STIRRED BALL MILLS

by

John E. Becker
UNION PROCESS INC.
Akron, Ohio

Presented
February 21, 1990

CLEMSON UNIVERSITY
College of Engineering

Clemson, South Carolina

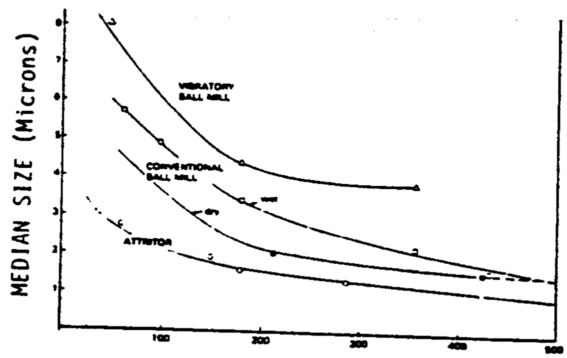
INTRODUCTION

The stirred ball mill, also referred to as an attrition mill or Attritor, is a grinding mill containing internally agitated media. The Attritor is one of the most efficient fine grinding and dispersing or comminuting pieces of equipment available today for the fine grinding of ceramic materials.

A key to the efficiency of stirred ball mill grinding is that the power input is used directly for agitating media for grinding and is not used for rotating or vibrating a large, heavy vessel in addition to the media charge.

To more clearly illustrate the efficiency of the stirred ball mill, Fig. 1 shows the relative effectiveness of the Attritor versus the vibratory ball mill and conventional ball mill for the ultra-fine grinding of Pima Chalcopyrite concentrate. The data for the vibratory ball mill is represented by the top curve with the middle two curves developed from conventional ball mills. The bottom curve was derived from Attritor data. This figure clearly shows that for a specific energy input of about 100 kwh/t, the median particle size obtained through the use of Attritors is approximately 50% smaller than that obtained from conventional ball mills and about 33% smaller than that obtained from vibratory ball mills. At a specific energy input above 200 kwh/t, the Attritor continued to grind into the submicron range while the other machines can no longer efficiently produce the smaller, sub-micron particles. Therefore, the time required for grinding sub-micron particles with the Attritor is much shorter.

Fig. 1



The stirred ball mill's operation is simple and effective, and this explains the Attritor's efficiency. The material to be ground is placed in the stationary Attritor tank with the grinding media. The material and media are agitated by a rotating central shaft with arms. Both impact and shearing action result in size reduction, as well as homogeneous particle dispersion with very little wear on the tank walls. These efficient impact and shearing forces are illustrated in Fig. 2, and must be present for the most effective grinding action.

The agitator arm configuration of the Attritor provides a constant moving motion of the slurry around the tank. The area of greatest media agitation is shown in Fig. 3, and is located approximately two-thirds the radius from the center shaft. In production machines, the movement is augmented by adding a pumping, circulation system. As can be seen in Figure 3, grinding does not take

(1) J.A. Herbst and J.L. Sepulveda, "Fundamentals of fine and Ultrafine Grinding in a Stirred Ball Mill", Proc. Powder & Bulk Solids Conf., Chicago, IL, May 1978.

place against the tank walls resulting in very little wear on the walls, leading to longer service life of the vessel and minimal contamination from the inner tank lining. The vessel walls can, therefore, be made thinner thus providing enhanced heat transfer and greater temperature control.

Fig. 2

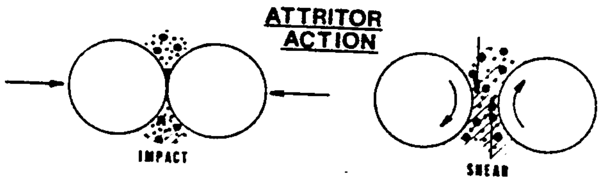
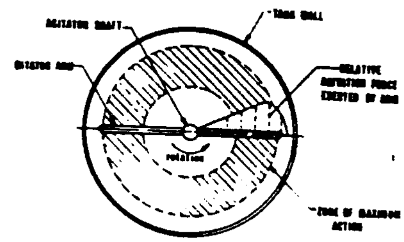


Fig. 3



GRINDING MEDIA

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

$$T = \frac{KD}{\sqrt{N}} \quad (2)$$

T = grinding time to reach a certain median particle size
K = a constant that varies depending on material being processed, type of media, and the model of Attritor being used
D = media diameter
N = shaft rpm

This equation shows that the total grinding time is directly proportional to the media, or ball diameter, and inversely proportional to the square root of the shaft RPM. This equation also shows that increasing the media size increases the grinding time, but decreasing the media size decreases grinding time.

Grinding media selection, however, must be based upon several interrelated factors:

1. Contamination - the media wear should not adversely affect the final product, or worn media material should be able to be removed chemically, or by a magnetic separator, or in sintering.
2. Specific gravity - normally, the higher the density, the more effective and faster the grinding. Ideally, the media should be denser than the material to be ground and materials with high viscosity require media with higher density to prevent floating.
3. Feed size - the diameter of the media should be greater than the initial particle size for effective breakdown of the large particles.
4. Hardness - harder media result in less contamination, greater grinding efficiency, and longer media life.
5. Discoloration - media composition must allow white or light colored materials to retain their clean color without adverse discoloration, etc.

(2) Temple C. Patton, "Paint and Flow and Pigment Dispersion", Second Edition, Wiley - Interscience, New York, 1979.

6. pH - some strong acid or basic slurries may have a tendency to react with certain metallic media.
7. Final particle size - generally, smaller media are more efficient when grinding superfine particles.

For Attrition grinding, media size range is from 1/8" to 3/8", with smaller grinding media generally resulting in faster particle reduction because, for a given volume, there will be more impact and surface contact. As media become smaller than 1/8", its mass is significantly reduced, resulting in less impact force resulting in longer grinding times. When ultra fine grinding is not needed, a larger diameter media may prove to be faster and more efficient, since its mass is greater.

Stirred ball mills use many different types of media, each suitable for specific materials in various industries. These include, carbon steel, stainless steel, chrome steel, tungsten carbide, glass, flint stones, and various ceramic materials.

For fine grinding applications in the ceramic industry, the types of media generally being used include steatite (consisting primarily of 64% silica, 26% magnesium oxide, and 6% alumina); high alumina (87%, 90%, 96%, and 99% alumina grades are the most commonly available); mullite (74% alumina, 21% silica, 2.5% magnesium oxide); and zirconium (silicate 69% zirconium oxide, 31% silica). The more expensive types of ceramic media currently being used include yttria stabilized high purity zirconium oxide, magnesium stabilized zirconium oxide, rare earth zirconium oxide, silicon nitride, and silicon carbide.

THE THREE TYPES OF STIRRED BALL MILLS

1. Batch
2. Continuous
3. Circulation

In wet Batch Attrition grinding, the material is charged into the top of the jacketed grinding tank and is processed until the desired particle size is achieved. Production size attrition mills are equipped with a built-in pumping system which contributes toward greater product uniformity and can be used for faster discharging. No premixing is necessary, and ingredients can be added at any time during processing, while sampling and formula corrections can be made at any time without stopping the mill. For dry grinding, the batch attrition mill can be used in either the batch or continuous mode, depending on the material's initial feed size, final particle size desired, and production rate requirements.

The continuous stirred ball mill provides a constant flow of finely ground, processed material. For wet grinding, the premixed slurry is pumped up through the bottom of the tall, narrow, jacketed tank with the fineness of the processed material determined by the "dwell time" and controlled by the pumping rate. Continuous mills can be arranged in series, using larger media and grid openings for the first unit.

The circulation stirred ball mill rapidly pumps the slurry to be ground through a confined bed of small grinding media. The media acts as a dynamic sieve - the fine particles pass through easily, and the larger particles are ground more finely - resulting in a narrow particle size distribution. The slurry passes through the mill until the desired particle size is achieved. Large quantities of material can be ground with a smaller investment in grinding media and attrition mill equipment. Additional material can be added at any time, and the product can be continuously monitored for quality control. Charging and discharging times are reduced with less manpower in this circulation Attritor.

PARTS SELECTION

For processing ceramic materials in the stirred ball mill, the appropriate materials for tank linings, agitator arms, and grid plates must be selected. Currently, several materials have been used successfully for lining and sleeving these machine parts to eliminate or minimize contamination of the final ceramic product. Once again, it must be remembered that in this type of mill, over 90% of contamination will come from the grinding media, consequently, the grinding media selection is of utmost importance. The remaining potential contamination will come from the tips of the agitator arms, the tank wall, and the bar grids.

In most ceramic applications, a high alumina tank lining with high density plastic sleeved arms, grid plates, and a plastic type pumping system are recommended. As we know, alumina is very abrasion resistant, and is resistant to most solvents, but for applications where alumina contamination is not desired, a tank lining made of a polymer type material, such as rubber, polyeurethane, or teflon may be appropriate. It must be remembered, however, that a polymer lining has a very poor heat transfer factor, therefore, a heat exchanger in the pumping line may be needed in some cases. However, rubber-lined Attritors have been used very successfully in grinding silicon nitride and zirconium oxide water based slurries.

In terms of grinding silicon nitride, silicon carbide, and zirconium oxide, these materials can be used for tank liners, grid plates, and arm sleeves, but presently are relatively expensive. In many cases, it seems to be more cost-effective to use plastic-sleeved shaft and arms, and replace them at appropriate intervals. Thus far, most high alumina sleeves have proved to be less cost-effective than plastic. Silcon nitride and zirconium oxide sleeves have proven to be longer wearing than plastic, but more expensive from an initial cost standpoint. New replaceable plastic sleeved type arms provide a fast and economical means of minimizing contamination. Recently, however, significantly longer wearing rare earth zirconium oxide arms have been developed which have proven very cost effective over previously used materials including plastics. Tungsten carbide is being used for agitator arm sleeves and facing for bar grids and other material contact parts for long wear, especially for the dry grinding application.

APPLICATIONS

The batch and circulation attrition mills are preferred for advanced ceramic grinding. The batch Attritor has the advantage of grinding both dry and wet in very small batches, while facilitating easier cleaning between different product runs. The circulation mill, on the other hand, can provide an even narrower particle size distribution along with greater batch size, flexibility, and lower capital investment for larger batch size requirements. The circulation mill, however, is limited to the processing of pumpable ceramic slurries.

The grinding and dispersing of silicon nitride powder has proved to be extremely successful using the batch attrition mill, Figure 4. Figure 5 is a Microtrac readout which shows a frequency distribution of unground silicon nitride with a mean diameter of 5.62 microns, ground to .98 microns in a 1-S Attritor for two hours. Here, 1/4" silicon nitride media was used along with deionized water. As is very common, this material took about 1/10th the usual time it takes to grind to the required median size in a typical ball mill.

Fig. 4

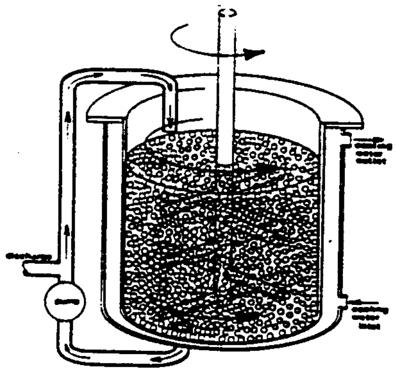


Fig. 5

SILICON NITRIDE POWDER:

	UNGROUND		AFTER 2 HOURS
35.50	0	35.50	0
25.10	0	25.10	0
17.75	-----8	17.75	0
12.55	---------13	12.55	0
8.87	----7	8.87	0
6.27	--4	6.27	0
4.43	------10	4.43	0
3.13	---------14	3.13	-7
2.21	---------14	2.21	-6
1.30	--------12	1.30	-----16
0.80	----7	0.80	---------26
0.55	--4	0.55	---------25
0.39	2	0.39	---11
0.30	0	0.30	3
0.20	0	0.20	1
0.15	0	0.15	2

		Unground	After 2 hours
(Surface Area)	CS=	3.13	9.64
(Mean)	MV=	5.62	0.98
(90% less than)	%90=	14.56	2.21
(50% less than)	%50=	3.25	0.74
(10% less than)	%10=	0.75	0.36
(Std. Deviation)	DV=	0.2586	0.1138

Another common ceramic application for the circulation type stirred ball mill is for grinding and dispersing of alumina slurries. Typically, the material is ground in a high-alumina lined mill using 95% alumina media with plastic arms, grids, a plastic air diaphragm pump and nylon coated or stainless steel premix/holding tank, ten times the size of the Attritor. Fig. 6 & 7 illustrate a typical circulating attrition system. The high pumping rate circulates the entire contents of the holding tank through the circulation mill at least once every 7-1/2 minutes or about 8 times per hour.

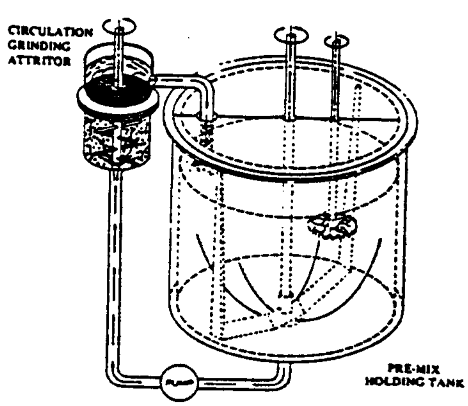


Fig. 6

Fig. 7

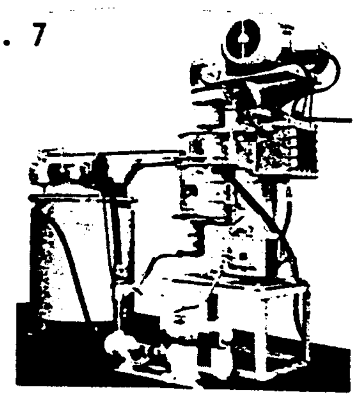


Fig. 8 shows a particle size frequency distribution for aluminum oxide slurry before and after grinding and dispersing in a production model Q-25 circulation Attritor. Here, 1/4" alumina media was used and the total production time was 8 hours to produce 1,600 lbs. of alumina. The initial alumina charge had a mean particle size diameter of 8.69 microns, and after 8 hours was reduced to a mean diameter of 1.68 microns. The total residence time in the slurry grinding chamber was 40 minutes. This material is typically ground in a ball mill for at least 24 hours to obtain this particle size.

Fig. 8

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ALUMINUM OXIDE SLURRY:

FEED MATERIAL                           AFTER 40 MINUTES RESIDENCE TIME

35.50  0                                35.50  0
25.10  --5                              25.10  0
17.75  -------13                        17.75  0
12.55  -----10                          12.55  0
 8.87  -------14                         8.87  0
 6.27  --------16                        6.27  1
 4.43  -------14                         4.43  --9
 3.13  -----10                           3.13  --10
 2.21  --6                               2.21  ---11
 1.30  -3                                1.30  --------27
 0.80  2                                 0.80  -------22
 0.55  1                                 0.55  ----15
 0.39  0                                 0.39  2
 0.30  0                                 0.30  0
 0.20  0                                 0.20  0
 0.15  0                                 0.15  0

(Surface Area)     CS=    1.48                CS=    5.72
(Mean)             MV=    8.69                MV=    1.68
(90% less than)   %90=   19.18               %90=    3.75
(50% less than)   %50=    6.71               %50=    1.26
(10% less than)   %10=    2.02               %10=    0.54
(Std. Deviation)   DV=  0.7276                DV=  0.4130
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Circulation Attritors are also presently being used successfully in the grinding of barium titanate electronic materials. These materials typically start at 20 microns and are reduced in the circulation mill typically to less than 1 micron.

SUMMARY

ADVANTAGES OF STIRRED BALL MILL

1. Fast and efficient very fine particle size reduction
2. Lower power consumption
3. Easy to operate
4. Good temperature control
5. Lower maintenance replacement part costs
6. Smaller plant area with simpler foundation with lower installed costs
7. Lower noise level to more easily satisfy OSHA standards

LIMITATIONS OF STIRRED BALL MILL

1. Used most efficiently for fine grinding only
2. Feed size of the material to be processed in the stirred ball mill. should typically be smaller than the media diameter used
3. Wet grinding is necessary for the most efficient grinding of ceramic materials below one micron
4. The availability of the appropriate type and size of media for contamination-free grinding of a particular product