GRINDING MEDIA

Optimised ball size distribution

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Ball size distribution is an important parameter in the application of ball mills, grinding performance can be significantly affected depending on the design of the grinding media. It is a difficult task to evaluate performance and where the problematic points are within a finish mill circuit. Simulation is the best tool to employ to improve the circuit performance if the model structures are accurate. Trial and error is an expensive and time-consuming approach. Industrial case results by Cemas indicate that a 15-20 per cent gain can be achieved by optimising the ball size distribution, using developed model structures.

Several investigators (Austin et al, 1975; 1984; Zhang, 1988; 1992; Benzer, 2000; 2001; Slanewski, 1985; Viswanathan, 1988; Ozer, 2006) have studied mathematical modelling of cement mills on the basis of population balance models (PBM) for simulation and optimisation of cement grinding circuits. However, to date there is no extensive research on the analysis of effect of design and operational characteristics of dry grinding ball mills on the grinding model parameters namely breakage and discharge rate functions of particles, based on the industrial scale data.

Importance of the grinding media quality
Grinding ball production is a metallurgical operation and its quality is determined by the quality of the production process. Quality of one process has an indirect effect of the quality of another process.
The ball specifications used in the cement industry are briefly outlined in Table 1. The ball quality parameters can be classified as the wear rate, dimensional tolerance, ovality, mismatch, gating knolls and cavity. The ball wear rate in the cement industry is 40g/t for a closed circuit application to produce a cement fineness of 3700Blaine as the abrasive content increases the ball consumption increases, ie 150-200g/t for cement with slag.

The dimensional tolerances of the grinding media should be in the maximum range of ±5 per cent. The rest of the quality figures are outlined in Table 2.

Once the quality of the balls used is assured then the optimal ball size distribution design has to be carried out for a better performance of the circuit and the balls.

### Measuring ball performance

Before an optimal design, a complete analysis should be conducted for each milling duty. Factors such as mill dimensions, mill speed, mill power, ore type, feed top size, feed size distribution, throughput, charge volume and product size should be considered. The measurement must take account of several parameters, ie:

- energy consumption
- capacity
- product size
- liner and grinding media performance and economy.

Complete analysis involves extensive circuit sampling, sample analysis, mass balancing and data analysis. Circuit sampling is carried out under normal operating conditions, while the circuit is running at its steady-state condition when the fluctuation of the critical parameters are minimised. A typical steady-state grinding circuit condition output is shown in Figure 1.

#### Table 1: technical specifications of the balls used in the cement industry

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>C %</th>
<th>Cr %</th>
<th>Hardness HRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,17,20,25,30</td>
<td>2.6-3.1</td>
<td>12-14</td>
<td>60-66</td>
</tr>
<tr>
<td>35,40,50</td>
<td>2.2-2.7</td>
<td>12-14</td>
<td>59-65</td>
</tr>
<tr>
<td>60,70,80,90,100,110</td>
<td>2.0-2.5</td>
<td>17-19</td>
<td>58-64</td>
</tr>
</tbody>
</table>

#### Table 2: ball quality parameters summary used in the cement industry

<table>
<thead>
<tr>
<th>Ball size (mm)</th>
<th>Ovality (%)</th>
<th>Ball size (mm)</th>
<th>Mismatch (mm)</th>
<th>Ball size (mm)</th>
<th>Gating knolls and cavity (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-30</td>
<td>5-8</td>
<td>&lt;25</td>
<td>0.25</td>
<td>&lt;25</td>
<td>1</td>
</tr>
<tr>
<td>40-60</td>
<td>9-14</td>
<td>25, 30, 40</td>
<td>0.25</td>
<td>25, 30, 40</td>
<td>1.5</td>
</tr>
<tr>
<td>70-100</td>
<td>15-20</td>
<td>50, 60, 70</td>
<td>0.4</td>
<td>50, 60</td>
<td>2</td>
</tr>
<tr>
<td>80, 90, 100</td>
<td>0.4</td>
<td>70, 80, 90</td>
<td>2.5</td>
<td>100</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Figure 1: a typical steady state condition output of the control system around the circuit

**Operating conditions are recorded during the sampling period. To evaluate the performance of the existing circuits, for each circuit sampling surveys around the circuit are needed. A simplified flowsheet of a typical circuit with its sampling points is shown in Figure 2.**

Sampling studies include all streams around the circuit, as well as inside the mill samples after a ‘crush stop’. The samples inside the mill are collected along the central-axis with in size reductions. Size distribution of samples are determined down to about 2μm. Raw size distribution data then need to be mass balanced, and flow rates around the circuit are calculated on the basis of measured feed flow rates. This first attempt identifies the potential bottlenecks. A grindability test is performed on the circuit feed sample to assess performance of the actual mill. Separator performance is evaluated by examining the efficiency curve. In the Figure 3, inside the ball mill sampling points are presented.

Milling performance depends on the ball size distribution poor vs good...
performance. Ball mill performance is affected by the ball size distribution. In the following paragraphs ‘good’ and ‘bad’ case studies will be presented as a part of previous work done to identify how a ball size configuration may affect the unit process.

In the first case the data collection indicated that good performance is achieved along the mill axis by obtaining the suitable ball size configuration at different points along the mill axis by classifying liner action (Slegten, 1973). Figure 4 shows the ball size distribution along the mill axis. As the material becomes finer along the mill axis, finer ball size distribution is required therefore the grinding performance is increased with a systematic size distribution (see Figure 5).

The analysis shows that systematic change in ball size distribution results a systematic size reduction along the mill axis. In this case liner configuration helps the gradation of the balls. This systematic change of the size reduction is an indication of normal operating conditions of a grinding circuit, but this does not necessarily mean that the optimum ball size distribution is being used in the system. System performance may be even better with another ball size configuration.

In the second case study, poor ball size use deteriorates the mill performance along the mill axis. Figure 6 and 7 indicate ball size distribution change and size reduction along the mill axis, respectively.

Figure 7 shows that random size distribution changes along the mill axis. This case study addresses the fact that when a good ball size distribution is not used in the system, milling conditions may be improved by another ball size distribution choice. These two practical case studies suggested that a thorough study is needed to establish an optimum ball size distribution for a given ore and operating conditions. As previously stated, trial and error applications are mostly expensive and time-consuming.

**Determination of the suitable ball size distribution-modelling and simulation**

Simulation is a valuable tool in process technology if the process models are accurate and if model parameters can be determined in a laboratory or plant. Mathematical modelling is now used widely for the design and optimisation of grinding circuits. The data obtained from the mass balancing studies were used in the model studies. Apart from the circuit data generated by extensive sampling, determination of feed material breakage characteristics is essential for the simulation study. Laboratory scale tests are performed to generate the breakage distribution information (Genc, 2009). In ball milling studies the models developed by Hacettepe University were used (Lynch 2000, Benzer, 2001). The model parameters were determined by using the non-linear regression technique. The model structure uses perfect mixing approach, providing that the mill can be modelled in segments.

\[
f_i - r_i \frac{P_i}{d_i} + \sum a_{ij}r_i \frac{P_j}{d_j} = 0
\]

It includes two sets of model parameters, ie the breakage function (aij) and a combined breakage/discharge rate (ri/di) function. Ball size distribution is significantly effective on breakage rates but in some cases it may have an effect on the discharge rate as well. Performance evaluation or a sampling study is essential to calculate the breakage rate of a certain system. Additionally, material characterisation in terms of the breakage properties should be completed. In Figure 8 the breakage rate distribution of the two different ball size distribution is illustrated. These samples were taken from industrial mills. The grinding rate of Plant 1 is higher than Plant 2.
The ball size distribution recommended for the second compartment of the mill is shown in Table 3.

By changing the ball size distribution in the mill, the breakage rate in the second compartment is improved (see Figure 9). The simulation studies were conducted and the results indicated a 15 per cent specific energy consumption decrease in the process.

After implementation of the new ball size distribution the energy consumption decrease was recorded as 17 per cent. The new ball size distribution did not change the power draw of the mill, but the mill’s production capacity was increased from 115tph to 150tph at the same quality figures.

The energy consumption fell from 34.48 kWh/t to 26.66 kWh/t.

**Conclusion**

Ball mill operation is a high cost unit operation and is affected by several parameters. Ball size distribution is an important parameter to achieve a better grinding performance. For an existing operation, measuring the performance by circuit sampling is the starting point to evaluate where the bottlenecks are located and how they are related to the performance of the circuit. Once the bottlenecks are defined, generally a better performance can be achieved by a better ball size distribution configuration. After completing the material characterisation, modelling and simulation is the best tool to achieve this goal. The aim is to increase the breakage rate of the mill. Ball size distribution is correlated with breakage rates so for different ball size distributions it is possible to determine the breakage rates. With the correct ball size distribution, energy consumption can be minimised while maximising the milling rate.

The aim is to increase the maximum impact energy and the work done by the charge. In this article it is shown that by using this technique it is possible to obtain reduced cost, due to less energy consumption per tonne of cement produced.

**References**

AJ LYNCH, CA ROWLAND, 2005: *The History of Grinding*, SME


