Attrition Mill Grinding of Refractories

John E. Becker
UNION PROCESS, INC.
Akron, Ohio

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The principles and applications of wet and dry grinding refractory materials in the Attritor, a high-energy stirred ball mill, are presented. Batch, circulation, continuous, and high-speed attritors are described along with the advantages of attrition milling and specific applications. Attrition mill fine grinding of refractories vs. conventional fine grinding methods are compared to relative cost/energy effectiveness, speed, temperature control, and particle size distribution characteristics. Available ceramic media, appropriate iron contamination-free linings, and auxiliary equipment for specific refractory applications are presented.

Introduction

The Attritor, an attrition mill; also referred to as a stirred ball mill, was formally introduced to the ceramic industry during the early 1980s. Since that time, the Attritor has been increasingly used successfully for many advanced and high-tech ceramic applications by adapting the Attritor concept to minimize contamination and wear by taking advantage of the latest ceramic parts or media materials.

During the last few years, the Attritor has been re-designed to a high-speed configuration for very fine and efficient dry grinding, which should be of special interest to the refractories industry.

Principles

The Attritor's operation is simple and efficient. The key to this efficiency is that the power input is used directly for agitating the grinding media and not for rotating or vibrating a large, heavy vessel in addition to the media charge. The Attritor also uses relatively smaller size grinding media resulting in faster and finer particle size reduction because for a given volume, there will be more impact, shear, and surface contact. The material to be processed is charged into the stationary Attritor vessel containing grinding media. The material and media are agitated by a rotating vertical central shaft with horizontal agitator arms. Standard Attritor tip speeds range from 6,000 to 10,000 fpm (feet per minute), while the high speed Attritor runs up to 5 times faster. Impact and shearing forces result in extremely efficient size reduction to the submicron range with a narrow distribution and very little wear on the vessel walls. These impact and shearing forces are depicted in (Figure 1).

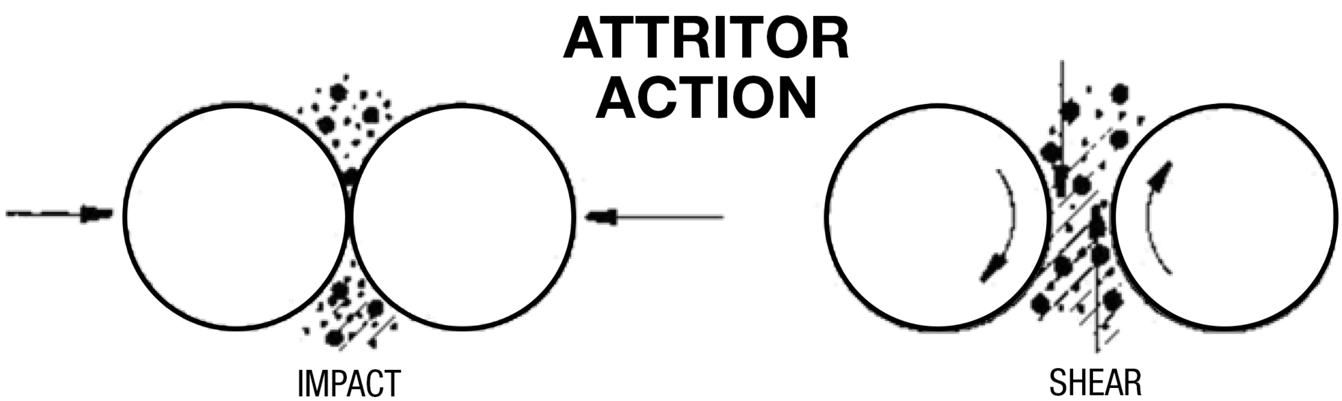

Figure 1

The Attritor arms provide a constant moving motion of material within the vessel. The area of greatest media turbulence is ~2/3rds the radius from the central shaft, as shown in (Figure 2). In production Attritors, the turbulence is enhanced by adding a circulating pumping system and modified agitator arm tip configurations when appropriate. Also, note in (Figure 2) that grinding does not occur against the vessel wall. This adds to longer service life of the vessel; allows minimal contamination from the inner lining, and makes thinner vessel walls possible resulting in enhanced heat transfer, and greater temperature control.

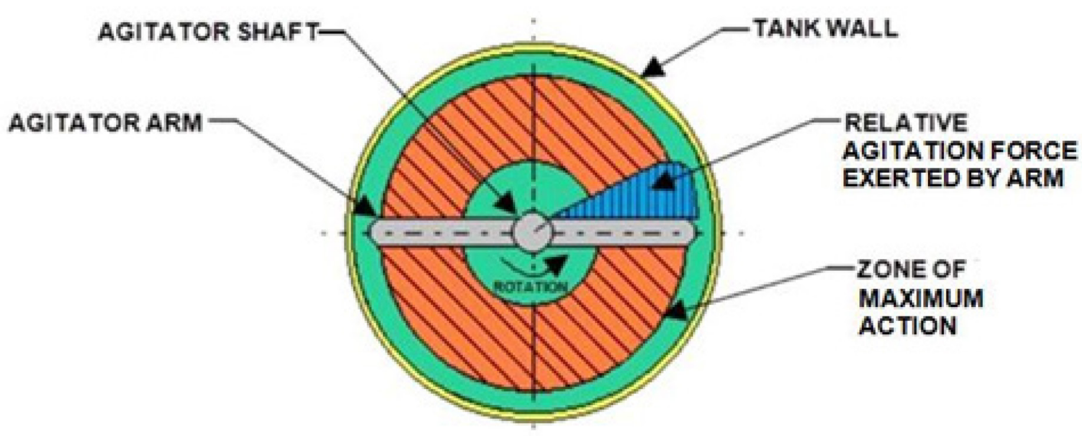

Figure 2

To illustrate the comparative efficiency of the Attritor, (Figure 3) shows the effectiveness of the Attritor vs. the vibratory ball mill, and conventional ball mill used for the ultra-fine grinding of pima chalcopyrite concentrate (footnote 1). Data for the vibratory ball mill is represented by the top curve, the middle two curves represent conventional ball mills, and the bottom curve depicts the Attritor. At a specific energy input of about 100 kWh/T, the median particle size reduction obtained in the Attritor is about half that obtained in the conventional ball mill, and about 1/3 that from the vibratory ball mill. At a specific energy input above 200 kWh/T, the Attritor continued to grind into the sub-micron range, while the other machines can no longer effectively produce smaller particles. Thus, the time required to grind sub-micron particles is much shorter with the Attritor.

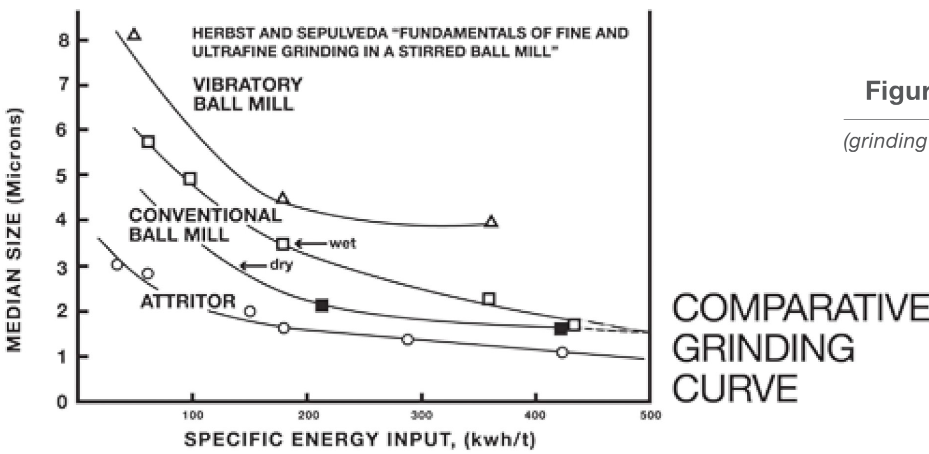

Figure 3

(grinding curve)

Grinding Media

The following equation can be used to relate grinding time to media diameter and agitator speed:

$$T = \frac{KD}{\sqrt{N}}$$

Where **T** is the grinding time to reach a certain media particle size; **K** is a constant that varies depending on the material being processed, type of media, and the model of the Attritor being used; **D** is the media diameter; and **N** is the shaft RPM. This equation shows that total grinding time is directly proportional to type of media and ball diameter, and inversely proportional to the square root of the shaft RPM. Also, increasing media size increases grinding time, but decreasing media size decreases grinding time.

Grinding media selection is based upon several interrelated factors:

- **Contamination**: Media wear should not adversely affect the final product; worn media material should be removable by chemical means, by magnetic separation, or in sintering.
- **Specific Gravity**: As a rule; the higher the media density, the more effective and faster the grind. Ideally, media should be denser than the product. Highly viscous slurries require a higher density media to prevent "floating."
- **Product Feed Size**: Media diameter should be greater than the initial particle size for effective breakdown of larger particles.
- **Hardness**: Harder media results in less contamination, greater efficiency, and longer wear life.
- **Discoloration**: Media composition must allow white or light-colored material(s) to retain a clean color without adverse discoloration.
- **pH**: Some highly acidic or basic slurries may react with certain types of metallic media.
- **Final Product Particle Size**: Generally, a smaller medium is more effective when grinding superfine or ultrafine particles.

Media sizes for attrition grinding range from 2.0 up to 25.0mm. Smaller grinding media generally result in faster particle size reduction because for a given volume there will be more impact and surface contact. As media become smaller than 2.0mm; mass is significantly reduced resulting in less impact force and longer grinding time. When ultra-fine grinding is not required, larger diameter media may prove faster and more efficient since its mass is greater.

Attritors use many different types of grinding media suitable for specific materials in various industries across various applications. The grinding media types currently used in the refractories industry include alumina, zirconia, zirconium silicate, steatite, silicon nitride, silicon carbide, tungsten carbide, mullite, glass, and sometimes steel. Variations of these basic types are currently available, but may be restricted to size and composition. Cost effectiveness as well as size and composition must be taken into consideration in determining user selection.

Features and Parts Selection

For processing refractory materials, Attritors are available for wet and/or dry grinding. Once again, it must be remembered that in the Attritor, generally over 90% of contamination will come from the grinding medium. Consequently, grinding media selection is of utmost importance. Most of the remaining potential contamination will come from the agitator arm tips, bar grids, and vessel wall.

For most wet refractory applications, a series of iron-contamination-free Attritors have been designed using several types of ceramic and polymer materials to line or sleeve the Attritor's internal parts. These materials include alumina, zirconia, silicon nitride, silicon carbide, tungsten carbide, polyurethane, high density plastics, and rubber.

In the case of dry grinding, the more abrasive-resistant materials such as alumina, zirconia, and silicon nitride, silicon carbide, and tungsten carbide are used. In some cases where small amounts of metal contamination is tolerable; stainless steel vessels are used in conjunction with tungsten carbide-sleeved agitator arms and tungsten carbide-faced bar grids while using ceramic media.

A standard feature on all Attritors is the jacketed vessel, or tank, which can be water-cooled or heated depending upon application requirements. Production-sized Attritors, in most cases, are equipped with a two-speed electric motor. High speed is used for the actual grinding while low speed (1/3 speed) is used for charging, discharging, and cleaning.

Attritors can be equipped with a tachometer, ammeter, or torque sensor to measure energy input which is also used to monitor the grinding process, control the feeder or continuous dry grinding, and provide a profile record for process and quality control purposes. When needed, a metering pump for dispensing a grinding aid can also be installed on dry grinding Attritors. Sealed covers are also available for fume and dust control or for inert atmosphere processing.

Types of Attritors

There are four basic types of Attritors;
batch, continuous, circulation, and high-speed.

Batch Attritors

Batch Attritors (Figure 4 and Figure 5) are versatile and simple to operate. They are used for wet batch grinding (S series, or SC series for tungsten carbide), dry batch and continuous dry grinding (SD series). The material is charged directly into the top of the vessel (no premixing or dispersing is required), and processed until the desired particle size is achieved. Ingredients can be added at any time during the process and sampling and formulation corrections or adjustments can be made without stopping the mill. For dry grinding, batch Attritors can be used in either the batch or continuous mode (Figure 6). Generally, maximum feed material size is ~10.0mm is the material is friable, otherwise, < 10.0mm material is required.

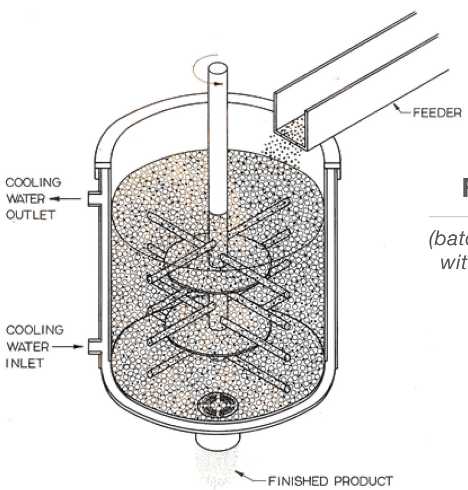

Figure 4

(batch processing with feeder and cooling)

Figure 5

(S10/S15 Attritor)

Continuous Attritors

Continuous Attritors (Figure 6 and 7) are best utilized for large, continuous slurry production runs. They are for wet grinding (C-series, or H-series for higher RPM). The premixed slurry is pumped up through the bottom grid opening of the taller, more narrow, jacketed vessel. The fineness of the product is controlled by the pumping rate or dwell time in the mill. Continuous Attritors can be arranged in series, the first using larger media, and coarser feed material, and subsequent Attritors with smaller media for finer product size reduction.

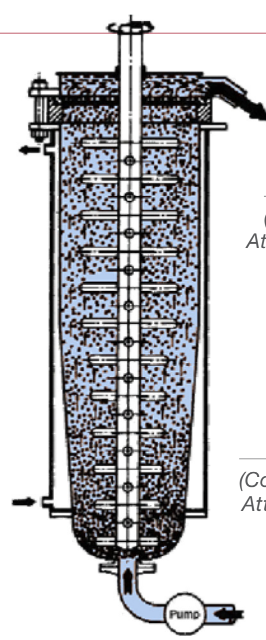

Figure 6

(Continuous Attrition Milling)

Figure 7

(Continuous CL-200 Attritors in tandem)

Circulation Attritors

Circulation Attritors (Figure 8 & Figure 9) made for wet grinding (Q-series), use the Attritor in combination with a premix/holding tank that is generally about 10 times larger than the Attritor. Thus, large volumes of slurry can be ground with a smaller investment in grinding media and Attritor equipment. As in each batch Attritor, additional components can be added at any time, and the product can be continuously monitored for quality control. Charging and discharging times are reduced since larger volumes of slurry can be processed at one time.

The circulation Attritor works on dynamic sieve concept (Figure 10) with the media acting as a confined bed allowing finer particles to pass through more easily while the coarser particles follow a more tortuous path and are ground finer resulting in a narrower distribution. The key requirement for this system is a high circulation or pumping rate. The entire contents of the premix tank are passed through the Attritor about once every 7-8 minutes.

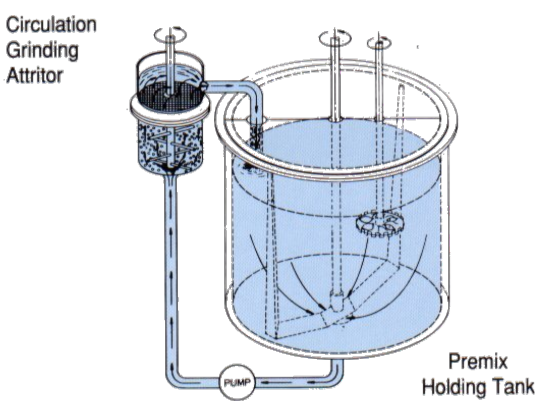

Figure 8

(Recirculation Milling)

Figure 9

(Q03 Attritor)

Figure 10

(Q25 with PT250 and Pump)

High speed Attritors

High speed Attritors (Figure 11 & 12) are used for batch and continuous dry grinding to finer sizes (HSA-series). The HSA Attritor is normally used in continuous dry grind mode with material continuously fed into the top and discharged through the bottom side screen outlet utilizing centrifugal force. The HSA is used when smaller particle feed size material (~40 mesh) needs to be ground to micron sizes (~2-10 um). The high-speed mill is also used to process large volumes of fibrous and polymer materials where additional shear forces are required for efficient size reduction.

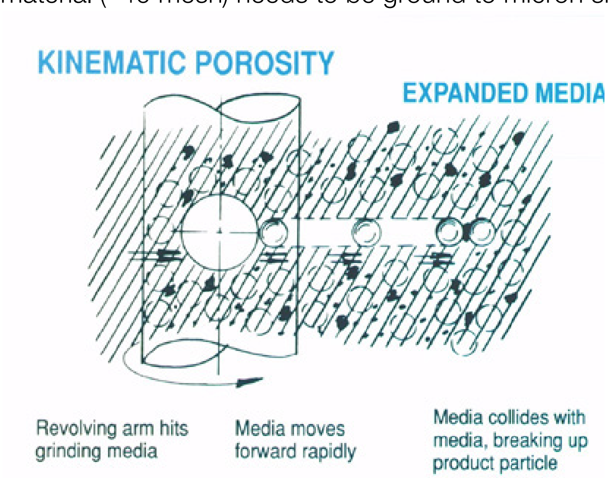

Figure 11

Figure 12

HSA-30

Applications

Typical examples of applications are given below.

Batch Attritor – batch wet grind

Material:	**fused silica, 50% 4µm**
Attritor:	S15 with Alumina lined tank, tungsten carbide agitator arms
Media:	2.5 – 3.0 mm Zirconium Silicate beads
Process Time:	4 hours
Particle Size:	50% < 0.5µm

Material:	**Zirconium Oxide, 90% < 10µm**
Attritor:	S1, Tefzel lined tank, tungsten carbide agitator arms
Media:	2 – 3 mm ZrO_2 balls
Formulation:	Zirconium Oxide/water (75% solids)
Process Time:	15 minutes
Particle Size:	90% < 1µm

Batch Attritor – batch dry grind

Material:	**Zircon sand, 60 mesh**
Attritor:	SD-30 with Alumina tank, tungsten carbide agitator arms
Media:	0.25 in ZrO_2 balls
Process Time:	2 hours for 90 lbs.
Particle Size:	50% < 4µm

Batch Attritor – continuous dry grind

Material:	**MgO, -325 mesh**
Attritor:	SD-1, Alumina lined tank, ZrO2 agitator arms
Media:	0 .1875 in ZrO_2 balls
Process Rate:	12 lbs./hr.
Particle Size:	50% < 4µm

Material:	**Zircon sand, 40 mesh**
Attritor:	SD-1, Alumina lined tank, tungsten carbide agitator arms
Media:	0.25 in ZrO_2 balls
Process Rate:	24 lbs./hr.
Particle Size:	50% < 9µm

Material:	**Silicon Carbide, -1.5 in**
Attritor:	SD-30 steel
Media:	0.375 in steel balls
Process Rate:	100 lbs./hr.
Particle Size:	50% < 35µm

Material:	**$MgCO_3$ (magnesite), 325 mesh**
Attritor:	SD-1, Alumina lined tank, ZrO_2 agitator arms
Media:	0.125 in. steatite balls
Process Rate:	4.5 lbs./hr.
Particle Size:	50% < 1µm

Material:	**Refractory fiber, 0.125 in.**
Attritor:	SD-1, Alumina lined tank, tungsten carbide agitator arms
Media:	0.375 in. Al_2O_3 balls
Process Rate:	7 lbs./hr.
Particle Size:	50% < 200 mesh

Continuous Attritor – continuous wet grind

Material:	**Alumina trihydrate, 48% ~ 325mesh**
Attritor:	C-3, Alumina lined tank, tungsten carbide agitator arms
Media:	0.25 in Al_2O_3 balls
Formulation:	alumina trihydrate/water (45% solids)
Process Time:	12 minutes
Particle Size:	50% < 4µm

Material:	**Magnesium Hydroxide**
Attritor:	C-3
Media:	2 – 2.5mm ZrO_2 balls
Formulation:	magnesium hydroxide/water (45% solids)
Process Time:	8 minutes
Particle Size:	50% < 2µm

Circulation Attritor – wet grind

Material:	**Zircon Sand, 100 mesh**
Attritor:	Q2, Alumina lined tank, Zirconium Oxide agitator arms
Media:	0.1875 in ZrO_2 balls
Formulation:	zirconium oxide/water (65% solids)
Residence Time:	12 hours
Particle Size:	50% < 2µm

Material:	**Rutile, 15µm**
Attritor:	Q2, Alumina lined tank, plastic agitator arms
Media:	5mm ZrO_2 balls
Formulation:	rutile/water (50% solids)
Residence Time:	30 minutes
Particle Size:	50% < 1.5µm

High Speed Attritor – batch dry grind

Material:	**Graphite, 100 mesh**
Attritor:	HSA-1
Media:	2-3mm in Zirconium Silicate beads
Process Time:	30 minutes
Particle Size:	50% < 5.5µm

High Speed Attritor – continuous grind

Material:	**Alumina, 100 mesh**
Attritor:	HSA-1, Al_2O_3 lined tank, ZrO_2 agitator arms
Media:	2-3mm in Zirconium Silicate beads
Process Rate:	10 lbs./hr.
Particle Size:	50% < 6µm

Material:	**ZrO_2, -325 mesh**
Attritor:	HSA-1
Media:	2-3mm in Zirconium Silicate beads
Process Rate:	7 lbs./hr.
Particle Size:	50% < 0.5µm

Summary

The advantages of the stirred ball mill are:

- Fast and efficient very fine particle size reduction
- Lower power consumption
- Ease of operation
- Good temperature control
- Low maintenance
- Smaller plant area, simpler foundation, and lower installation cost
- Noise levels compatible with OHSA standards

The limitations of the stirred ball mill are:

- Most efficient use is for fine grinding final product to 200 mesh to sub-micron
- Material feed size should typically be smaller than media diameter
- Wet grinding is necessary for the most efficient grinding of refractory materials below 1 µm
- Limited availability of the appropriate size type and size grinding media and parts for iron contamination-free grinding of a particular product

References:

1. J.A. Herbst and J.L. Sepulveda, "Fundamentals of Fine and Ultrafine Grinding in a Stirred Ball Mill"; in *Proceedings of the Powder and Bulk Solids Conference*, Chicago, IL May 1978.
2. Temple C. Patton, *Paint and Flow and Pigment Dispersion*, Second ed. Wiley Inter-science, New York, 1979.

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1925 Akron-Peninsula Road Akron, OH 44313
(330) 929-3333 Fax: (330) 929-3034
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