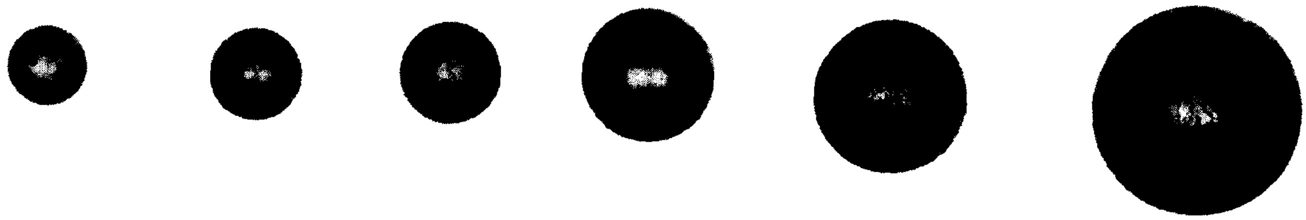

Grinding Ball Rationing

Determining the optimum size assortment of grinding balls for a makeup charge is a practical means of improving mill operation.

by Walter L. Crow

MUCH has been published on highly technical phases of grinding. Very little has been written on how a mill man can improve his operations by determining the optimum size assortment of grinding balls that should be added as a makeup charge. This ball rationing is not to be confused with the ball ration used as an initial charge when the mill is started up.

Ball rationing is considered for one or more of the following purposes: 1) to increase throughput of the mill, 2) to reduce the power required per ton of ore ground to the desired size, 3) to reduce steel consumption per ton of ore ground, 4) to improve product size, and 5) to lower retention time of ore in the mill.

An increase in throughput of the ball mill offers a big advantage. Since total milling cost is the sum of fixed or indirect costs (capital investment, salaries, etc.) plus variable or direct costs divided by the tons of ore processed, and since indirect costs remain constant irrespective of increases in throughput, the total mill cost (in cents per ton) will decrease. This advantage can be realized in plants that can raise the rate of mining and all steps in ore processing to match the increase in throughput of the ball mill.

Indications That Rationed Charge Is Needed: When a one-size ball addition to a mill is being established, the following conditions may warrant ball rationing:

1) There may be a certain amount of tramp oversize that can be reduced by replacing a portion of the balls by a larger size.

2) There may be crowding of particles of reduced size but not of finished size, showing a deficiency of small-size balls.

When a new mill is started up, of course, a certain time is needed to get the processing running smoothly. During this period a further problem of ball rationing would be ill-timed.

Not all mills should attempt ball rationing, and these words of caution are offered. Most small mills, and some of the larger ones, have not the facilities to blend mine run ore for mill feed, and with a great variation in character of feed there may be a difficult problem in establishing even an optimum single-size ball charge. Small plants may find that this has taxed their personnel enough without going into ball rationing. This does not mean that the personnel lacks technical ability, but that facilities, personnel, and sufficient time are not available for careful testing. Moreover, the cost of such an effort may not be justified. Total savings in dollars and cents, through a relatively minor improvement in grinding practice, will not be as great in a small operation as in a larger one.

Ball Wear Pattern: When one-size balls are used for addition, the seasoned charge in the mill ranges from balls of the original diameter to those small enough to purge from the mill. If a screen analysis of the charge is made using screens with openings of equal increments, such as ½ in., the weight of the balls on each screen will show a certain pattern, or distribution of the charge by weight, whether ball wear varies in direct proportion to its surface area as D^2 (attrition grinding), as maintained by Rittinger; or in direct proportion to its volume as D^3 (impact grinding), as maintained by Kick; or somewhere between these two figures as suggested by Bond (a combination of attrition and impact comminution).

These theories of ball wear do not hold true, in the writer's opinion, for apparently the rate of wear of different ball sizes in the charge is affected by size structure of the mill feed and by crystal size of the minerals. Also the physical and chemical characteristics of the ball may vary with the distance from its center.

There is evidence that there is a difference in the wear pattern of grinding balls of different manufacture. Some appear to be *self-rationing* compared with others.

The advantage of large balls in the charge is that they drop with greater impact and have a more effective *nipping* action on the larger particles. Small balls make a greater number of contacts because

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there are more of them, so that attrition grinding is more effective and there is a higher crushing incidence due to nipping action on the smaller particles. Ball rationing is employed to change the size distribution of the ball charge to one that has a better ratio of impact, nipping, and attrition.

One-Size Ball Makeup for a New Mill: Before an attempt is made to work out a rationed makeup charge, the best one-size ball makeup charge should be established. Ball size is determined mainly by the factors listed below:

Ball

1) Specific gravity (affected by voids in the ball)
2) Shape
3) Homogeneity
4) Relative cost of balls by diameter

Mill

1) Inside diameter
2) Speed (peripheral speed, rather than percent critical speed)

Manner of Operation (Assuming One-Stage Grinding Only)

1) Open or closed circuit. (Percent circulating load of closed circuit)
2) Mill pulp density (specific gravity of pulp constituents)

Feed Material

1) Size structure of mill feed
2) Desired particle reduction
3) Character of ore
   a) Specific gravity of gangue and of mineral or minerals
   b) Grindability characteristics
      1) Comminution to crystal sizes
      2) Comminution through crystal sizes
      3) Sliming characteristics

Grindability tests have been made with laboratory-size equipment by mill manufacturers, institutions, and mining companies. These tests indicate grindability of the ore, but scale-size work has its limitations. The ratio between mill diameter, mill peripheral speed, ball diameter, and particle size which is obtained in laboratory work is not the ratio that exists in the full-scale operation. A mathematical solution of the problem may indicate the proper ball size. The simplest mathematical aid is the Coghill and DeVaney formula, $D^2 = Kd$, where D is the ball diameter, d the particle size, and K a constant varying between 25 and 50 depending on the relative hardness of the ore.

This empirical formula cannot always be trusted, and it is evident that many factors listed on page 752 under General Method of Rationing are ignored.

Bond has gone further in developing the empirical formula:

$$B = \sqrt{\frac{F\,W_i}{K\,C_s}\sqrt{\frac{S}{\sqrt{D}}}}$$

In this formula B is the diameter of the ball to be charged, in inches; C is the percent critical speed of mill; D is the inside mill diameter, in feet; F is the size of screen opening, in microns, that 80 pct of the new feed to the mill passes; K is a constant which has a value of 200 for a closed circuit ball mill; and S is the specific gravity of the ore. W_i is called the work index, which is determined in the Allis-Chalmers laboratory. This formula assumes the use of a spherical steel or iron ball and takes into account the more important factors listed above. The factor most difficult to determine is W_i. It is of course dependent on the sample of ore submitted for laboratory test and is limited by the shortcomings of laboratory tests. Some people question that the factor F is an ideal criterion.

When a new mining property is being developed it is often not accessible, so that sampling is not thorough enough to indicate all the types of ore that eventually will be encountered. It is important that the comminution problem of various ores be studied in terms of the subsequent metallurgical processes, both physical and chemical. The degree to which the ores will be blended before entering the ball mill should be taken into consideration. If no blending or poor blending is anticipated the most difficult grinding ore should be given the most weight in determination of ball size, although this size may be too large for the softer ore.

Through past experience some mill manufacturers have prepared tables that specify ball sizes for each mill size. Tables are usually set up with different ball sizes recommended under ore classified as hard, medium, and soft. The question is, how hard is a hard ore?

An important consideration is the ball size used by other mills with similar ores, especially when similar ball mills are used.

In an operating mill it is not difficult to determine whether the optimum one-size ball makeup charge is being used. Variation in grindability of ore is the chief complicating factor. It is better to add too large rather than too small a ball, although fewer balls are used, giving fewer contacts and less attrition grinding. This is a precaution against encountering ores that are more difficult to grind, which may cause an increase of tramp oversize to be circulated through the closed circuit, choking up the circuit and necessitating reduction of mill feed.

Too large a ball will reduce the larger feed particles with little tramp oversize, but the reduced particles will crowd before they reach the required size for further processing, and excessive slimes may also be produced. In closed circuit, recirculation of the crowded sizes will overload the classifier, requiring reduction in mill feed. Added to an open circuit mill, grinding balls that are too small allow tramp oversize to enter the next process, and balls that are too large do not produce the desired fineness of grind or liberation size, while at the same time they may produce too many slimes.

Prices of the different size balls are worth considering. The lowest-priced steel ball is commonly the 3-in. diam ball. Larger sizes are slightly higher in cost. For smaller sizes the price becomes rapidly higher. If 3½ and 3-in. diam balls give similar results the 3½-in. ball is preferable, as it gives insurance against production of excess tramp oversize in case the feed becomes more difficult to grind. However, the lower price of the 3-in. ball may be the deciding factor. Balls of 3-in. diam are more commonly used in beneficiation plants and are usually more available for immediate delivery.

It is an interesting contention that a grinding ball with a softer core is less subject to splitting from impact and that when the ball is worn down to the size considered of little value in comminution, it is then reduced in size at a faster rate by abrasion and thus ejected from the mill sooner, making way for the addition of balls of more useful size.

As in other experimental work in an operating circuit, it is good practice not to make too radical a change. If it is indicated that 4-in. diam grinding balls would be more satisfactory than the 3-in. diam balls in use, it would be better to test 3½-in. diam balls first and then check results. Or, if it is thought that 2½-in. diam balls will improve results over the present use of 3-in. diam balls, it may be better to use only one quarter or one half the charge of 2½-in. diam balls to check for improvement before going to 100 pct 2½-in. balls as the makeup charge.

General Method of Rationing: How can the ideal ratio of different sizes of balls for a mill be determined? How can the ratio be varied? The second problem is relatively easy.

Many operating personnel in the cement industry believe that when raw materials and clinker are ground the seasoned charge contains too many balls worn to small sizes and irregular shapes, giving ineffective contact on impact. These take up space that could be utilized by larger spherical balls that would grind more effectively. To increase the ratio of larger balls in the charge the mills are periodically dumped, the charge is screened, and the larger balls are returned to the mill. *Cull* balls are replaced by new ones.

If it is determined that there is a shortage of small balls in the seasoned charge, the makeup charge may be partly replaced by one or more sizes of the smaller balls. This is a *rationed* charge.

Steps in Working Out the Ball Ration: Complete records should be kept so that the throughput of the mill, power consumption, and ball wear are known. It is also well to record liner wear, although this requires observation over a long period of time. It is very important to keep records of feed, discharge, classifier overflow, and classifier sands screen analyses. Classifier sands size structure will give indications as to whether smaller or larger balls in the charge will give better results. Davis's rules should be used:

1) Crowding will appear at the fine sizes of particles in the classifier sands, if the seasoned charge is graded too much towards the larger sizes of balls.

2) Crowding will appear at the coarse sizes in the classifier sands, if the ball charge is graded too much toward the smaller sizes.

3) Best efficiency is obtained when there is a minimum crowding at any size of the size structure of the classifier sands.

Complete records should be kept to show the effect of any change in ball addition to the mill throughput, power consumption per ton, and ball wear in pounds per ton. These changes will affect the size structure of the mill discharge and the classifier overflow and sands. Before the full effects of a change in ball addition occur, the ball wear pattern should be given time to reach its new equilibrium. This will require the time necessary for the old ball charge to be entirely replaced by the new charge. For example, if the ball load in the mill is to be maintained at 100,000 lb and 1000 lb of balls are added per day to maintain the ball level in the mill, it is reasonable to assume that more than three months will be needed to complete the modified ball charge.

If the new makeup charge is one that would increase the rate of comminution of the ball mill, and if the new ball charge reaches its equilibrium *without* an increase in feed rate, the new charge will *not* show an increase in throughput, the steel consumption will be too high owing to steel on steel wear, and power consumption per ton of ore ground will be unnecessarily high. To prove the value of a charge in ball ration, it is important that the mill feed be kept at capacity at all times.

A study of the classifier sands using the graphic method presented by Coghill maybe made. The size structure is plotted using the abscissa to represent each mesh size of the standard series screen and using the ordinate to represent the respective percent weight of material on each screen. If the plot shows a bulge in finer sizes, a smaller ball should be considered in the ration. The size and number of balls must be determined by trial and error. All the sizes of balls in the mill do work in reducing all the sizes of ore particles, but each size of particle is most effectively reduced by a certain size of ball. This is simply a restatement of Davis's rule. As Davis suggests, best results in grinding are obtained when the size analysis of the classifier sands is uniform.

W_i in Bond's formula and the K in Coghill and DeVaney's are subject to the weaknesses of laboratory determinations and may be somewhat in error in calculation of a one-size ball makeup charge. When an optimum one-size ball makeup charge, B and D, has been proved by practice, the formulas can be solved for W_i and K. By observing the bulges on a Coghill type of plot of the classifier sand size structure, it is possible to estimate a new F and D. With the variables solved for, W_i and K, and estimated, F and D, the formula can be solved for a new B and D, and these values can be used as an indication of the ball sizes to be added to the ration.

By screening a dumped ball charge as described under Ball Wear Pattern, it may be found that there is a deficiency in certain ball size or sizes in the wear pattern. This may be correlated with the bulges in the plotted curves of the screen analysis of mill feed and classifier sands and with the crystal sizes of the minerals being ground. This deficiency of a certain size of ball in the wear pattern may indicate that this size or one slightly larger should be added to the makeup charge for grinding improvement.

Ideally, comparative tests of different ball rations should be made in mills that are in parallel, with identical mill conditions, with feed as similar in character as possible, and with independent control of feed and water to each mill so that the mills may be fed at capacity. If the same mill must be used for comparative tests, any change in ore characteristics and liner condition must be correlated.

Conclusion

Attaining an ideal ball ration is not easy. However, by using common sense in applying established principles of grinding, by keeping complete records and avoiding changes that are too radical, and by allowing enough time for changes to take effect, many mill operators can increase the efficiency of their ball mills.

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