ENERGY ASPECTS OF BALL MILL GRINDING
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Summary
Grinding performances of a dry batch ball mill were investigated in relation to mill power measured, changing such variables as ball size, mill rotational speed, ball and material loadings, geometry or number of lifter bars and grinding time.

Introduction
In the field of study on 'comminution' there appear some kinds of polarization, i.e. macro-micro, software-hardware and practice-theory and so on. For instance, numerous papers are available on mathematical modelling or simulation of practical ball mill grinding circuits. Few discussion, however, has been made in those papers from the viewpoint of energy consumption on the basis of its quantitative measurement. On the other hand so-called 'fracture of a single particle' phenomena have been investigated exclusively from this point of view in other papers concerned.

The authors, therefore, are trying to fill the gap of this type and conducted so far some experimental work on a laboratory scale ball mill system facilitating precise measurements of torque.

Experimental
Fig. 1 and Fig. 2 show respectively a photograph and a block diagram of the experimental system used. Batch tests only have been carried out within the extent of this paper, although the system can be applied to continuous ones planned to be conducted in near future.

A series of batch ball mill grinding processes was thus performed with predetermined input variables
Fig. 1: Photograph of the system

ball size, ball and material loadings, mill rotational speed, number of lifter bars and grinding time. Then output variables of torque values and fineness of products were determined. The fineness was assessed by the surface area from Blaine method and size distribution from standard sieves or L & N MICROTRAC (a light scattering method).

Variation of mill power with rotational speed

This item has been investigated by other investigators /1/. In this study, however, in order to get additional information the effect of ball size was observed. As illustrated in Fig. 3 in case of no lifter, i.e. smooth lining, within a considerably wide range of rotational speed and an ordinary extent of ball loading, an almost identical variation curve was obtained for small balls of 23mm and large ones of 32mm. At higher rotational speeds, however, a
A steeper decrease in power was shown in case of the balls of smaller size. It is thought to be probably because of inter ball layer slippage.

Fig. 3: Power variation with rotational speed

Figures in the diagram correspond to J value, and solid and dotted lines to Db=23mm and 32mm respectively.

Effect of lifter bars to mill power

In all the experiments where power was measured changing the number of lifter bars and the ball loading mill power was much more increased in using the smaller balls (Fig. 4). Furthermore mill power maximum points always shifted towards the smaller rotational speed side on abscissa. It must be mentioned, however, that the lifter bars applied here have a somewhat exaggerated dimension, i.e. a rectangular cross section of 23mm height x 40mm width.

Fig. 4: Effect of lifter bars to mill power in case of 10 bars

Figures, solid and dotted lines indicate the same as noticed in Fig. 3
Effect of material charge to mill power

An identical pattern of curves showing variation of power with mill rotational speed was maintained by shifting along ordinate when powder to be ground was charged in a range of normal quantity (Fig. 5). It can be therefore suggested that the behaviour or action of the balls might be essentially not influenced by a normal charge of powder, where $U$ is nearly equal to unity.

![Fig. 5: Effect of powder charge to mill power](image)

Power variation with grinding time elapsed

Although a general explanation has not been attained on this item, almost the same results as mentioned in wet ball mill grinding processes were illustrated in Fig. 6, which is from the experiments under relatively ordinary conditions. The same explanation /2/ as for wet processes can be applied to this dry case.

However under some other 'extraordinary' -from a conventional point of view- conditions, e.g. under $J=0.2$ and/or $U=0.3$ or $1.5$, any determinate...
or reproducible trend has never been recognized.

Energy efficiency under various mill conditions

The specific ares produced vs. energy input plotting (Fig.7) shows that a good linearity of the relationship has prevailed and that ordinary mill conditions can allow a high energy efficiency, e.g. in case of J=0.4, U=0.5 or 1.0 and N/Nc=0.75.

On the other hand, however, other abnormal or extraordinary mill conditions can be optimal from the viewpoint of diminishing rate of particles in coarser size fractions. This is significant considering that to increase surface area of particles is not necessarily a sole purpose of grinding processes.

<table>
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<th></th>
<th>J</th>
<th>U</th>
<th>N/Nc</th>
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<tr>
<td>A</td>
<td>0.2</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>B</td>
<td>0.2</td>
<td>0.5</td>
<td>0.95</td>
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<tr>
<td>C</td>
<td>0.4</td>
<td>0.5</td>
<td>0.75</td>
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<tr>
<td>D</td>
<td>0.4</td>
<td>0.5</td>
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<tr>
<td>E</td>
<td>0.4</td>
<td>1.0</td>
<td>0.75</td>
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<tr>
<td>F</td>
<td>0.4</td>
<td>1.0</td>
<td>0.95</td>
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Dp=23mm

Fig.7: Specific surface area vs. specific energy

Conclusions

Some experimental results were presented and explained on the basis of the data obtained from a laboratory scale ball milling system facilitating precise power measurements.

That is, the authors observed and discussed effects of various parameters such as ball size, mill rotational speed, ball and material loadings and so on.
Ordinary or normal—from a conventional point of view—mill conditions yielded a high energy efficiency concerning the surface area produced. It is thought, however, that there should remain some feasibility or possibility for the other mill conditions when the purpose of grinding is focused on other than increasing surface area of material.

Acknowledgment

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Nommenclature

Db: ball size
J: ball loading; fractional bulk volume of ball bed to mill volume
U: material loading; fractional bulk volume of powder to void volume of ball bed
N, Nc: rotational mill speed and its critical value
t: grinding time elapsed
Sw: specific surface area
\( \varepsilon \): specific energy input

References


/2/ Pietsch: Wet grinding experiments in a torque ball mill, 3rd European Symposium on Comminution (1971)