Understanding your material’s properties and establishing clear goals are important to an efficient and effective milling process. This article describes how particle analysis can help you optimize your agitator bead mill’s operating parameters for your application.

Fine grinding is an important part of many bulk solids manufacturing processes, and an agitator bead mill is often the best option for grinding and dispersing materials to the micron and nanometer range. Agitator bead mills are suitable for grinding a wide range of materials, including adhesives and sealants, ceramics, agrochemicals, paint and coating ingredients, inks and pigments, and materials for additive manufacturing.

An agitator bead mill consists of a cylindrical grinding chamber, an agitator (a rotating shaft with disks or pins mounted on it), a drive motor, and a media separator located at the grinding chamber’s discharge. The grinding chamber is filled up to 95 percent of its volume with grinding beads (typically between 30 microns and 9 millimeters in diameter). The beads can be made from various materials, including stainless steel, glass, or ceramics, depending on the application.

In operation, feed material enters the grinding chamber (typically in a liquid suspension) and fills the space between the beads. The agitator rotates, moving the beads and material around the chamber. This motion imparts compressive and shear stress to the material, fracturing and dispersing the particles. Centrifugal forces and pressure from the pump force new material into the grinding chamber, and move the material through the mill. The material passes through a dynamic classifying cartridge (DCC) and screen before being discharged from the mill. The DCC and screen inhibit grinding media from exiting the agitator shaft.

An agitator bead mill’s operating parameters can vary widely and should be determined by the application’s requirements. A qualified milling equipment supplier can help you with this, so you should work closely with a supplier when planning a new fine grinding process. Grinding outcomes depend on many variables, some of which are often overlooked, ignored, or simply misunderstood. Equipment suppliers have experience with a wide variety of materials and access to resources and tools that can help determine the best milling solution for your application. Optimizing the equipment (including both the mill and the grinding media) and the operating parameters to the application can make the difference between a successful process and a process that’s ineffective, inefficient, or both.

Efficiency versus effectiveness

Optimizing your grinding process requires finding a balance between milling efficiency and milling effectiveness. A grinding process that’s solely concerned with efficiency will produce a high-quality finished product with clearly defined particle size cut lines and a discrete particle size distribution (PSD). The mill operates relatively slowly, however, applying minimal energy to the material. This reduces component wear but also lowers production capacity and increases energy costs because of the long milling time required to achieve the desired PSD.

A grinding process that focuses solely on effectiveness, on the other hand, produces high product output and low mill residence time, but the high operating speed increases wear to the mill’s components. Repairing and replacing worn and damaged components (including the grinding media in wet milling applications) can increase costs and downtime, offsetting output gains. Also, the damaged mill components can contaminate the material, affecting product quality.

A mill’s operating parameters determine how efficient or effective the milling process is. With a thorough understanding of your process requirements and material, you can create a milling process that balances efficiency and effectiveness, saving time and money and ensuring repeatable results.
Material properties

Achieving a balanced milling process requires that you understand the material you’re working with. The first step to optimizing your milling process is to identify your feed material’s initial properties as well as the properties you require for your final product. Material type, PSD, bulk density, flowability, friability, abrasiveness, temperature sensitivity, hygroscopicity, moisture content, volatile content, and chemical corrosiveness can all influence equipment selection and operating parameters.

A particle characterization analysis establishes a better understanding of the feed material, which can help you improve mill performance and control product quality. When developing a milling process or monitoring milling performance, the most important physical properties to measure are:

- Particle size
- Particle shape
- Surface properties
- Mechanical properties (including hardness, elasticity, modularity, adhesion, and friction)
- Charge properties
- Particle microstructure (whether the particles are solid or agglomerates)

A variety of methods are available for acquiring this data, and many suppliers and independent test labs have software for collecting and analyzing these particle properties.

A material’s composition will influence whether the material requires mild dispersion, real comminution, or both. Mild dispersion uses low shear, pressure, and impact forces to separate agglomerated particles from one another without changing the material’s primary particle size or structure. Typical agitator tip speeds for mild dispersion range from 4 to 6 meters per second. Real comminution uses high shear, pressure, and impact forces to grind and fracture particles to a smaller primary particle size. Particles are separated and then crushed, destroying the original particle structure. Typical agitator tip speeds for real comminution range from 13 to 16 meters per second, and the tip speed should be maximized for motor power and material temperature requirements.

A PSD analysis and three-dimensional image of the material can help determine whether mild dispersion or real comminution is required but may not provide sufficient information. Determining the most appropriate milling process often requires additional data that can be provided by a more thorough examination of the material.

Particle analysis

Particle analysis uses a scanning electron microscope (SEM) equipped with element identification software (EID) to examine multiple points in a material sample to better understand the material’s composition and identify hidden elements. For example, results from an EID analysis of a tungsten oxide material are shown in Figure 1. The results identify the individual elements within the sample — tungsten and oxygen — and the percentage of each element by weight. This is helpful in identifying abrasive contaminants, such as silica and zirconia, which can affect the Mohs hardness of a material, ultimately influencing operating speed required to break apart the material’s particles.

An image of the material captured using SEM at 730x magnification is shown in Figure 2, offering insight into some of the feed material’s physical characteristics. The particle shape appears asymmetrical, and the particle surface appears relatively smooth, with some ultrafine particles adhering to the surface. Other characteristics, such as mechanical properties, charge properties, and particle microstructure, are difficult to determine from this image and require further investigation.

An SEM image of the same particles, taken at 6,200x magnification, is shown in Figure 3. This image reveals that the particles aren’t solid pieces but are, instead, agglomerates comprised of smaller elongated pieces of various lengths woven together in a porous structure. Viewing the particles at this magnification level reveals that true comminution isn’t necessary to further reduce the particle size; this material requires only mild
dispersion to break up the agglomerated particles. If we’d looked only at Figure 2, we might have concluded that true comminution was required and applied more energy than necessary to grind the material. Using the incorrect grinding method could still have achieved the desired PSD but would also result in excess wear to the mill and grinding media as well as damage the structure of the material.

As this example shows, knowing your material is critical to optimizing your fine grinding process. Even if you think you understand your material, you may still benefit from a complete material analysis. A mill is a big investment and fine grinding is an inherently expensive process, but a thorough understanding of your material will help you optimize the mill’s operating parameters to minimize energy and maintenance costs while producing a consistently high-quality product.

References

For further reading
Find more information on this topic in articles listed under “Size reduction” and “Particle analysis” in Powder and Bulk Engineering’s article index in the December 2016 issue or the Article Archive on PBE’s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.)

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