enable a full validation of the proposed operating approach.

Though the maximum throughput is most likely to occur when there is no addition of hard waste, this condition does not provide an adequate feed for AG milling. The extremely soft UG2 ore experiences high breakage rates at coarse sizes, so in reality, it cannot sustain a stable mill load. The base model used to establish this multi-component mill model does not have an adequate mill transport function, so it cannot predict the build-up of this soft fine load. The model assumes that all the product can be discharged, which is not the case in a

TABLE 2

Build-up of hard silicate (experience versus simulation).

% Hard silicate					
Feed	Load		Feed +60 mm	Load +60 mm	
	Exp	Sim		Exp	Sim
62.4	88.9	91.5	85.0	95.6	97.5
63.5	95.4	95.3	92.7	99.2	99.1

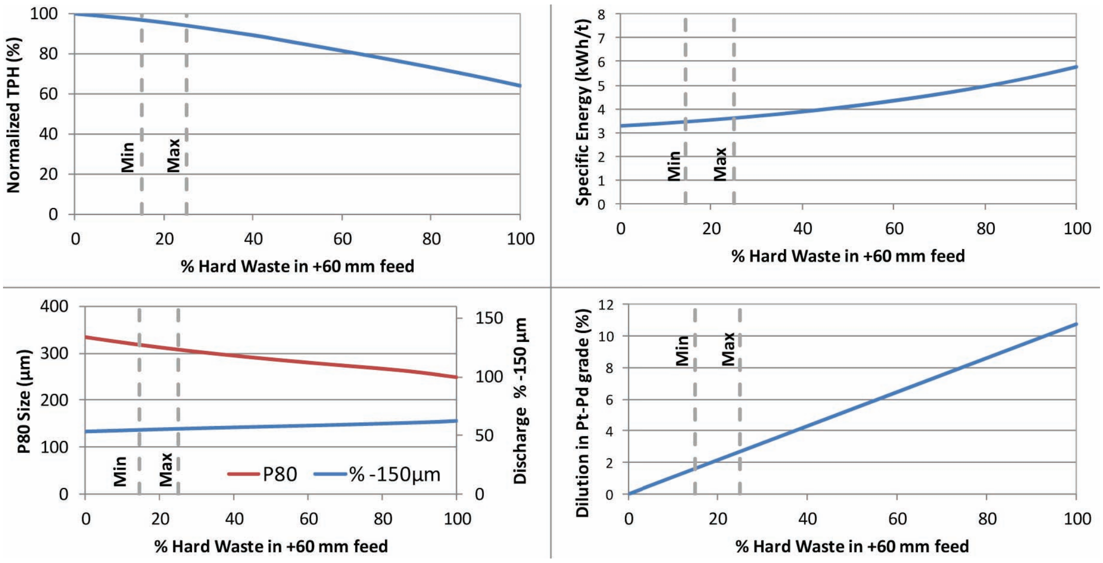

FIG 7 - Simulated mill throughput, energy consumption, product size and dilution according to blend.

real mill. The need to maintain coarse grinding media in the mill means the operation is highly dependent on the feed rate of coarse silicate particles, as the lack of same can lead the AG mill to 'sand up', resulting in decreased throughput and reduced energy efficiency. Additionally, the high throughput (achieved prior to reaching the sanding limits) results in a coarser product, which can be problematic downstream, particularly as chromite and silicate have high bond work indices. This is the reason why ROM ball mills have been adopted for grinding UG2 ore.

This mill instability was observed during the pilot trials, especially when searching for the minimum amount of hard waste required to keep the mill stable in Test 3 (Bueno *et al*, 2011). Figure 8 shows the mill load response during the tests using UG2 ore and waste material in the +60 mm feed. In both tests, the mill was rapidly brought to steady state by preferentially feeding more coarse material to rapidly build up the mill load. It is clear that the use of hard silicate waste reduced the stabilisation time, from eight to five hours, although it limited the mill throughput.

Therefore, a minimum addition of waste is desirable for improved stability and a finer grind. The mill's response to this instability cannot be simulated by the new model since it assumes steady-state conditions. A dynamic version of the model would be required to simulate this instability. However, the model indicated that the breakage rates of coarse chromite are very high, which is the cause of this problem.

In operation, the harder waste component should be viewed as grinding media and its use should be kept to a minimum to avoid grade dilution and reduction in the mill throughput. The simulations have shown that additions between 15 to 25 per cent of waste in the mill coarse feed will produce the following side effects:

- a slightly reduced mill throughput (97 – 94 per cent of maximum simulated throughput)
- a small increase in specific power (five to ten per cent)

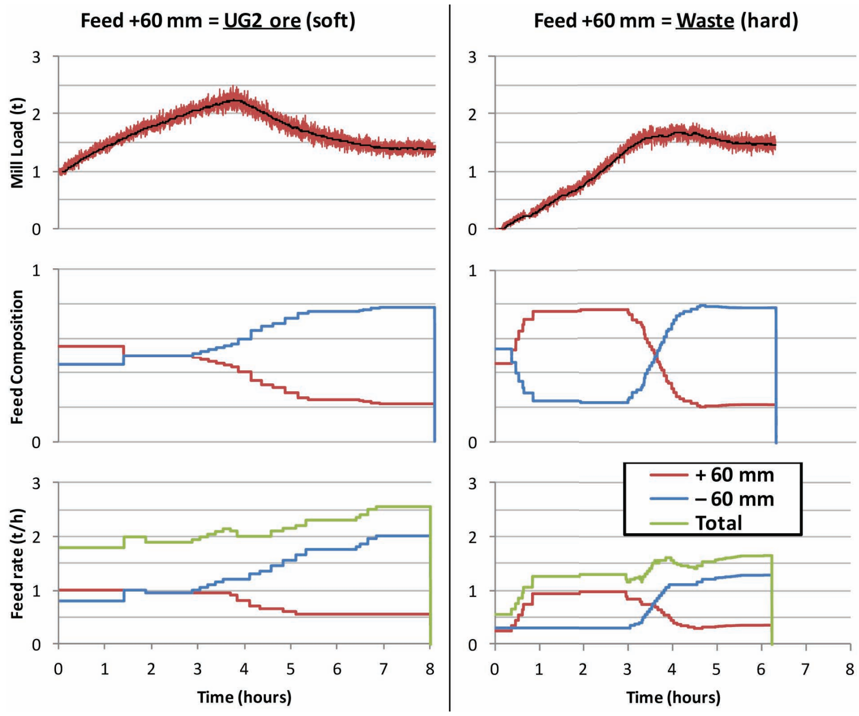

FIG 8 - Mill load response to feed.

- a reduction in product size, smaller P_{80} and more fines below 150 µm
- very little dilution in platinum grades (one to three per cent).

As an operating strategy, the ball addition in the ROM ball mills could be substituted with coarse waste rock. This would be trickled in at a constant rate and adjusted to maintain a stable mill load. As ROM ball mills have a high ball consumption, they typically have good ball feeding systems which could be adapted to feed rocks at a rate of one to three per cent of total feed.

CONCLUSIONS

Based on an extensive program of laboratory, pilot and site test work, data has been collected to establish a new multi-component SAG/AG mill model. This model is based on the independent breakage of components of substantially different competence. The model has been used to investigate a particular challenge facing the industry; the current inability to predict the fraction of competent ore required in the feed to Autogenous mills.

It is known that a small fraction of competent ore is required to maintain a load of grinding media in an AG mill. However knowing and maintaining the required quantity of this competent ore is a challenge yet it is critical to the successful operation of the mill. The new model was fitted to pilot tests conducted on UG2 Platinum ore, and then used to test the influence of a widely varying feed blend of competent waste and soft ore. The model showed that using 15 per cent waste should be adequate, generating only a three per cent drop from the theoretical maximum in throughput, a fine grind, and about a 1.5 per cent drop in platinum grade. These numbers, however, assume that the waste is barren, but in reality waste contains a low subeconomic grade which can add value to the grinding media. Additionally since waste is an unavoidable by-product of narrow seam mining, it is readily available. An upper limit of 25 per cent waste is recommended in order to limit the resultant reduction of throughput and grade.

The new multi-component capability is being incorporated into a more advanced SAG/AG model structure to enable improved scale-up and simulation of the mill limits (Kojovic *et al*, 2012). This can then be used to simulate the required competent ore fraction in production mills.

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