U.S. STONEWARE

Jar, Ball and Pebble Milling
Theory and Practice

Operating Division of ER Advanced Ceramics, Inc.
700 East Clark St. ● P.O. Box 270 ● East Palestine, Ohio 44413
ph: 330-426-4500 ● fax: 330-426-1859
e-mail: pjurjavcic@eracinc.com
website: www.usstoneware.com

Founded in 1865

Theory and Practice for Jar, Ball and Pebble Milling

Types of Mills

Ball and Pebble Mills: The expressions "ball milling" and "pebble milling" are frequently used interchangeably. Usually, however, a ball mill is referred to as one that uses steel balls as grinding media, while a pebble mill is one that uses flint pebbles or manufactured ceramic shapes.

Fundamentally, milling is a process for reducing the particle size of solids to some required degree of subdivision. It is also a method for dispersion or mixing materials when grinding is secondary.

Basically, a mill consists of a horizontal vessel whose length exceeds its diameter. The vessel is fitted with shafts and rotated about its longitudinal axis. There are, however, some exceptions where the diameter exceeds the length. By increasing the diameter of the mill, and reducing the length, the efficiency of operation increases. This is caused by the greater height of fall and impact energy imparted to the grinding media because of the increase in cylinder diameter. However, due to increased fabrication and higher operating costs, the later is the exception rather than the rule.

There are two standard US Stoneware mill designs based on cylinder capacity. The first design (shown at the right) is typically used on smaller mills (12, 27, and 52 gallon sizes). Cylinders are one-piece construction of high alumina ceramic to reduce contamination and increase wear resistance and reinforced at each end by dome shaped steel end caps held in position by steel tie rods. The cover is made of the same wear resistant material and formed to match the internal shape of the mill to maintain uniform milling.

The second design (shown at the right) is used on larger mill sizes (87, 117, and 210 gallon). Cylinder liners are of the same high alumina ceramics, made with three cylinder shaped ceramic pieces and two ceramic end caps. The cylinders are fired together to form one piece and the end caps are ground and lapped to form a liquid tight seal providing a very low contaminate milling environment. The finished cylinder is then reinforced and completely protected by a flanged steel casing.

Loading and unloading is accomplished through a large port located on the peripheral surface of the mill cylinder. A solid ceramic cover completes the surface continuity when the mill is rotating, while screen or grid-like discharge covers are available in different forms for wet or dry discharging. These discharge covers retain the grinding media while permitting the material to be removed.

Jar Mills:

For laboratory use or for limited and small production runs, jar mills are employed in place of ball or pebble mills. The jar mill consists of one or more pairs of motor-driven friction rolls mounted on steel frames. They are available in a wide range of sizes and types including models with variable speed drives. The mill jars are rotated by being placed on the rolls.

Mill Jars:

Mill jar sizes range from ½ pint to about 6 gallons total capacity. Jars 6 gallons and larger are quite unwieldy and often require special handling equipment. Mill jars most commonly used are made of alumina fortified ceramic material, formed with a wide opening neck for easy loading and unloading. They are also available in high alumina material, unlined stainless steel, carbon steel and rubber or polyurethane lined steel.

Ball Mill Lining

Ceramic Linings – Mill cylinders are made from two different ceramic formulations, one having silicon oxide as the dominant material and the other having aluminum oxide as the dominant material. These differences in oxide content allow some choice to be made with respect to the most acceptable wear-off.

Comparative laboratory tests show that the high alumina composition is at least 25 to 100 percent more resistant to impact abrasion than is the more siliceous composition, very low wear rates with only trace amounts of alumina.

Rubber – Special abrasion resistant low-ash rubber linings have been developed for milling of contaminant-sensitive materials. Batch contamination is reduced to such a low lever that spectrographic analysis is the only quality control technique that can measure the negligible inorganic contamination introduced into the batch from the lining.

Because of the resiliency of rubber, which contributes to the abrasion-resistance of the lining, negligible wear-off is produced and no appreciable quantity of organic material is found I milled products. Subsequent ignition of ground material in an oxidizing atmosphere removes the rubber worn off into the batch, leaving only a trace amount of oxide contamination. Colloidal carbon will remain it the batch is fired in a neutral or reducing atmosphere.

Low-ash rubber has been utilized successfully in mill jars and large production mills for either wet or dry size reduction of alumina, steatites, titanates, zirconates, ferrites, nuclear ceramics, high temperature refractories, and other material whose end properties might be altered by alumina or porcelain wear-off.

Polyurethane – a polyurethane lining has the greatest abrasion resistance and the highest tensile and tear strength of any synthetic rubber. It provides a unique combination of toughness, resilience, and load bearing properties. Polyurethane affords excellent resistance to oils, greases, and fuels and is unaffected by oxygen, ozone, and weathering. It can be used in service with aqueous salt solutions, dilute mineral acids and greases, aliphatic hydrocarbons and other non-polar organic compounds.

Metal - Mill cylinders made with abrasion-resistant steels and other metals are satisfactory where metallic contamination is not important or where further treatment will be undertaken to remove the metal particles.

Since faster grinding rates are typical with steel ball mills, more economical production will be the result. All but the finest white and pastel paints can be milled in a steel lined unit, and steel is definitely recommended when milling ceramic ferrites in both solvent and water dispersions. Many types of inks, carbon paper coatings, wax compounds, rubber compounds, and even food stuffs can be milled in the faster possible time in steel ball mills.

Grinding Media

Wet or dry grinding is usually accomplished by the use of high-density alumina spheres or cylinders and zirconia cylinders.

High Density Alumina Spheres and Cylinders – Commercially available with specific gravities from 3.6 to 3.8 and an alumina content between 85 and 99 percent, this media provides faster grinding than is usually obtained with porcelain balls or flint pebbles, and may be used with any lining. High-density media will out wear standard-density porcelain, grind faster, finer and cut milling time in half.

The choice between spheres and cylinders depends upon the application and milling needs such as particle uniformity and hardness of the material being ground.

Zirconia Cylinders – With a specific gravity of 5.5 equivalently sized zirconia grinding media generally will mill twice as fast as high alumina. Zirconia media is 1.6 times denser than high alumina, has a hard nonporous surface that is chip resistant and easily cleaned. It is unaffected by most chemicals, is nonconductive and nonmagnetic, and has outstanding resistance to mechanical and thermal shock.

Specialty grinding media is also available in alumina and zirconia for ultra fine grinding and dispersing. Sizes starting at .2mm for zirconia media and .4mm for the alumina media. Standard sizes for cylindrical grinding media are ¼”, ½”, $^{13}/_{16}$” and 1 ¼”. High density alumina spheres sizes include ¼”, ½”, ¾”, 1”, 1 ¼”, 1 ½” and 2” and the ZIrconia radiused end media is available in ¼”, 3/8”, ½” and ¾” sizes. Estimated charge factors for alumina media is 9 pounds per gallon and 14 pounds per gallon for zirconia.

Milling Procedures

Speed of Rotation – The action of the grinding inside a mill is determined be the speed at which the mill cylinder is rotating.

It is generally accepted that a speed that creates a cascading action of the media is most desirable. Cascading usually occurs when the mill speed is such that the media charge breaks away from the mill wall at an angle of 45 to 60 degrees above the horizontal.

Cascading is the case where grinding media from the outer edge falls and rolls in a coherent, mobile mass as suggested be a waterfall. The impact fractures the grains or the charge. Moreover, there are secondary actions as the media not on the periphery cataract downward and cause further attrition through their own rotational and rubbing action. These secondary effects occur between the media, the cylinder wall and the material being ground. Such actions lead to intensive disintegrations, better dispersion, and in wet milling, more complete particle wetting, due to the high rate of shear from the spinning of the grinding media.

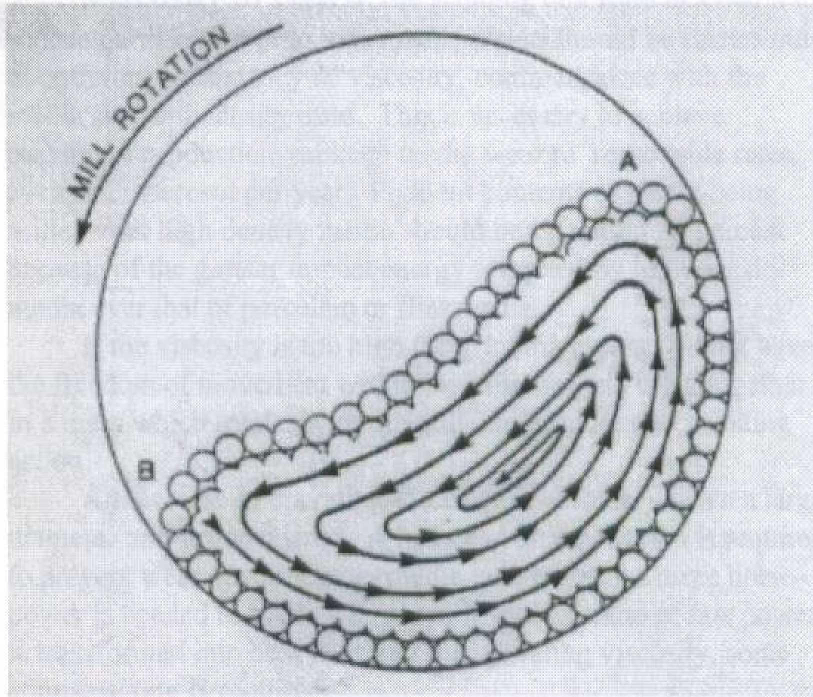

FIG. 3- Showing grinding action of mill under cascading conditions with an angle of break of 50 degrees.

When mills are rotated at too fast a rate centifuging will occur. Individual media are thrown clear of the media mass and move independantly until they rejoin the charge at the bottom of the mill. Unground material is held with the centrifuging balls and resulting in uneven disintegration or dispersion.

When mills are rotating at too fast a rate, centrifuging will occur. Individual media are thrown clear of the media mass and move independently until they rejoin the charge at the bottom of the mill. Un-ground material is held with the centrifuging balls and result in uneven disintegration or dispersion.

When too slow speeds slipping of the media occurs. Here the grinding media acts as a static unit in relation to the walls of the rotating mill. This leads to grooving of the mill walls and flattening of the media. The same action can result in mills operating at optimum speed if low media charge or low consistency is used in the mill.

The use of lifter bars welded or bolted to the mill cylinder in unlined mills reduces media slippage in mills whose rotational velocity is slow. Lifter bars are recommended when the grinding media charge is below 45 percent of the mill volume. Even with lifter bars, it is not practical to go below a 33 percent media charge. Critical speed in RPM is calculated by this relationship:

Nc = 54.2 / (square root of R) = 76.6 / (square root of D) where R and D are the inside radii and diameters of the mill in feet, respectively.

Depending on the job being done and on plant preference, speed usually ranges from 35 to 115 percent of Nc. Where particle size reduction is quite critical, a variable speed drive is recommended. This permits the operator to control his mill speed to suit. Most mills rotate at 60 to 65 percent of critical speed (Nc). This formulation is for wet milling where as dry milling needs to be adjusted by 2 to 5 RPM faster. These speeds hold true for any media regardless of shape for density.

Generally, lower rates of rotation are used for wet milling of paint materials and dry milling of soft materials than are used for wet milling of ceramic frits and glazes. At higher mill speeds slip between media and mill lining is low and media wear is minimized.

An illustration of the practical use of greater than usual rotational speeds comes form the manufacturers of bronze and aluminum powders which often resort to critical or near critical speeds. The balls fly across the top of the mill striking the other side with hammer-like blows which tend to flake the metal instead of grinding it.

Size of Grind Media: The size of the media to be employed will depend on the milling conditions.

Most effective grinding will be accomplished b the smallest media that will do the job. Smaller media offers more contact per mill revolution. More uniformly fine-ground particles will result since the smaller voids will determine the size of particles that can exist as well as assure more physical contact and decrease distance through which shear forces must act.

Larger media will have greater impact energy and may generate excessive heat in the mill if this energy is not efficiently consumed in the grinding action. However, this extra energy will be useful when large or tough particles are to be ground or when the wet mixture is thixotropic.

Viscosity of Batch: The grinding of a solid in a liquid to reduce particle size or to make a dispersion should be carried out at optimum consistency or viscosity, commensurate with the media size and density used. This is necessary to achieve maximum production yet keep media wear to reasonable rates, such as 20 percent per year. Pigment contents of paints being milled with high density media should be increased 25 percent because of the greater impact energy imparted be the high density media over that of porcelain or flint media.

If the viscosity is too high the grinding media will not have the freedom of movement within the mill, but will cling together in a mass which rotates with the mill and produces no grinding action.

An increase in operating viscosity is necessary when a large diameter mill is considered. A heavier-bodied cushion is required to prevent wear due to greater media weight. Since more horsepower is needed to rotate a larger mill, and as some of this power is transformed into heat lowering the operating viscosity, some compensation is required.

When milling paint, the paste consistency should match the media size and the density used. A Stormer viscometer with the 52.2mm seep flat paddle (Krebs' modification), may be used for measuring consistency. For most efficient grinding with flint pebbles and porcelain balls, the batch should be comparable to a free flowing slurry with a viscosity 600 to 1100 cps (70 to 90

KU). When using high-density media, a viscosity over 2200cps (110 KU) is recommended. (Water at room temperature has a viscosity of 1 centipoise).

Amount of Grinding Media: Good practice calls for mills to be filled from 45 to 55 percent of the total volume. With high-density ceramic media a 45 to 50 percent charge is typical, while a 50 to 55 percent charge is typical with flint pebbles or standard porcelain. For wet milling porcelain enamel frit, the Porcelain Enamel Institute recommends a 50 to 55 percent charge from both standard and high-density media. They also recommend that the frit charge (slip), expressed in pounds, equal three to four the total volume of the mill, expressed in gallons. If standard porcelain is used, the ratio should be about 3 to 1. if high density alumina media is used, the ratio should be between 3.5 to 4.5 to 1. When steel balls are used, 33 percent and 45 to 50 percent ball charges are common, depending upon the desired mill output. With 33 percent ball charges, lifter bars are usually recommended.

To minimize excessive ball and shell wear, full charges (50 to 55 percent) or charges no less than 45 percent are recommended. At values lower than 45 percent media tends to slip on the shell unless lifter bars are used.

Amounts of Material to be Ground: For dry milling it is generally agreed that a material charge occupying 25 percent of the mill cylinder will give the best results. This loading permits the grinding media (50 percent charge) to make effective contact with the material charge.

The rule of thumb for wet milling is to fill the mill to about an inch over the media level. A minimum charge of 25 percent total mill volume should be maintained with food results obtained be filling the mill from 30 to 40 percent of its total volume.

A charge of balls has an apparent volume of approximately 60 percent solid and 40 percent voids, thus a mill 50 percent full of media would have a capacity in the voids of 20 percent of the total mill volume.

Greater capacity at lower cost per unit mill load can be obtained in the same mill if a high product charge is used, but at the cost of longer grinding time. When it is desirable to regulate the length of milling time to fit in with shift changes or other factors, this can be accomplished by altering the product charge. Increasing the product charge results in longer milling time and decreasing the product charge reduces the milling time. Changing the amount could result in excessive temperature rise and increased media wear.

Grinding with low consistency increases abrasion in the mill, but this is not as harmful as running undercharged. It the charge is not loage enough for the mill it should be increased.

Wet Grinding and Dry Grinding: Wet grinding a material may be faster than dry grinding, if properly handled. Dry grinding may result in the material packing up as it becomes finer unless the fines are removed or unless a grinding aid is used.

Another factor to consider is dry grinding the problem of discharging the product. In order to collect the dry milled product (unless it is extremely free flowing) without removing the media, the mill must be rotated, and if the mill id rotated to discharge the product, a discharge housing must be used.

MILLING RULES OF THUMB:

Media – Media size is a key factor in mill performance. As a general rule the media should be 4 to 10 times the size of the largest agglomerate to have sufficient flatness for the hammer-like effect required.
The most effective grinding will be accomplished by the smallest media that will do the job. Small media offer more contact per mill revolution.
Larger media will have greater impact energy and may generate excessive heat in the mill if this energy is not efficiently consumed in the grinding action. However, this extra energy will be useful when large or tough particles are to be ground.
A mil must periodically be recharged. A bead that has lose half of its diameter has also lost 87.5% of its mass. Reduced mass sharply reduces the media's impact energy.

Good practice calls for mills to be filled from 45 to 55% of their total volume. To minimize excessive ball and shell wear, full charges (45 to 55%) or charges no less than 45% are recommended. At values lower that 45% media tends to slip on the shell unless lifter bars are used.

MATERIAL CHARGE: For dry milling it is generally agreed that a material charge occupying 25% of the mill cylinder will give the best results. This loading permits the grinding media to make effective contact with the material charge.

The rule of thumb for wet milling is to fill the mill to about an inch over the media level. A minimum charge of 25% total mill volume should be maintained, with good results obtained by filling the mill from 30 to 40% of its total volume.

TRANSITION FROM LAB TO PRODUCTION: The transition from grinding in laboratory mill jars to grinding in production sized mills is a fairly straight forward one. There is scarcely any difference in particle reduction, providing comparable grinding media action exercised. Output will, of course, vary with longitudinal or diametric variations, and selection for production output should be on a volumetric basic.

The volume of a mill varies as the square of the diameter, while the horsepower necessary for the mill rotation varies as the 2.6 power of the diameter. A mill 8 feet in diameter requires 40 to 80 times more horsepower than a mill 2 feet in diameter. However, the 8 foot unit will produce a batch in approximately ¼ the time, other conditions being equal.

INITIAL CONDITIONING OF NEW MILLS: Pebble or ball mill lined mills must be "ground in" to remove loose or excess material. It is best to use a cheap material, such as a charge of fine sand and 50% water, or scrap product with the media charge for this operation, followed by a through rinsing. The time required is usually 1 to 5 hours. If the mill is not clean after one treatment, the cleaning operation should be repeated.

MILL CLEANING METHODS: One of the most important factors in reducing batch contamination is the cleaning procedure. A good method for cleaning paint is to dump a moderate amount of solvent into the mill, run it for one minute, and then dump immediately to avoid settling out of solids. Several washes may be necessary to do the job.

The same procedure is used for water-based emulsions or ceramic slips, using water plus a wetting agent, or small amount of detergent to promote draining. Keep in mind that when cleaning a mill the media and lining can wear excessively if the period of mill rotation during the cleaning is excessive. When cleaning the mill, try to keep the rotation time under one minute.

HANDY HINTS ON MILLING: Extremely small containers, such as test tubes or small paint cans, can easily be rolled on you jar mils by placing them inside a piece of pipe or large round container.

If you experience bending or breaking of the jar lid locking bars, check for hardening of the gasket. It should be soft enough ro indent with your fingernail.

You can keep grinding jars separated and positioned exactly where you want then on any long-roll mill with patented "jar positioners". Made of long-wearing hard rubber or metal, simple to install, can be quickly moved to any location.

Where contamination is a critical problem, ceramic and even metal mill jars should first be run wet with grinding media plus sand for 8 hours of so, to knock lose or wear down any particles that might contaminate the first batch.

Wear on interior surfaces of mill linings will be more evenly distributed, and you'll get longer mill life by reversing grinding direction of rotation on a regular basis.

Fresh charges of new media should be left running in a mill with sand to condition the media prior to its first use to lesson the chance of contaminating your batch.

The level of grinding media should be checked frequently. If it falls below operating level, the required grinding media should be added. About once a year the charge should be dumped and inspected. All grinding media which are excessively worn should be removed and replaced with new media. Added media should consist of the largest size initially used.

Powders frequently tend to cake up on the grinding media and on the mill walls when being ground dry. Addition of about ½% of ammonium chloride, or ammonium carbonate, to the mill batch will eliminate, or minimize this condition.

An approximate indication of the rate of ware of a mill can be gotten be making a caliper measurement, using some fixed point on the outside of the mill for reference.

If paint is the product being milled or any materials dispersed in solvents, leaks can results around the gasket, specific purpose gaskets are available.

Your jar mill can also be used for mixing, or dispersing, where particle size reduction is not desired. Removing all or , or most or, the grinding media will permit tumbling and intermixing with moderate, or no, attrition.

Fully loaded larger size mill jars are very heavy. Put these on the lower roll, and construct an inclined ramp of "2 by 4 wood to assist in the positioning, and in the removal.

If you are experiencing excessive breakage of mill jars, consider the use of jars protected with urethane, metal or plastic armor.

When jars have obviously lost a noticeable percentage of their original wall thickness, cracking can be expected in a relatively short time. The application of a few lengths of tape around the circumference will insure that the jar will not catastrophically break in two.

When a jar has lost approximately 35% of its initial weight, it should not be used for unmonitored milling. This degree of weight loss indicates that the jar is nearing the end of its useful life.