AUTOGENOUS MILL FEED PREPARATION TO REDUCE UNIT ENERGY CONSUMPTION

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ABSTRACT

The through-put and energy efficiency of an autogenous (AG) grinding mill are adversely affected by variability in rock size and rock competency. This applies to both fully autogenous and semi-autogenous (SAG) grinding circuits. In this paper we focus on an approach to overcome the problem of inconsistent mill through-put related to variability in mill feed size and rock competency. The focus is on ores containing hard, competent rock. This approach consists of preparing feed to an autogenous mill that contains 20% coarse media rock and 80% of material crushed to pass 37 mm. Results of pilot-scale testing for two iron-ores will be presented to show that a 10% to 12% reduction in unit energy consumption is possible with prepared feed, compared with feeding the mill with conventional primary crusher discharge.

KEYWORDS

Autogenous grinding, media rock, critical size, hard ore, competent rock

INTRODUCTION

In the past 30 years or so, autogenous grinding and semi-autogenous grinding have been the comminution technologies of choice for most mining and mineral processing operations. These technologies saved both capital and operating expenses associated with the installation and operation of multi-stage crushing and screening plants required for conventional rod mill – ball mill circuits. However, SAG and AG are inherently inefficient in terms of energy consumption, especially for very hard ores. In cases of hard ore, changing characteristics of rock fed to the mills causes wide fluctuations in mill capacity, which contributes to the inefficiency. Rising electric power costs make this the most expensive unit operation used in the extraction of valuable minerals from an ore. The objective of the concept discussed here is to reduce the energy consumption in AG grinding for hard ore and eliminate the use of large-diameter steel grinding balls that are required for SAG grinding.

DESCRIPTION OF PROBLEM

Autogenous grinding and semi-autogenous grinding both rely on the presence of large, competent rock in the mill feed to act as crushing/grinding media. Semi-autogenous grinding also relies on a relatively small percentage of large-diameter steel balls in the mill to act as supplementary crushing/grinding media. If large, competent media rock is not present in sufficient quantity in the mill feed, the intermediate size rock in the mill will not be broken at the required rate and a load of intermediate or "critical size" rock builds up in the mill, reduces the mill through-put and increases the unit power consumption expressed as kWh per tonne of mill feed. Media rock needs to be both large and competent

Two major factors contribute to the high unit energy consumption for AG and SAG operations. The first is related to variability in the size and competency of rock fed to the mill. Mine planning, ore blasting and primary crusher controls, while quite advanced from years ago, are not sufficient to limit the inherent variability that occurs in ore feed size. Variability in feed size and varying ability (competency) of coarse rock to crush the smaller rock leads to decreased mill through-put and increased unit power consumption. The second factor is the accumulation of critical size rock in the mill that is difficult to break. Critical size material consists of intermediate size rock (typically 37 to 90 mm diameter) that is hard and very slow to break down. When a sufficient amount of this material accumulates in the mill, the capacity (through-put rate) is reduced and the unit energy consumption increases. Often, this leads to a "plugged" condition where the mill feed has to be stopped while the mill is "ground out" to reduce the amount of critical size material in the mill and reduce the total volume of the mill charge. This procedure consumes power with no through-put and greatly increases the unit power consumption for an operation.

The two factors discussed above are related in that critical size material in the mill can develop if the optimum amount of competent, media-sized rock is not available in the mill feed, and the formation of critical size material in the mill can simply be an ore characteristic. If the effect of these two factors could be reduced, the energy efficiency of a typical AG or SAG operation could be reduced by an estimated 10% to 20%.

The classical way of reducing the effect of critical size material in these types of grinding mills is to extract the material from the mill using pebble ports, crush the extracted material, and return it to the mill. This requires considerable added expense for the mill construction (pebble extraction ports) and considerable expense for additional material handling equipment (conveyors, transfer towers, etc). While this concept has helped some operations, it cannot be applied to iron-ores, even those with just weakly magnetic material, because of the need to remove tramp iron material from the crusher feed using overhead magnets.

DESCRIPTION OF CONCEPT

Ideally, if an autogenous grinding mill could be fed only coarse, competent rock and rock that is just smaller than the critical size, the mill performance would improve in two ways. First, since the variability in the feed size is reduced, the variability in the mill feed rate would also be reduced, which results in higher through-put. Second, the amount of critical size rock in the mill feed would be reduced and the mill through-put would increase. Both of these effects would allow the mill feed rate to increase and the unit power consumption (kWh/t) would decrease.

The concept includes sizing of the primary-crushed rock from the mine with a grizzly at a coarse size (150 to 200 mm, for example). Ore that is larger than the grizzly opening is sent to a separate stockpile as "media rock." Ore that is finer than the grizzly opening is sent to a secondary crusher operated in open circuit with a screen(s) to produce the "fine rock" (minus 37-mm to 50-mm, for example). This fine rock would go to a separate stockpile.

A schematic flowchart for this concept is shown in Figure 1.

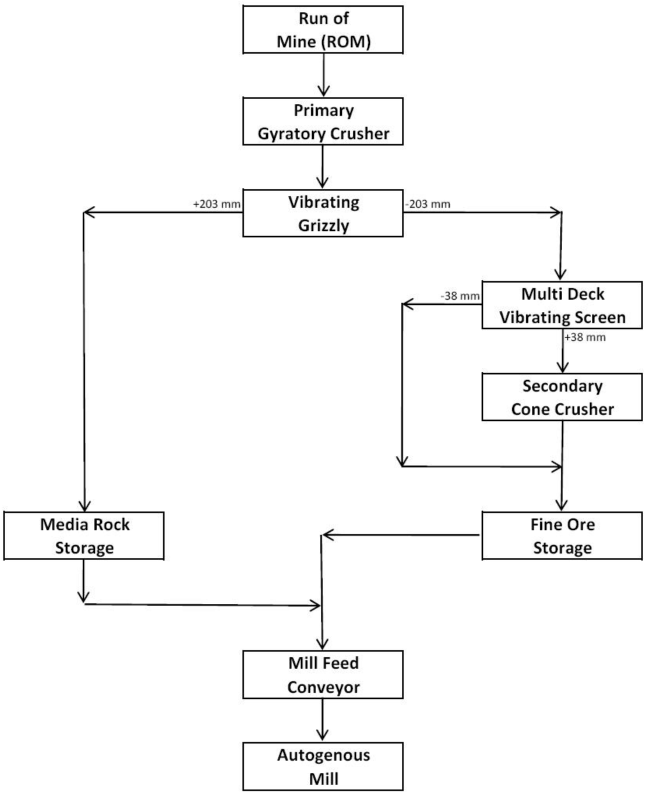

Figure 1 - Schematic flowchart of AG circuit with prepared feed

The feed rates of both the media rock and the fine rock to the primary grinding mill are controlled with variable speed feeders and the ratio of media and fine rock is adjusted to maintain maximum total through-put at a given mill power draw. This concept eliminates the need for large steel grinding balls for SAG mill grinding.

TESTING AND RESULTS

This concept was tested with two different materials including:

- A Minnesota magnetic taconite iron-ore with a standard 74-microns Bond work index of 13.9 (metric)
- A Venezuela hard, low-grade iron-ore (hematite) with a standard 74-microns Bond work index of 13.7 (metric)

Batch testing, process simulation, and a pilot plant were conducted on a magnetic taconite iron-ore in 2005. Compared with SAG mill grinding, autogenous grinding using feed prepared to include coarse, competent rock and crushed finer rock resulted in a 14% reduction in grinding energy expressed as kWh/t and no steel balls were required as additional grinding media. The coarse rock amounted to about 20% of the mill feed.

This concept was also tested for another hard, non-magnetic iron-ore in 2008.

Results of both tests are presented in the following paragraphs.

Minnesota Magnetic Taconite

The iron-ore used in these tests was a typical Mesabi Iron Range hard taconite. Drop weight tests and batch scale grinding tests were performed by Metso to provide the breakage parameters needed for their proprietary MinOOcad grinding circuit simulator. Their batch grinding tests were done with a 1.83 metre x 0.61 metre Cascade mill. The following three circuits were evaluated with the simulator:

- Autogenous grinding fed with primary crushed ore with crusher OSS at 305 mm
- Autogenous grinding of prepared feed consisting of 20% rock coarser than 153 mm and 80% of the feed crushed to pass 19 mm
- Semi-autogenous grinding of ore crushed to pass 153 mm

Results of three circuit simulations based on the drop weight tests and batch grinding tests are summarized in Table 1.

Table 1 – Results of Circuit Simulations

Circuit	Feed Rate mtph	Specific Energy, kWh/t	Estimated Power Draw kW	Preliminary Mill Requirements Dia X EGL
AG of Pri Crushed Ore	893	16.2	14,200	11.6m X 6.7m
AG of Prepared Feed	893	10.8	9,500	11.0m X 5.2m
SAG of Pri Crushed Ore	893	12.7	11,000	10.4 X 6.1m

These simulations indicated that AG of prepared feed had the lowest specific energy requirement. The specific energy requirement for autogenous grinding of prepared feed was 15% lower than SAG mill grinding of primary crushed ore and 34% lower than for autogenous grinding of primary crushed ore.

Subsequently, pilot-scale primary grinding tests were performed in Minnesota on the magnetic taconite iron-ore as part of an overall effort to develop a concentrating process to produce an iron-ore concentrate containing less than 1.7% silica. As part of this effort, we wanted to develop a lower cost alternative for primary grinding.

Based on the simulation results, the two schemes selected for primary grinding in the pilot plant included:

- Fully autogenous grinding with feed consisting of 20% by weight of 153 mm media rock and 80% of rock crushed to pass 19 mm

- Semi-autogenous grinding with “as is” ore and 127 mm diameter steel balls

With the exception of the two variations for primary grinding, the process flowsheet in all tests was the same.

The primary mill used was a Nordberg 1.67 metre diameter mill with an effective grinding length of 1.16 metre. For the SAG tests, the ball charge was maintained at about 6%, which was typical for past experience with this ore. The initial ball charge consisted of a graded charge and new balls added were 127 mm in diameter. The mill rotated at 25.26 rpm or 76.6% of critical speed.

Mill power was determined using a calibrated power meter that measured the input power to the motor. Power measurements were made every 30 minutes during each test. The tare power (empty mill power) of 3.65 kW was determined for the mill prior to starting the tests. The specific power consumption (determined by subtracting the mill tare power from the gross input power) is the actual power input to the mill charge (rock and/or balls). This allowed for direct comparison with the results from Metso’s simulation studies.

Results of these primary grinding tests are summarized in the Table 2.

Table 2 – Average Performance Data for Primary Grinding Circuits for a Magnetic Taconite Iron Ore

Type of Primary Grind	Primary Mill Feed Rate mtph	Gross Power kW	Specific Power Consumption kWh/mt
Autogenous Grinding with Prepared Feed (average of 5 tests)	1.35	18.14	10.73
Semi-autogenous Grinding Tests with Primary Crushed Ore (average of 6 tests)	1.26	19.27	12.46

The unit power consumption shown in Table 2 is to grind the material to pass 3175 microns (trommel opening that was used). Typically, a commercial scale plant would grind this material to pass 6350 microns. The average specific power consumption (power at mill pinion shaft) for the AG tests was 10.73 kWh/mt, compared with 12.46 kWh/mt for the SAG tests. The specific power consumption values for both types of primary grinding agreed very well with the results of the simulation work performed by Metso.

The average feed rate for the semi-autogenous primary grinding tests was 1.26 mtph, compared with an average of 1.35 mtph for the autogenous primary grinding tests. The highest feed rate for the autogenous grinding tests was 1.46 mtph and the primary mill was easily handling that rate. However, this higher feed rate did appear to cause the secondary circuit to overload and the feed rate was reduced after the formal sampling for this test.

Operation of the pilot plant was much smoother with autogenous primary grinding. When semi-autogenous primary grinding was used, considerable variation was observed in the amount of oversize from the trommel screen and from both number 1 and number 2 classification screens. All of this variation was most likely due to the normal variation in grinding rates that occurs with primary grinding of ore that has only gone through a primary crusher. When autogenous grinding was used with about 80% of the feed crushed to pass 19 mm, the variations in the amount of oversize from all three screens was much smaller, and, for the most part, imperceptible. Variations in concentrate grade were also smaller.

Conclusions drawn from this pilot study were as follows:

- Primary grinding power for autogenous grinding of ore with minus 153 mm material crushed to pass 19 mm can be done with specific power input of about 10.7 kWh/mt. The amount of media rock in the mill feed was about 20% (+153 mm rock) and 80% of material crushed to pass 19 mm. This is 14% lower than the specific power required for SAG grinding of primary crushed ore.

- If semi-autogenous grinding is used with a 6% ball charge, the specific unit power consumption will be about 12.5 kWh/mt. This is 17% greater than for autogenous grinding of prepared feed.
- In addition to lower power consumption for autogenous grinding of prepared feed, no 127 mm balls are required as for semi-autogenous grinding.
- Primary autogenous grinding of ore with partial pre-crushing allowed for smoother operation of the pilot plant because the normal variations in mill through-put with semi-autogenous grinding (due to critical size formation in the primary mill) were avoided.

Venezuela Hematite

The material used in these tests was a blend of low grade hematite material from four different deposits in Venezuela. Drop weight tests were performed by Metso to provide the breakage parameters along with the pilot plant grinding tests to provide the initial estimates for the AG mill size, and to model that mill using their proprietary ProSim simulator.

Autogenous grinding with prepared feed consisting of 20% rock coarser than 153 mm and 80% of the feed crushed to pass 19 mm was the circuit evaluated with the simulator.

Results of the circuit simulation based on the drop weight tests with the test results from one of the pilot plant tests are summarized in Table 3.

Table 3 – Results of Circuit Simulation

Circuit	Feed Rate mtph	Specific Energy KWh/t$^{(1)}$	Estimated Power Draw (kW)	Mill Dimensions Dia X EGL
AG of Prepared Feed	600	7.73	5,000	9.8m X 3.5m

$^{(1)}$ The specific power of 7.73 kWh/t is from a pilot test discussed later.

This simulation provides a preliminary indication of mill size using the breakage parameters from the drop weight testing and the specific energy achieved in the pilot plant mill. Additional testing will be required on multiple samples of varying hardness to validate the preliminary estimates.

Subsequently, pilot-scale primary grinding tests were performed in Venezuela on the same blend of hard low-grade material from four different deposits as part of an overall effort to develop a concentrating process to produce an iron-ore concentrate containing low silica content for local iron- and steel-making industry.

The fully autogenous grinding with feed consisting of 20% by weight of +153 mm media rock and 80% of material crushed to 19 mm was the circuit of choice. The traditional SAG grinding circuit was not considered at this stage due to the difficulty of obtaining 127 mm diameter steel balls at the potential concentrator site.

A series of seven primary grinding tests were conducted over a one week duration. The series of tests had varying amount of feed rate and varying percentages of media rock to crushed material.

The primary mill used was a Metso (Svedala) 1.83 metre in diameter by 0.61 metre in width. The mill rotated at 24 rpm. The mill was equipped with rubber liners and rubber grates with slotted openings.

Mill power was determined using a calibrated power meter that measured the input to the motor. Power measurements were continuous and could be accumulated over the test period. The tare power (empty mill power) of 2.90 kW was determined for the mill after the series of tests. The specific power consumption (determined by subtracting the mill tare power from the gross input power) is the actual power input to the mill charge (media rock and crushed material). The specific power consumption from primary grind test B was considered to be most representative of all the test conditions and was picked by Metso for their simulation studies.

The results of this series of primary grinding tests are summarized in the Table 4.

Table 4 – Performance Data (series and average) for Primary Grinding Circuit for a Hard Low Grade Hematite Material

Primary Grinding Test	Primary Mill Feed Rate mtph	Gross Power kW	Specific Power Consumption kWh/mt
A	0.911	11.88	9.86
B	1.229	12.40	7.73
C	1.096	12.05	8.35
D	0.995	10.17	7.31
E	1.015	10.18	7.17
F	0.998	11.71	8.83
G	0.898	10.81	8.81
Average	1.020	11.31	8.29

The unit power consumption shown in Table 4 is to grind the material to pass 3175 microns. The average specific power consumption (power at mill pinion shaft) for all the AG tests was 8.29 kWh/mt and ranged from 7.17 to 9.86 kWh/mt. The average feed rate for the series of AG test was 1.020 mtph and ranged from 0.898 to 1.229 mtph. The product size (expressed as P80) averaged 1,588 microns.

The operation of the pilot plant was very stable and controllable. The minor variation in product size can be attributed to varying the feed rate and the percentage ratio of media rock to crushed material. The best test in the series was considered Test B due to high and stable feed rate and mill output performance being steady state with stable mill power draw.

Conclusions drawn from the pilot study are as follows:

- Primary grinding power for autogenous grinding of minus 153 mm material crushed to pass 19 mm can be done with specific power input of about 8.29 kWh/mt. The amount of media rock in the mill feed was about 20% plus 153 mm and 80% of material crushed to pass 19 mm.
- The autogenous mill in the pilot plant was able to maintain steady state conditions without any build-up of the critical size in the seven different tests conducted.
- The autogenous mill discharge product obtained a particle size of 80% passing 1,588 microns, which is very acceptable for this application and stage of grinding.

OPERATING COST COMPARISON

The utilization of autogenous grinding with prepared feed can offer a substantial operating cost saving over the use of conventional semi-autogenous grinding for hard low-grade iron-ore. The most significant cost components in an iron-ore concentrator are listed in Table 5 and shown as cost per tonne. These cost components are the top six, with the rest significantly at lower values. The absolute values may differ depending on local cost factors but provide a valid comparison.

Table 5 – $ per tonne of Crude Ore feed of the top six cost components for a typical low grade iron ore concentrator

Cost Component	$/tonne with Conventional SAG	$/tonne with AG/Prepared Feed
Power (Primary Mill)	0.709	0.581
Labour (Concentrator)	0.554	0.554
Liners (Primary Mill)	0.270	0.089
Steel Balls (Primary Mill)	0.258	-
Power (Ball Mills)	0.177	0.177
Steel Balls (Ball Mills)	0.158	0.158

The three cost components that result in savings are the primary mill power, primary mill liners, and the elimination of the primary mill steel balls. The comparison of these cost components is shown in Figure 2. In the case shown, utilization of AG with prepared feed offers a $0.55/tonne cost savings over the use of conventional SAG. For a concentrator that process 20.0 million tonnes per year, the savings can amount to $10,000,000 per year.

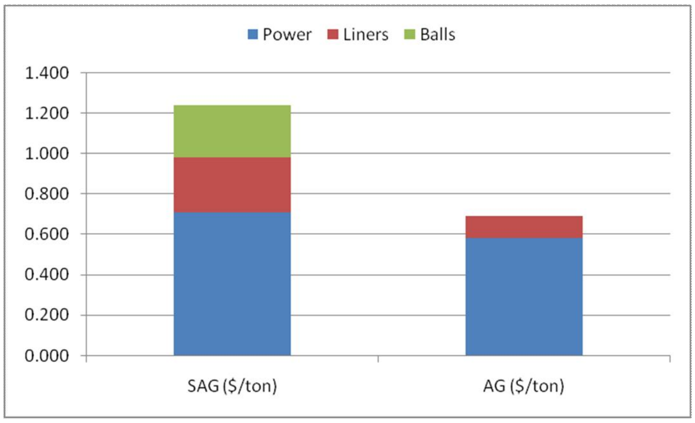

Figure 2 - Primary mill cost components in $/tonne of crude feed

CONCLUSIONS

The concept of utilizing AG with prepared feed has proven technically feasible for grinding of hard low-grade iron-ore. It offers another option to conventional SAG or the ABC circuit using autogenous grinding.

A substantial cost savings can be realized with the AG/prepared feed as compared to conventional SAG in terms of a 10 to 12 % reduction in mill power, a reduced mill liner consumption, and elimination of steel balls.

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