

Finish Milling and Grinding

by Nile R. Strohman*

The finish mill system in cement manufacturing is used for reducing the size of the clinker from as large as several centimeters in diameter to a size that is a maximum of 100 micrometers across. This process is accomplished by grinding (milling) with the use of ball mill, roller mills, roll presses, or some combination of these processes. Out of 110 to 130 kWh/ton of electrical power consumed in making cement, between 30 and 50 kWh/ton are consumed by the finish milling operation. This is the largest single consumption point of electric power in the process of converting raw materials to finished cement.

The main focus of this chapter is the ball mill, since this type of equipment produces most cement. However, the main features of this chapter apply regardless of the type of equipment. A typical ball mill for finish grinding at a cement plant is shown in Figure 4.1.1.

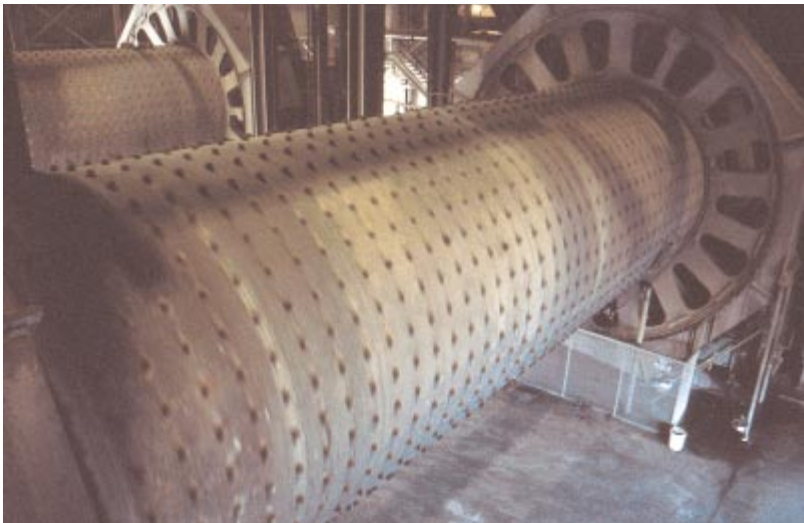


Figure 4.1.1. A ball mill used for finish grinding at a cement plant.

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Clinker may be harder or easier to grind depending on how it is burned, its chemical composition, and how it is cooled. One of the major causes of hard grinding is the amount of C_2S (belite) in the clinker. One of the reasons for the formation of belite clusters in clinker is either the use or the inclusion of coarse silica such as quartz, in the raw mix. This is readily determined by the use of microscopic examination of the feed which is very useful in diagnosing burning as well as grinding problems. Regardless of the grindability of the clinker, it is very important that uniformity of the clinker be maintained so the grinding operation may also maintain a good degree of uniformity for optimum quality and production rates.

The raw mix also needs to be maintained uniform in addition to being a mix that is not hard burning so that long retention times in the kiln are avoided. Long retention times in the kiln result in large C_3S (alite) and/or large C_2S (belite) crystals. Both of these large crystals are hard to grind, in addition to causing a dusty clinker with higher than desirable amounts of fines. It is well known that the clinker chemistry and burning conditions can have a great effect on the grinding rate as well as on the quality of the cement produced.

FINISH MILLING SYSTEM

In cement manufacturing plant, the finish milling system is comprised of four basic components namely, 1) feeders, 2) mill, 3) elevator, and 4) separator. A schematic of the finish milling systems is shown in Figure 4.1.2.

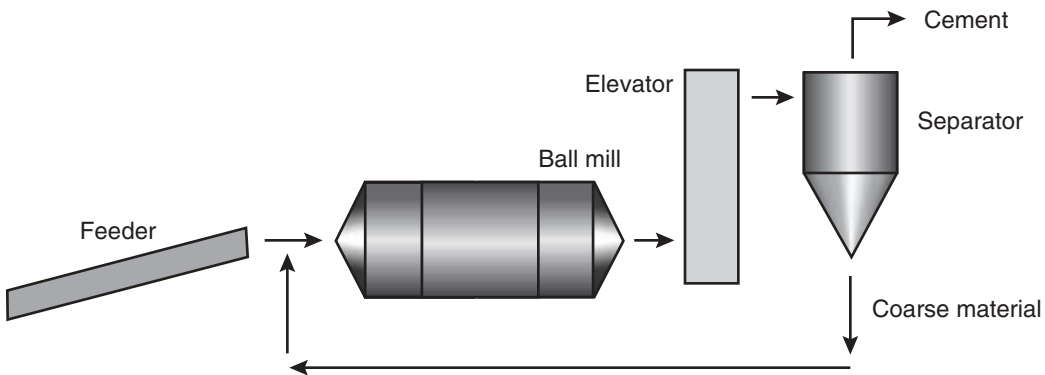


Figure 4.1.2. Schematic of finish milling system in a cement plant.

The following sections will briefly describe the operations of these components of the milling system.

The Feeders

In too many instances, the weigh feeders give a nonrepresentative view of how much cement the mill is producing. These readings are subject to errors in their data from the calibration of the feeders. Regular calibrations should be performed as per the manufacturers recommended proce-

cedure. Normally this involves a known weight “chain,” which is placed on the feeder belt; the calibration is performed using this weight. Recently, it has become popular to calibrate weigh feeders electronically without weights; this procedure is rapid, but is regarded as less reliable than the one which uses live weights.

A simple method of checking the accuracy of the feeder is to measure the amount of material on a known length of the feeder belt, while measuring the speed of the belt. This is accomplished by measuring the cross section of the material and timing the speed of the belt to give a volume of material. By using the bulk density of the plant-specific clinker, a reasonable feed rate can be determined as follows:

$$F_R = A \times L \times D / t \quad (1)$$

where,

F_R = feed rate (mass of new feed to mill per minute)

A = cross-sectional area

L = length

D = bulk density

t = time in minutes

The Mills

Many mills are operating with an impact scale in the reject (tails) stream. Although these can be calibrated electronically, it is ideal if this scale is calibrated by actual weight. Consideration should be given to inclusion of facilities to dump and weigh a timed portion of material from the impact scale to correct the calibration to a “real” weight for accurate real-time circulating load numbers.

The liners. A ball mill is typically identified by connected horsepower (or kW) and internal dimensions, length, and diameter. The ball mill shell is protected by carefully designed wear-resistant liners, which provide lift to the ball charge. As depicted by the diagrams in Figure 4.1.3, there are straight lifting liners on the left, ripple liners in the center, and rarely used smooth liners on the right.

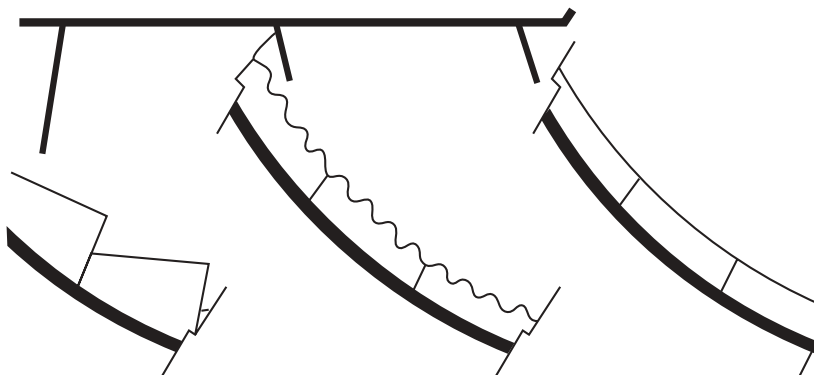


Figure 4.1.3. Three different lifting liners of a ball mill; straight lifting liners (left), ripple liners (center), and smooth liners (right).

Figure 4.1.4 gives a view of a second compartment and liners in a ball mill. One can see the wear grooves in the liners. This compartment is typically used to reduce the size of the clinker down to less than 5 mm.



Figure 4.1.4. View of second compartment of a ball mill showing liners.

Some examples of classifying liners that are typically used in the second compartment of a ball mill are shown in Figure 4.1.5.

These liners generate a classification of the ball charge and are used primarily in the second compartment to promote the classification of ball sizes, so the small balls are at the outlet of the mill and large balls at the division screen.

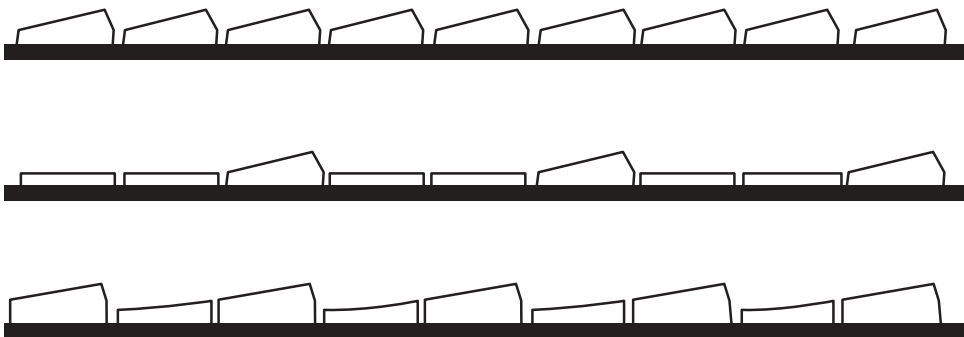


Figure 4.1.5. Classifying liners typically used in the second compartment of a ball mill.

The ball charge. Typical ball charges run from 30% to 35% of mill volume with some mills slightly higher and some lower. If the ball charge is increased above about 36% with classifying liners, the ball charge will probably reverse classify, causing a reduction in grinding rate. Below 30%, the production rate will suffer. However, it is sometimes possible to reduce the kWh/ton by reducing the ball charge, but with a reduction in the production rate. The relationship between ball charge percentage loading, production, and kWh should be carefully watched. The decisions on how to charge the mill should be made with full knowledge of the costs and consequences generated by these decisions. Consideration must also be given to the fact that the use of classifying liners reduces the internal volume of the mill by up to 10%.

A typical equation employed in calculating the ball charge is as follows:

$$\% \text{ volume loading} = \frac{0.0087278 \times R - [C (R-H)/2]}{(\pi R^2)} \quad (2)$$

where,

R = radius of the mill inside liners

C = horizontal distance liner to liner at ball charge surface

H = free vertical height, charge to liner

D = diameter of the mill inside liners

Critical speed. The definition of critical speed (CS) is the slowest speed at which an infinitely small particle on the mill liner will centrifuge, i.e., the speed necessary to prevent this infinitely small particle from collapsing away from the mill shell at any point. The calculation for critical speed of a mill is:

$$CS = 76.63 / \sqrt{D} \quad (3)$$

where,

CS = critical speed

D = internal diameter of mill in inches.

The percent of critical speed a mill is running at is expressed as:

$$\% \text{ Critical speed} = \text{Actual rpm} / \text{CS, as a percentage} \quad (4)$$

Typical percent of critical speed is about 75% but may range from as low as 65% to 80%. The only way to change the critical speed is to change the motor speed or the gear reduction. This calculation should be done so that the critical speed is known. This knowledge may help explain operating parameters and help to determine ball sizing.

The division head, or diaphragm, divides the mill into compartments. Typically, this is a double plate design with lifter plates to facilitate the flow of material through the plates. These plates are typically slotted with the slots comprising approximately 5% to 10% of the total area of the division head. Slot sizes are usually about 6mm with slot sizes in the discharge screen plate being

larger, at about 8 mm, to make sure no “spitzers” remain in the second compartment. Some plants use so-called “flow control” diaphragms to enable the plant operators to adjust the lifting action so the filling level of the first compartment can be controlled.

Grinding balls. Grinding balls, also known as grinding media, are used in various sizes ranging from as small as 12 mm to as large as 100 mm. in diameter (Figure 4.1.6). The various sizes are used in combinations to adjust the density of the charge, to regulate the speed the material flows through the mill, and to deal with various degrees of hardness of the materials to be ground. The first compartment (or primary compartment) will typically be charged with a mixture of balls from 50 mm up to 90 mm. Occasionally, with very hard to break materials, some 100 mm balls will be used.



Figure 4.1.6. Grinding balls in the first compartment of the ball mill.

The secondary or fine compartment may contain balls as small as 12 mm ranging up to 50 mm diameter balls.

On the subject of ball size and ball charge in a grinding mill, Duda (1977) recommended that the first compartment of the mill, where the grinding is primarily done by impact alone, should contain ball size between 60 mm to 100 mm. In the second compartment where grinding is performed by a combination of impact and trituration, the balls sizes should range between 35 mm to 60 mm. In the third compartment, where the grinding is done mostly by the trituration effect, the ball size should range between 20 mm to 30 mm. The ball size and the corresponding ball charge in different compartment of ball mill is given in Table 4.1.1.

Table 4.1.1. Recommended Ball Size and Total Charge in a Three-Compartment Ball Mill (Duda, 1977)

Mill compartments and grinding mode		Ball size, mm	Ball charge, wt. %
I	Impact	60 – 100	30
II	Impact and trituration	35 – 60	27
III	Trituration	20 – 30	24

Evaluation of Mill Operation

In order to evaluate the mill operation, a complete set of circulating load samples is needed. This includes mill discharge, separator feed, separator fines discharge, and separator coarse discharge (“tails” or “rejects”). These samples should be a composite of at least five samples taken over a 15 to 20 minute time period. (These samples should be taken close to the mill or separator.)

Mill Retention Time

An additional test for evaluating mill operation is a mill retention time test that can be conducted during the same period of time as the circulating load sample is being taken. This data is then all from the same period of time and operating conditions.

The mill retention test consists of adding a dye (typically fluorescein) to the mill at a given time and taking samples from the discharge of the mill at least every 1 minute for 15 minutes. These samples are then tested to determine the time at which the maximum amount of dye was in the sample. This time is considered to be the “mill retention time” (MRT)*.

Mill retention time procedure. The mill retention time procedure, as developed by W.R. Grace, consists of tagging cement clinker with fluorescein that has been put into a water solution and poured into a plastic bag of clinker. Typically this plastic bag would be at least doubled to preclude leaking of any of the fluorescein solution. The amount of fluorescein is about 15 grams for every 20 tons per hour of feed (total of fresh feed and rejects) to the mill. The fluorescein is put into solution with a minimum amount of hot tap water and poured into the doubled bag containing about 5 kilograms of clinker with a lot of fines in it. An ideal clinker is one that has been run through a jaw crusher. Precautions should be taken against breathing any of the dust or getting the solution on the skin, as with any chemical. (These tagged bags may be prepared ahead of time and even stored for several days if necessary.)

* CAUTION: Prior to running the circulating load tests and/or the MRT test or any other test, the milling system must be in equilibrium to have any meaning! If the system is not in equilibrium, the tests will reflect the instantaneous conditions existing at the time and will be meaningless with regard to normal operations.

The tagged material is added to the finish mill by dropping the bag and all its contents into the feed chute of the mill. The stopwatch is started at this point. A sample of at least a 50 g is taken exactly every 1 minute from the mill discharge. In the case of very short mills or the ones in which the retention time may be very short, sampling should be done every 30 seconds for the first 5 minutes to improve the accuracy of the testing. These samples are analyzed by taking the same quantity (typically 3 to 5 g) and adding 25 mL of water to each sample. This sample is then stirred, allowed to set for at least 30 seconds, and filtered. The liquid is then analyzed in a photometer set at 484 nm wavelength. This is plotted, absorbance vs. time, and the peak in minutes is used as the mill retention time.

Mill retention time (MRT) is very helpful in determining the operating conditions of the finish mill. One of the calculations where it is used is determining the % void fill of the mill without the need for shutting the mill down in a crash stop manner. The calculation is done as follows:

$$\text{ICC} = \text{MRT}/60 \times \text{TPH} \times 2000 \times (\{100 + \text{CL}\}/100) \quad (5)$$

$$\text{Void Capacity} = (\text{BC}/285) \times 0.45 \times (\text{avg. ft}^3 \text{ cement in mill}) \quad (6)$$

$$\% \text{ Void Fill} = (\text{ICC}/\text{Void Capacity}) \times 100 \quad (7)$$

where,

ICC = instant clinker charge

MRT = mill retention time

TPH = tons per hour mill production

CL = circulating load

BC = total ball charge in mill in pounds

A depiction of the filling of a ball mill in a static condition is shown in Figure 4.1.7.

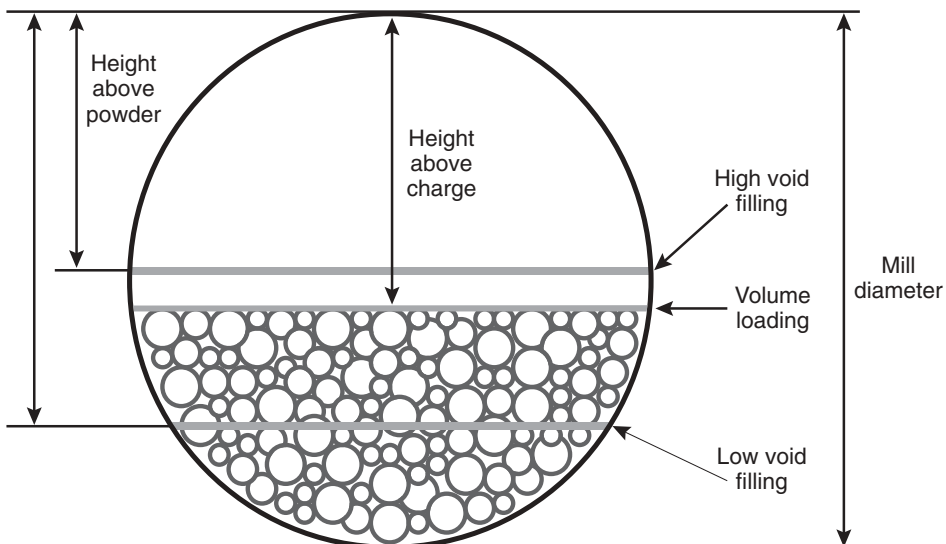


Figure 4.1.7. Filling of ball mill in a static condition.

This calculation will give a very accurate determination of the operating condition of the mill as far as void fill is concerned, provided the measurements, testing, and determinations are conducted accurately. The best operating conditions are when the mill has between 85% and 100% void fill. The mill retention time for a closed circuit mill will be between 6 and 9 minutes. Short “stubby” mills may have a very short mill retention time, down as low as 3 or 4 minutes. It is difficult to change this, due to the configuration of the mill. However on a normal mill grinding closed circuit, there are several things that can be done to change the MRT. If the mill has an adjustable diaphragm, adjustments to it may change the MRT. Changes to the composition of the ball charge have the largest effect on the MRT. A denser ball charge will increase the MRT, and conversely, a less dense ball charge will shorten the MRT. The airflow through the mill will affect the MRT to some extent, as when the airflow is increased more material will be pulled through the mill with the air into the dust collector. If the airflow is too high, this will hurt the performance of the mill by not allowing it to grind all the material sufficiently for optimum operation, but it will also shorten the MRT.

Mill Efficiency

To help determine the efficiency of the mill, by itself, in a closed circuit system, a method that has proven very beneficial is the 325-mesh improvement through the mill. The calculation is as follows:

$$325 \text{ increase through mill} = MD \left(\frac{T \cdot CL}{1 + CL} \right) \quad (8)$$

where,

MD = mill discharge passing 325

T = tails (rejects) passing 325

CL = circulating load of the mill system

This increase in the 325 should be between 20% and 30%, if the mill itself is grinding well. If it is below this value the mill is not preparing the cement well enough for the separator and is reducing the output of the mill system by overloading the separator and sending an excessive amount of rejects (tails) back to the mill for regrind. If the increase is above 30%, then the mill is overgrinding and not allowing the separator to do its share of the work. This again reduces the mill system production rate as the mill is operating more like an open circuit mill.

Mill Throughput

The throughput of a ball mill is another parameter for gauging the mill efficiency. The throughput is often estimated from a grindability curve that relates the throughput as function of product size in Blaine numbers (Duda, 1977); the grindability curve is shown in Figure 4.1.8.

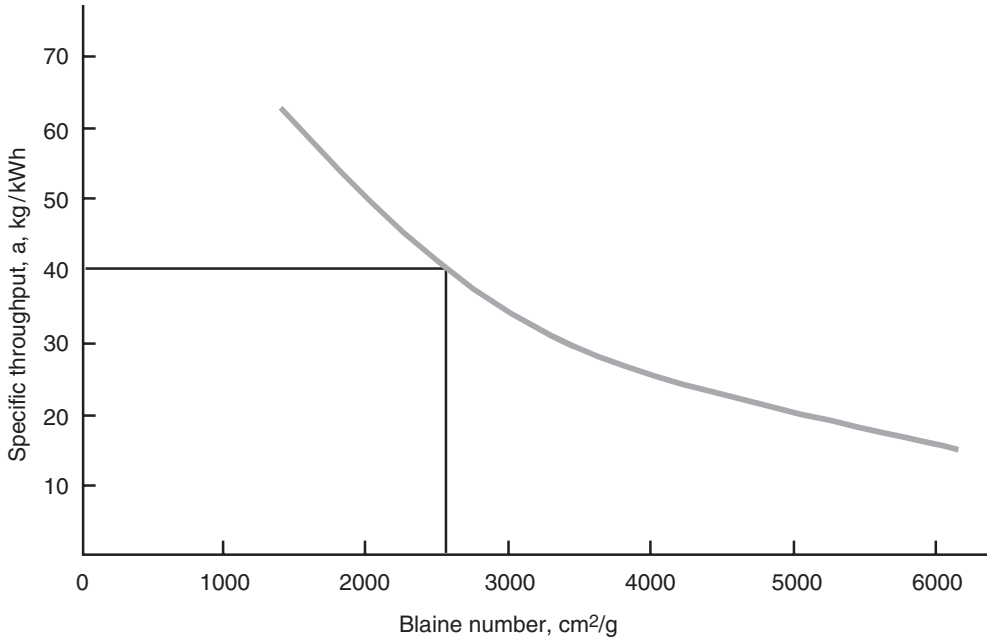


Figure 4.1.8. Grindability curve showing relationship between specific throughput and fineness of finished product in grinding mill (Duda, 1985).

To estimate the specific throughput in kg/kWh from the curve, the fineness of the finished product from the mill in Blaine number (cm²/g) is used. From this value the actual mill throughput is calculated in tons/hour using Jacob's throughput formula as follows:

$$L = (M_g \times T_p \times D_m \times V) / 20,000 \times D_{Mb} \quad (9)$$

where,

L = mill through put (t/hr)

M_g = mill capacity value

T_p = specific throughput (kg/kWh) taken from the curve using the Blaine number

D_m = mean grinding path diameter, m

V = volume of grinding space, m³

D_{Mb} = reference grinding path diameter, 1.0m

Particle Size Distribution

Particle size determinations (PSDs) are very useful in helping determine the operating efficiency of a mill system. These values of the separator product (fines), separator feed, and rejects (tails) can be used to develop a Tromp curve for the separator.

Size selectivity curve or Tromp curve. The size selectivity curve or Tromp curve describes classifier performance for *all* particle sizes in the feed to the classifier. The curve is based on particle

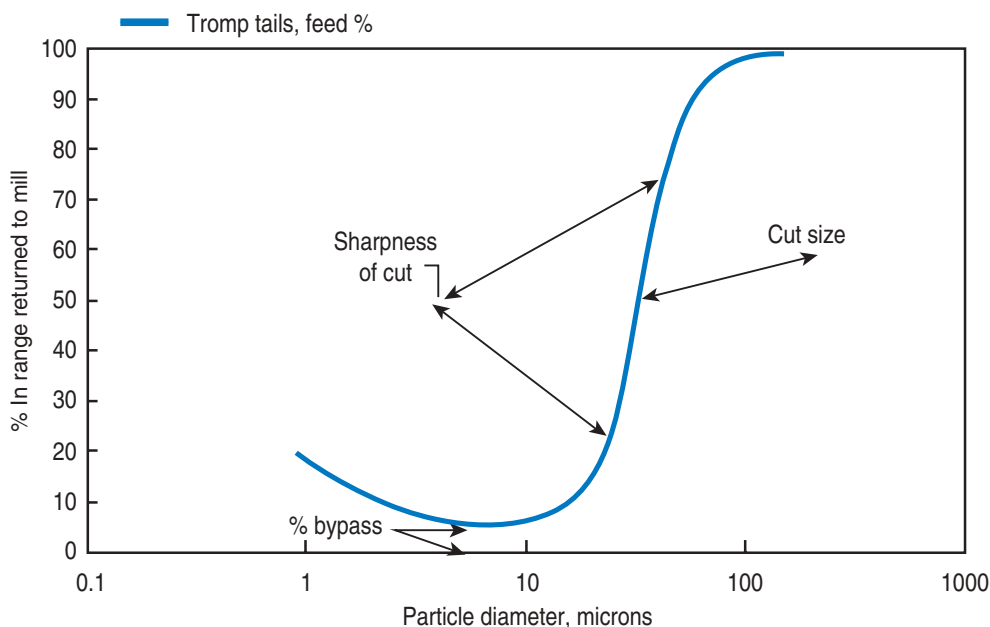


Figure 4.1.9. Size selectivity curve or Tromp curve depicting classifier performance.

size distribution measurements of the actual fines and coarse streams, as well as the calculated feed (Figure 4.1.9). The calculated feed is a summation of the actual fine and coarse stream particle sizes.

The size selectivity curve is based on actual PSD measurements. After measurements are made, the percentage of the feed of a particular particle size that appears in the coarse (i.e., tails) stream is plotted versus that particle size. There are three important features of the size selectivity curve, 1) *cut size* at which separation occurs, 2) *sharpness of cut*, which is a measure of spread about the cut, and 3) *by-pass* amount returned to the mill. These features are best understood by examining a classification curve.

The *cut size* is commonly defined as the particle size at which there is equal probability of the feed passing to either the coarse or fine streams. The ideal cut size is between 25 and 30 microns.

The *sharpness of cut* is measured by the ratio of d_{25}/d_{75} . The nearer the ratio is to 1.0, the sharper the separation.

The *by-pass* is the amount of feed that is not classified by the separator and therefore immediately returned to the finish mill with the rejected material.

An additional but less important feature is the 'fishhook effect' commonly seen in classification curves. It is associated with the finer particles and shows the degree of return of fine particles to the coarse stream. The following factors may cause this effect:

- Larger particles are coated with finer particles
- Incomplete feed dispersion
- Fines are entrained in the rejects
- Aggregations of fine particles that pass into the coarse stream.

It needs to be remembered that the Tromp curve is an indication of how the separator is working and *not* an indication of the entire mill system.

Separator Performance

The separators are often most problematic pieces of equipment in the milling system, particularly the first generation separators, namely Sturtevant™ and Raymond™. The separators need to be inspected frequently for problems. A quick way to keep a good check on the separator is to run 100 grams of the finish product through a 100-mesh sieve every day. All the material should pass a 150-micrometer sieve; if 1% or 2% is retained, it is a good indication there is a leak in the separator and would justify an inspection.

Following are some checkpoints to observe when a separator is being inspected for normal maintenance or if there is a problem.

Raymond™ separator checklist. A list of check points for a efficient operation with Raymond™ type separators are as follows:

- The main fan blades should be straight and not bent at the corners. They should be securely bolted to the brackets. Unless the main fan blades have been intentionally moved, they should be at full diameter, just to the edge of the inner cone.
- Check the dampers to make sure they are not worn or bent and that they move freely.
- The linkage that connects the dampers should be checked with the external position of the indicator to make sure that all of the dampers are in the same position.
- The upper set of whizzer blades should fit to the shelf casting so there is not a big gap at the tip of the blades which could allow coarse material an easier route to get over into the fine material. Clearance should be approximately 12 mm vertical and the whizzer should be about 25 mm under the shelf casting. Check for wear and proper clearance of both the upper and lower whizzer blades. They should be square-cornered and tight, so they cannot come out of adjustment. When making blade changes, fineness and throughput are of prime concern. Records should be kept of production and fineness at various blade patterns.
- The feed chute and the opening to the distribution plate should be clear and free of any buildups of chunks of hydrated cement.
- The distribution plate should be checked for wear; also make sure it rotates evenly and is not warped.

- The return air vanes should be at the proper angle and should all be in place.
- The separator should be inspected using a beam of light, for leaks or holes. Some areas that are susceptible to wear are under the drum cover and the tailings pipe that goes through the fine side of the separator.

Sturtevant™ separator checklist. Similarly, a list of check points for a efficient operation with Sturtevant™ type separators are as follows:

- The point where the drum cover connects to the drum liner is very susceptible to wear and should be checked frequently, since typically the auxiliary valves have been pulled all the way out for room to work on the separator as they then may cover the holes. Also, the complete interior should be checked between the inner and outer cones at all flanges and bolted seams, especially where the tailings pipe goes through the fine side of the separator.
- The clearance between the upper edge of the selector blade and the drum cover is very critical and should be maintained at about 12 mm. This clearance should be checked on the circumference. The selector blades should extend under the drum cover about 38 mm to 50 mm.
- The selector blades should be checked for wear and to see if any blades are bent. If blades are bent, the cause should be determined and repairs made. If support strips are attached to the bottom edge of the blade, they should be secure and in full contact with the blade.
- The upper distribution plate and the supports should be checked. The supports can become worn and weakened; this could cause the outer edge to the plate to sag, resulting in a large gap between the upper edge of the selector blade and the drum cover.
- Tailings from the coarse side may pile up on top of the outlet air pipes to the point that coarse material can be pulled over or just fall over to the fine side of the separator. To correct this, several of the air vanes directly over the pipe can be removed and the area blanked off. The air inlet pipe should not be cut off to prevent this buildup because it needs to extend into the inner cone.
- The return air vanes should be 60 degrees tangential to their mounting, facing into the wind. All the vanes should be in place. No extensions should be used on the air vanes.
- It is important to have some means to control the amount of make-up air with a damper, so that the separator is not being over swept and too much material is pulled into the dust collector. If this happens, loss of control of fineness occurs.
- The main fan blades should be checked for wear and to see if they have been bent. The number, diameter, and blade area should be recorded. The rotation of the blades should be checked; they should turn counterclockwise, looking down from the top of the separator. The speed should be checked, especially on the belt-driven machines. The capacity of the separator is determined by the number, diameter, blade area, and speed of the main fan blades; if changes are made, opposite blades should be moved equally to maintain rotor balance.

- The feed chute discharge ports can become plugged with chunks of hydrated cement, and should be kept clear at all times. If one or two of the ports are plugged, this could result in an uneven flow of material off the distribution plate which could affect the fineness or set up a vibration in the separator.
- If the packing ring that seals the stationary feed intake cone and the rotating assembly is missing or worn, coarse material may leak over to the fine side of the separator because of the difference in pressure. This can be checked with a small rod around the circumference of the rotor. When working in the separator, care should be taken that no nuts or bolts get in this area, because they will bind the rotor.
- The rods on the auxiliary valves should be checked to make sure they are securely welded, the cotter pin has not been sheared off, and the rods are actually moving the valves. Also, check the guides to make sure they are lined up. Check for buildup under the auxiliary valve. Buildup between the auxiliary valve and the drum cover will cause the valve to rise up when the valve is moved causing the rod to bind and making it hard to screw in the valve. It also increases the gap clearance between the valve and the selector blade, and there are times when it will be raised high enough for the valve rod block to hit the bottom edge of the main fan blade.
- Always make sure the door gasket to the inner cone is in good condition and well sealed when replacing the door. This area is constantly bombarded with coarse material and any leak would go over to the fine side of the separator.

GRINDING AIDS

Grinding aids have an immense impact on the production and cost of cement manufacturing. They impact the quality, power consumption, and handling both in the cement plant and in the final users' hands. Grinding aids are used primarily for two reasons; 1) first they are used to minimize the "pack set," defined as the condition that inhibits the start of flowing of the cement, 2) second they are used to improve the "flowability" of cement, defined as the ease with which cement flows once it has been set in motion. However, a third cement flow problem is "silo-set," which is due to the absorption of moisture in storage and possible syngenite formation. This problem is helped only minimally by the use of grinding aids.

Theory of Grinding Aids

The most widely accepted theory for the need for grinding aids is the concept of surface energy forces. This theorizes that when a structure is fractured, the fracture lines sever electrovalent bonds that then cause unbalanced primary valence forces of opposite polarity to exist on the two surfaces created. This fracturing then is as much a chemical reaction as it is a physical grinding operation. If it were possible to fit the two particles back together perfectly, they would be reestablished as one unit since these attraction forces are so strong. This is analogous to cold welding of metals. The chance of perfectly fitting the particles back together in the same way as they were fractured is

statistically remote, to say the least. However they can be close enough to a fit that a strong bond is accomplished.

While grinding cement in a ball mill fractures the particles, it also compresses them as well as other individual and groups of particles. This causes agglomeration of these particles, as a result of these unsatisfied valence forces attracting one another. This agglomeration behavior can be especially damaging when it occurs on the surface of the grinding media. This agglomerate is initially an open structure of linked particles but when it is subjected to the impact densification in a ball mill it can produce a strong rigid structure. These agglomerates act as if they were one unfractured particle instead of a group.

In addition, water molecules tend to latch onto the newly formed surfaces that are created in the grinding operation. The water is made available from the moisture in the air, cooling water, grinding aid dilution water, dehydration of gypsum, and surface moisture on clinker and gypsum. These water molecules then bond two or more particles together by what is termed hydrogen bonding. This is a weak bond between an electropositive hydrogen atom and an electronegative atom such as oxygen.

Grinding Aids Function

Experience and test data indicate that the most effective grinding aids are polar in nature. Polar compounds have a more positive portion on one part of the molecule and a more negative part on another. They therefore develop a dipole moment in a force field, which causes the dipole to orient itself with the direction of the force field. Polar compounds are therefore reacted at the unbalanced valence points as the new surfaces are generated by the grinding and crushing action of the mill, with the negative parts of the molecule attracted to the positive valences and the positive part attracted to the negative valences. By this action of these polar compounds, agglomeration tendencies of the cement particles are reduced far more effectively than if the compounds were nonpolar. The grinding aids function by coating the new particles and thereby shielding or satisfying the unsatisfied valence forces that are produced by the grinding (comminution) of the material.

Reduced agglomeration. By preventing or reducing agglomeration through the use of grinding aids, each particle of cement can exist as a separate piece of material, reducing the cushioning effect of the agglomerated particle between the grinding balls. This improves the efficiency of the mill system, which translates into reduced costs and improved quality.

Reduced ball coating. The use of grinding aids also reduces the ball coating which is accomplished by satisfying the positive and negative charges generated by grinding with the grinding aid. This again is accomplished by the dry dispersion of the cement by the grinding aid and the attendant satisfying of the positive and negative charges on the particles, which minimizes the coating of the mill.

Improved separator efficiency. Reduced agglomeration resulting from the use of grinding aids also improves actual separator efficiency because the separator will treat an agglomerate as if it were a unground particle of that approximate size, rejecting it back to the mill for regrind, when in actuality these individual particles should have gone out as finished product. If a grinding aid is not used, extra material going back to the mill reduces the mill's grinding capacity, increases temperatures, and causes more agglomeration. When the cement particles are treated as separate entities by the separator, it is able to make a better "cut" and be more efficient.

The term flowability refers to the ease with which cement flows once it is set in motion. This effect is demonstrated by the improved flowability through the mill when proper amounts of grinding aid are used. This can manifest itself in the extreme when an excessive amount of grinding aid is added to the mill, causing it to flush. This is not a desired condition, as overloading of the mill auxiliaries can, and probably will, occur and an inferior product will be produced during this time.

Application of Grinding Aid

From an operating standpoint, the use of grinding aids reduces the void fill and hold up (instantaneous clinker charge) in the mill. This must be taken into account when designing a ball charge so that the desired void fill can be maintained. The effect of grinding aid can be clearly shown by determining the mill retention time using a tracer material or even by crash stopping the mill both with and without grinding aid. When a mill is crash stopped, one will find that there is less cement in the mill when using grinding aid than when not using one. Even different types of grinding aids can give different mill retention times. The amount of grinding aid is extremely important as too much or too little can adversely affect the operation of the system.

One ton of cement has about 4000 million sq cm of surface area. A grinding aid must be spread uniformly over this area, particularly the surface points at which the electrovalent bonds have been broken. If these points only account for 10% of the surface area, then we still have to cover over 400 million sq cm of surface area per ton.

This demonstrates how very important the accurate, uniform distribution of the grinding aid is. In order to meter and distribute the grinding aid accurately, a diluting medium is necessary. The cheapest and most effective is water, since it is somewhat polar in nature and so has a small degree of grinding aid effectiveness in itself. All grinding aids should be diluted at about 1 part grinding aid to between 4 and 8 parts of water. It has been found that by diluting the material to the degree mentioned above, at least a 10% reduction in usage can be accomplished without any loss of benefits from the grinding aid. This does not mean that if it isn't done this way it won't work. Some plants have particular reasons for not diluting this much. The mentioned dilution does the best job in most applications and should be considered.

Methods of Addition

Proper metering. The method of grinding aid addition has several facets. The first one is metering. It has been shown that many cements do not have as much grinding aid in them as the plant thought they did. In some cases one mill has too much and one mill not enough. This is not good, as grinding aid needs to be interground, not intermixed! Cement that is the result of intermixing will have the flowability properties of the worst of the two cements.

The portion of the cement that lacks sufficient grinding aid will not be flowable and will override the portion that has excessive flowability. This is *not* an averaging situation as the less flowable material will not move or pack easily, and the portion that is flowable cannot move. When one mill is getting more grinding aid than the other, the one mill is probably unstable because the cement is so fluid that it isn't being transported as it should be or is flushing. The other mill system is coating up, separating poorly, flowing erratically, and operating at a reduced grinding capacity. This problem may be caused by poor quality or a poorly adjusted and/or maintained metering system. A good system would more than pay for itself in a short period of time in just the more stable operation of the grinding system. A 10% to 20% reduction in grinding aid costs may be realized by installing a good high quality, reliable grinding aid system. These systems may include adjustable and/or duplex pumps, a flow metering system, and reliable delivery to the pumps.

Use of hydrometer. Another common problem in introducing grinding aid is the inconsistent dilution in a system that uses the grinding from a dilution tank prior to metering to the mill. These systems are commonly controlled by the use of a hydrometer. A small and often unnoticed difference in the specific gravity can mean a significant difference in the addition of actual grinding aid. The use of an optical refractometer is suggested for control purposes, as this is very easy to use, it is difficult to misread, and it is not as fragile as a hydrometer. It is however necessary to check each load of grinding aid at a lab-verified dilution to determine the proper refractive index that you need to maintain the desired dilution.

Addition by aspirator. One of the best ways to introduce grinding aid into a milling system is by the use of an aspirator. The aspirator is made of black iron pipe and can be made up in any plant with minimal cost and time. This system does need a good air pressure regulator to maintain the 70 to 100 kpa necessary to spray – and not vaporize – the grinding aid solution into the mill. The aspirator should be installed above the center line of the mill, sloping at a slight angle down into the mill to prevent any solution from running back along the outside of the pipe and dripping on the mill trunion. The pipe should be angled across the feed chute to direct the grinding aid into the cascading material. The pipe should be extended into the mill just so the balls begin hitting it, and then pulled back about 75 mm.

One thing to avoid is directing the aspirator straight back into the mill, as the air sweep may pull the grinding aid directly back to the division head. This can lead to the blinding of the division

head, particularly when the feed is shut off for any reason. Ideally the grinding aid would be interlocked with the feed, and be shut off when the feed is shut off, but even with this system it is still possible to cause a blinding of the division screen with improper aiming of the pipe. Figure 4.1.10 shows a sketch of the type of aspirator discussed above.

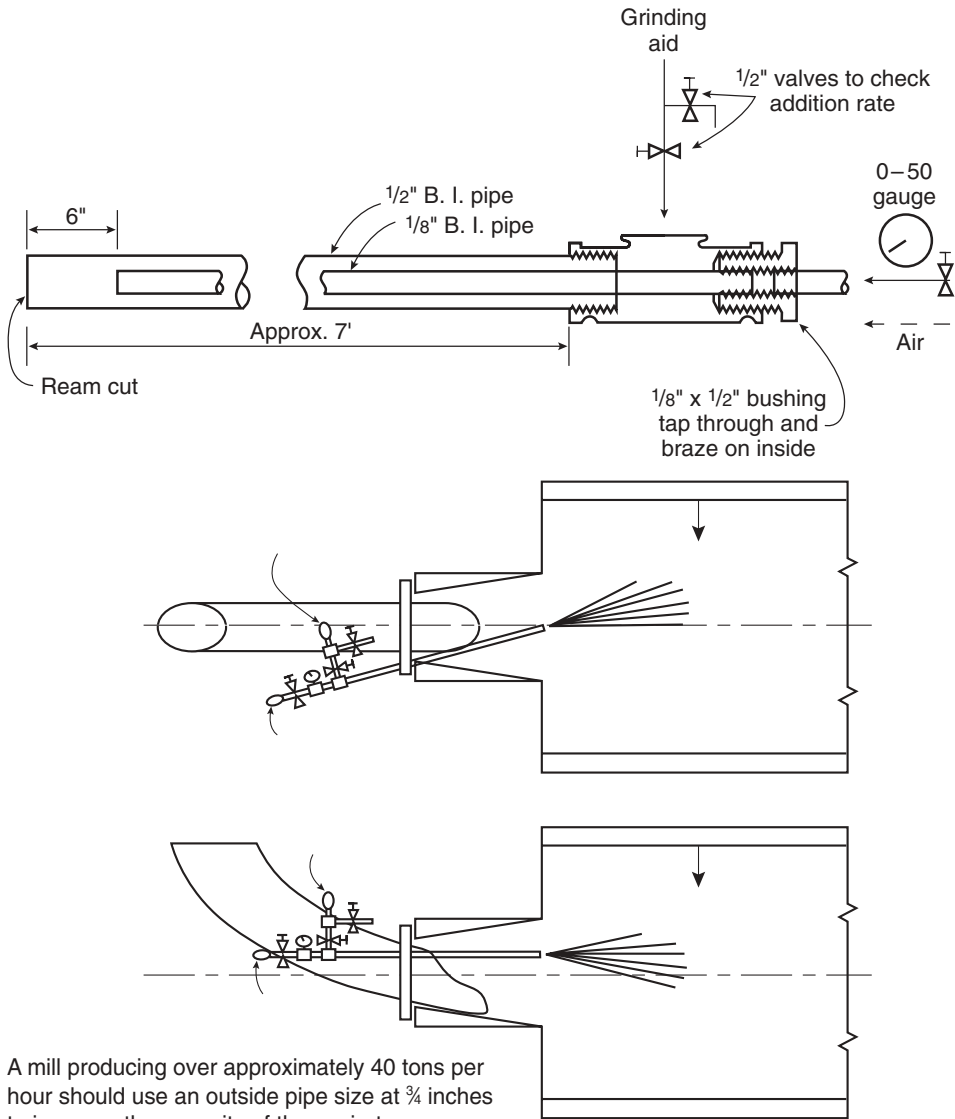


Figure 4.1.10. A sketch of aspirator spraying grinding aid in finish ball mill.

Some plants cannot use this system because of particular mill systems such as feed screws, drag chains, feed boxes, etc. The methods described are better, but if care is taken additional methods can also be successfully employed, although some degree of efficiency may be lost.

Grinding aids are a necessary production item in today's cement marketplace. They reduce costs by improving production and reducing the manpower necessary to handle the cement. They need to be managed by determining correct quantities and type, as well as the method of incorporation into the cement. They improve quality when properly used.

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