Minerals Engineering 49 (2013) 116–120

Contents lists available at SciVerse ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

A new approach for evaluating the performance of industrial regrinding tumbling ball mills based on grindability and floatability

Parviz Pourghahramani [a,*], Hamed Dehghani [b], Abbas Sam [b]

[a] Sahand University of Technology, P.O. Box 51335/1996, Tabriz, Iran
[b] Division of Mining Engineering, Engineering Faculty, Bahonar University of Kerman, P.O. Box 7618868366, Kerman, Iran

ARTICLE INFO

Article history:
Received 18 July 2012
Accepted 22 May 2013
Available online 12 June 2013

Keywords:
Regrinding
Liberation
Grindability
Floatability
Industrial regrinding mill

ABSTRACT

This paper aims to develop a new approach for determining the performance of regrinding tumbling mills, which is based on the grindability and floatability of locked particles through regrinding systems. The approach combines the grindability factor, in which the grinding of coarse particles is only considered, with the floatability of the regrind mill feed and product using the corresponding grade–recovery curves. The approach was examined in the Sungun industrial regrinding tumbling ball mill using various feed rates. The results showed that the efficiency of the regrinding mill is extremely low and some practical approaches and means are proposed to enhance its efficiency.

1. Introduction

In most cases, the existence of a regrinding mill in mineral processing plants is inevitable and plays an important role. The main objective of a regrinding mill in mineral processing plants is the liberation of locked valuable minerals. The performance of regrinding mills often deviates from the initial design operating state due to the changes in ore characteristics and operational conditions. To improve the efficiency of such mills, many means and ways have been continuously proposed by researchers.

In this sense, the Bond standard grindability test has been widely employed to determine the energy required for grinding middlings and fine particles. As stated by Levin (1989), the Bond grindability test cannot properly be applied in the case of fine materials and middlings. Some limitations of the Bond grindability test have been raised through the application of a mill without lifters and screenings, instead of classification in a closed circuit (Levin, 1989). In addition, the Bond grindability test does not take into account the relationship between the distribution of feed size and media size. Also, the same media size combination is often applied in the test, resulting in a higher work index value in the case of fine materials due to hindering of breakage phenomena.

Considering these facts, Levin (1989) employed a comparative grinding test in which a reference material from an operating plant is ground in the laboratory mill to determine the equivalent energy consumption per revolution of the laboratory mill. Consequently, the following grindability index was proposed for fine materials.

$$B = \frac{4.9 \times 10^{-3} \times G^{0.18}}{P_1^{0.23}(100 - U)} \text{kW h} \tag{1}$$

where B is the equivalent energy per mill revolution and is almost constant, making up 1.98×10^{-7} (kWh), P_i is the aperture of the limiting screen (μm), G is the net mass of screen undersize produced per mill revolution (g), and U is the percentage undersize in the minus 6 mesh feed. Once B is obtained, the grinding energy is supposed to be calculated as follows:

$$\frac{19.8 \times N}{m} \text{kW h} \tag{2}$$

where m (g) of the desired product are obtained in N revolution (Levin, 1989).

Based on the approach proposed by Liven, the specific energy required for material grinding is considered equal to the equivalent energy per revolution of the laboratory Bond mill. This energy cannot be accurately estimated since the grinding energy of fine materials considerably differs from the equivalent energy per revolution of the laboratory Bond mill. This implies that the effect of material size on grinding energy is still present and the approach does not takes into account changes in the relationship between size and breakage behavior of material. In addition to this approach, Morrell (2008) presented a new approach for determining the specific energy requirement of tumbling mill (grinding) circuits. As stated by Morrell, the application of this approach is limited by the

* Corresponding author. Tel.: +98 412 3459288; fax: +98 412 3444311.
E-mail address: pourghahramani@sut.ac.ir (P. Pourghahramani).

0892-6875/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.mineng.2013.05.021

product and feed size range and cannot be employed for regrinding circuits fairly.

Ghaghazanian et al. (2008) used grade–recovery curves of the regrind ball mill product and feed to evaluate the performance of regrinding tumbling mills. The performance of regrinding mills is satisfactory when the grade and recovery in the product is better than that of the feed.

The objective of this study is to propose a new quantitative approach combining floatability (grade-–recovery curves) and grindability for various feed rates in a circuit. The applicability of this approach will be finally validated using several industrial surveys in the Sungun copper beneficiation plant.

2. The Sungun regrinding circuit

The Sungun copper complex is located at the East Aazarbaijan province, in the north-west of Iran. The Sungun mine is an open pit mine of the porphyry copper deposit which is the second largest copper mine in Iran. At this plant, a 3.962 $\times$ 5.791 m regrinding tumbling ball mill with an overflow discharge is used to grind and subsequently liberate locked valuable minerals from an entering feed ground to -300 μm using primary and secondary milling processes in a circuit closed with cyclones. The discharge of the regrinding mill is mixed with the rougher and scavenger concentrates and then sent to the secondary cyclones. The discharge of the regrinding mill is named as the regrinding product through the manuscript. The underflow of the secondary cyclones is the regrinding mill feed (Fig. 1).

Some important characteristics of the regrinding mill are summarized in Table 1. To obtain insight into the performance of the regrinding mill, samples were taken for testing from the regrinding mill feed (cyclone underflow) and product (mill discharge).

3. Data collection and experiment

To validate the new approach, the regrinding circuit was surveyed 4 times under various feed rates ranging from 72 to 100 t/h, approximately corresponding to 1/10th of the Sungun plant feed rate at any plant feed rate according to the mass balance results in a stable operating condition. The sampling from the regrinding mill product and feed was made using a proper sampling cutter. During the sampling, it was tried to avoid over filling of the cutter. The samples of the regrinding mill discharge and feed were collected within a 45 min operating period. The representative gross samples were obtained by mixing of increments collected in equal time intervals.

Once the representative samples were collected, a number of the samples were dried and weighed for size analysis. The size distribution of the regrinding mill feeds and products were

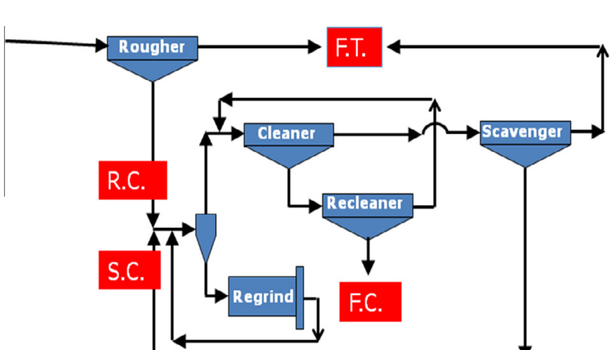

Fig. 1. The regrinding circuit in the Sungun plant F.T.: Final Tail, R.C.: Rougher Concentrate, S.C.: Scavenger Concentrate, F.C.: Final Concentrate.

Table 1
Operating conditions of the Sungun regrinding mill in initial design.

Parameter	Value
Availability (%)	90–97
Ball filling (%)	40
Ball size (mm)	25
The d80% passing product size (μm)	100
Feed top size (μm)	300

determined using the sieve analysis to -37 μm. The size analysis was repeated to maximize the measurement reliability.

More than 1000 particles from each size class were processed for the liberation study using an optical microscopy.

Another part of the representative samples was immediately subjected to the flotation kinetics tests to extract grade–recovery curves. The flotation kinetic tests were conducted on the taken samples without adding any chemical reagents, i.e., the relevant chemical reagents have been already added at various points in the plant regrinding system. The flotation tests were carried out in a Denver flotation cell at pH 11.5.

In the flotation kinetic tests, froth was collected in a pan for a certain period of time and the pan replaced by another pan. Each pan of the concentrate was weighed and assayed for copper to calculate copper recovery to the concentrate over time. The flotation tests were extended up to 13 min residence time and the froth samples were collected at time intervals of 1, 3, 5, 8 and 13 min from the beginning of the flotation tests. The recovery of each pan was then added to the recovery from any previous pans to obtain the cumulative recovery. In addition to the cumulative recovery, the cumulative grade was also calculated. In the next step, the cumulative grade against the cumulative recovery was plotted to develop a "grade–recovery curve". At the low recovery, the grade is quite high, since the concentrate mainly contains very hydrophobic particles. Once all the very hydrophobic particles were virtually floated, less hydrophobic particles were recovered.

Any change on variables affecting the rate or extent of flotation will lead to changes in the operating point on a grade–recovery curve, or to a new grade–recovery curve. For example, factors affecting all particles in the same manner, such as residence time and air addition rate, will cause movement along a grade–recovery curve. Those factors that affect the flotation of one particle type more than another will lead to a new grade–recovery curve. Thus, careful attention should be paid to run the flotation kinetics experiments in a similar manner and at fixed conditions. Finally, the floatability index (D) was calculated using grade–recovery curves as explained in the following sections.

4. Proposed approach

It is thought that any approach for evaluating the regrinding mills should meet the following criteria which are the metallurgical objectives of the regrinding process in the mineral beneficiation plants:

1. The approach must explain the grinding process, whether the regrinding is performing or not.
2. In the regrinding process, not only the production of much more fine materials (slime production) must be limited (due to the detrimental effects of the fine materials in downstream processes like flotation) but also the liberation of locked valuable minerals must have occurred sufficiently.
3. For a given beneficiation condition, the regrinding positive effects must be reflected on the grade–recovery curves for any given feed.