Different Approaches to Grinding Abrasive Materials

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I have been grinding materials or particle size reduction for over 30 years. I was introduced to making powder out of lead pigs in a ball mill at my first job, and have been working in the field of particle size reduction in one form or another for most of my life. The purpose of this article is not to show a complete listing of all types of particle size reduction machinery, but to list the ones that I have used and found to be effective in their capabilities in grinding very hard or abrasive materials. This grinding takes a little more thought and consideration for wear and the potential contamination that may become imparted on the material which is being attempted to be ground.

Primary Reduction

Jaw Crusher
In quarry operations, very large jaw crushers can be found. These are primarily used to reduce shot blast size materials such as limestone and road bed materials to a wide variety of sizes.
In specialty particle size reduction, one discovers very hard to grind or specialty materials. In the area of very abrasive or just extremely hard materials (i.e. mohs of up to 7 or 8), jaw crushers of 36 x 24 in. have been found to be able to reduce large chunks of material from about 24 in. top size to -6 in. For very abrasive products that are ground, it is one of the most economical ways of reducing the particle size. The need to replace jaws for processing hard, abrasive materials is routine, but it sure beats trying to hydraulically jackhammer the materials. Jaw crushers can easily work in tandem with other jaw crushers. The smaller the jaw opening, the smaller the top size of the finished material can be delivered.
Often the need is to initially take up to 24-in. material and reduce it to a nice beginning size for secondary grinding machines (a maximum size of 3-4 in.). To accomplish this, the primary jaw (36x20 in.) has been successfully used as a pre-crusher to feed a 16x10-in. jaw crusher. Average top size has been around 3 in. with minimal fines and minimal wear using this equipment configuration, although very large and some smaller jaw crushers are also available. The use of manganese steel wear parts is preferred, but other materials of construction can be engineered to each specific need.

Further Reduction
Some industries need particle sizes in the screened or grit size ranges. To further reduce these particles different machines can be used, depending on the final product required and the abrasiveness of the materials. All of the following pieces of machinery are used in circuit with a multi-deck screener. The fraction required is recovered as final product and the oversized materials are returned to the grinding machine for additional particle reduction.

Impact Mill
Abrasive grinding operations can utilize an impact mill, which is basically a set of rotating hammers with breaker plates that can be set to a specific gap between the hammer and the breaker plate to affect the particle size required. However, this type of milling can have high wear on the hammers. There are a variety of wear materials of construction that can be used in the hammers and breaker blocks which can be tailored to the type of material being ground. Although the wear can be very high, the
cost of the wear parts is relatively low, but replacement must be performed often. Some materials require hammer changes every eight hours. Impact milling gives a long distribution of fines in the particle size distribution. For materials that need to have a fines component, the impact mill performs this task well.

Cone
There are also cone crushers that can reduce the amount of fines collected. A cone crusher is generally used as a secondary crushe
r in a crushing circuit. Pre-crushed product is fed through the top of the crushe
r and flows over the mantle. The vertical cone crushe
r drive shaft rotates the mantle eccentrically below the concave, or bowl liner, squeezing the product and crushing it between the mantle and concave. Cone crushers are used extensively throughout the aggregate and mineral processing industry. The wear parts can also be made out of a variety of materials specific to individual processing needs. The benefit is that the wear parts last longer but the tradeoff is that they are more expensive and it takes longer to change out the wear components. This type of crushing produces a final distribution with fewer fines in it. This can be advantageous to some companies’ specific needs.

Roll
A roll crushe
r is a set of opposed rolls, spinning in opposite directions which at the top of the mill, material is pulled in and crushed between the rolls and drops it out the bottom of the rolls. Setting the gap between the rolls allows an operator to obtain the desired particle size. The operating speeds and wear on this unit is low, and if set up properly, this method of grinding creates very few fines in the particle size distribution. The roll crushe
r limitations are in the reduction percentage, in that it takes the material and reduces the particle by up to 10 fold. For larger reduction percentages, the roll can be set up in a series from wider gapped rolls to progressively smaller roll sets. This gives a very nice reduction in size, without contamination and minimal fines creation. The drawback to roll crushing is the cost of the parts and the time needed to change out the roll shells.

Fine Grinding
Fine grinding abrasive materials is typically needed to create particle sizes in the minus 50 mesh range (297 microns) down to about 95% minus 325 mesh (45 microns). Some of these sizes are typically referred to as talc, flour, pulverized, or ball-mill fine grades. Following are three different types of machines that can be used to obtain the grinds.

Ring-Roll Air Swept Pulverizer
This grinding unit uses a set of grinding rolls suspended on a pendulum assembly. When rotated, the rolls spin outward against a grinding ring where the material is delivered for crushing. The force between the roll and the ring crushes the material, and the fines are swept upward by the air flow through the mill. Integral to and at the top of the mill is a classifier of some sort which rejects any oversized materials and returns them internally to the mill for further grinding. Again, the material type of roll and ring can be designed specifically for the type of material being ground. The mill does impart some metal to the products, but in some cases it is below the threshold of perceived contamination for that particular product. There is a nice efficiency to the pulverize style of grinding, and the changing of particle sizes is easy. Depending on the mill size, starting particle sizes can be from 2 to ¼ in. The mill is versatile and it is relatively easy to clean out the system.

Ball Mill
The ball mill has been around for eons. There are many shapes and sizes and types. There is a single enclosed drum-type where material is placed in the drum along with a charge of grinding media. These can be in various shapes, and typically they are balls. There is a whole science in the size of the starting material versus the ball size, shape material of construction and charge percentage of grinding media. All of these variables affect particle size, shape, and grinding efficiency. This type of grinding is very good for abrasive materials to prevent contamination. The grinding media as well as the interior surfaces of the mill can be lined with abrasion resistant materials suited to the material being ground. In some cases, it can even be the material being ground. However, the batch type system is not a very efficient means of grinding. There is a variety of ball mill that is a continuous process versus a batch process. It has an external classifier which returns the oversized material to the ball mill for further milling. This system is much more efficient in the grinding ability, but it is much more difficult to line the entire system with wear parts to grind an abrasive material.

Vibrating Mills
A vibrating mill is almost a version of a rotating ball mill, but the unit is set to vibrate. Media of balls, cones, rods, etc., are loaded into the mill, and with batch or continuous processing the material is introduced into the grinding zone and reduced in particle size. This equipment can be effectively lined with wear parts and the material of construction of the grinding media can be designed for the particular material being ground to have minimal impact on contamination. These systems can be used in concert with a mechanical separator, but have also been used with screeners to minimize contamination. The particle sizes are typically not as fine as the rotating ball mill or the fine grinding mills listed below. These systems however can be very compact and effective for small to handle high value materials.
Micron and Nano-Sizing
A number of materials need to be reduced to sizes smaller than 95% minus 325 mesh (45 microns). Typically, top sizes of 44 microns to 10 or 15 microns with average particle sizes in the 3 micron to 30 micron range for abrasive materials can be processed using a jet mill. There are a number of types of jet mills for grinding abrasive products to the particle sizes listed above.

Spiral Jet Mill
Spiral jet mills use compressed gas (typically air) at over 100 psig (6.9 bar(g)) to form a spiral air stream in the mill at rates of about 500 m/sec. The material to be ground is injected into this air stream to where the particles collide with each other as well as the sidewalls to reduce the particles. An internal cyclonic effect classifies the materials and they exit through the central portion of the spiral. The benefit to this type of mill for grinding abrasive materials is limited to very small quantities to be processed. These mills have been made with wear liners appropriate for the material being ground. However, the wear on the liners is great and can prove costly in terms of parts as well as downtime.

Fluid Bed Jet Mill
The fluid bed jet mill is ideal for, but not limited to, abrasive materials. The difference in grinding action between the spiral mill and the fluidized bed is that the jet mill reduces the high speed incidental wall collisions to near zero. In a fluid bed, the air nozzles convert the pressure to velocity in a bed of material at the bottom of the mill, entraining and accelerating the particles within the bed. This grinding action utilizes the extreme edges of the bed as a wear liner, preventing contact at high velocities to parts of the machine. It prevents pick up of contamination to the material being ground to less than parts per million, and depending on the material, even to less than parts per billion.

The mill has an internal mechanical classifier to perform the particle sizing, and it is easy to change the particle cut required. The oversized material is rejected from the classifier wheel within the mill and returned to the grinding section of the mill for further size reduction. This particular machine can also be run with hot gasses. This can make the mill more efficient by using heat to raise the escape velocity of the gas without requiring the 100 psig (6.9 bar) pressure, making the cost of compressing the gasses less. It still maintains the same 500 m/sec velocity. It can also perform some drying of the material.

Steam Fluidized Bed Jet Mill
A version of the fluidized bed jet mill that can grind even finer than noted above utilizes superheated high-pressure steam (up to 1450 psig/100 barl) to perform dry grinding of material. It can reach grinding velocities of 1500 m/sec and grind about 2.6 times finer than possible when utilizing ambient temperate gasses. So in the example above, if the best particle size achieved is a dv50% of 3 microns, the steam operated mill can produce a 1 micron dv50% material. Some dense materials have been successfully ground using this dry processing method to 100% less than 1 micron. Traditionally, wet processing systems were the only method to process materials to less than 1 micron. Again, the bed action of the mill prevents the material from hitting the sidewalls of the mill at high velocities, giving a very pure grind to the end material. This system does not wet the product, and it can even initialize chemical reactions on some products or it can even dry other materials from some levels of moisture.

Wet Processing
High Flow Bead Mills
There are a number of types and designs of wet processing mills. Some refer to these mills as sand or bead or media mills. They all typically have a set of media that is stirred and, in some fashion or another, a slurry of material to be ground is pumped through this rotated volume of grinding media. A screen or separator is typically used to keep the media in the mill while passing the finished product through the screen. This type of milling process can also have lined walls and coated stirring parts, and the media can be of the type needed for a particular material to be ground, to have the least impact on contamination. Particles in this type of process can be reduced to 100% less than 1 micron with dv50% ranges in the 20-30 nanometer range. This milling is also effective for economically grinding materials in the 2 to 30 micron dv50% range. This milling can be performed in an aqueous or solvent based slurry. Depending on the type of material that needs to be ground, solids levels up to 75% can be achieved. If the material must remain in a slurry, this type of processing is very effective as it grinds and mixes the solids in one step. Additional surfactants or other reaction materials can also be included in the slurry. There is some wear on this type of system, but it is minimal.

Wet Autogenous Mills
For those materials that cannot withstand much of any contamination, autogenous grinding is preferred. Autogenous means arising from within or from a thing itself. In this case, the grinding media is made from the same material that is being ground. This type of grinding has been successful in grinding materials as hard as diamond without contamination. The milling system is specially designed to handle the autogenous grinding media with specialty separators to keep the grinding media in the mill while
allowing the fines to pass. Like its wet milling counterpart listed above, the autogenous grinding mill can make particles up to a fineness of less than 1 micron in aqueous or solvent slurries. This is an excellent way to manufacture ultra-fine materials without contamination.

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