EXPLORING THE ULTRASONIC COMMINUTION OF COPPER ORES

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SUMMARY

This paper presents grinding results obtained with a chilean porphyric copper ore in the ultrasonic nip roll grinder of the US Comminution Center. Comparison with ball milling is performed by scaling-down industrial ball mill behavior to the ultrasonic grinding conditions. For small gap setting in the ultrasonic device, size distribution and specific energy consumption are in the same order of magnitude for both alternatives, but for larger openings in this ultrasonic prototype, the ball mill is much more efficient.

Current design of the ultrasonic device is analysed and reasons why too small and too large particles are not well fractured are discussed. In spite of current limitations, it is concluded that exist a large potential to improve performance.

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INTRODUCTION

Chile annually consumes about US$ 120 millions in size reduction of copper ores and same figure in a world-wide basis is over US$ 600 millions, only in the comminution of copper ores from primary sources. Between 40 to 60% of this energy is spent in fine grinding operations, typically to go from 85% below 6 mm to 40-60% below 200 Tyler mesh (74 μm).

Available technology is based on different versions of tumbling mills, introduced as early as 1880 (1). There is consence that space for improvements of this technology is limited, and new alternatives have to be investigated.

On the other hand, in spite of the success of the high pressure roll mill developed by Schönert (2), it has not been possible to extensively incorporate this technology to the industry of basic metals from orebodies, such as copper, iron, aluminum, zinc, lead and others. For heavy duty work with low economical value materials, the Schönert mill is not an economical alternative at this moment. From the multiple other attempts developed or under development, the use of ultrasonic vibrations to achieve size reduction seems to deserve to be analysed even though it is to early to affirm that this is the rigth technological direction in this area.

PREVIOUS WORK ON ULTRASONIC FRACTURE

In 1981 an ultrasonic comminution project was started up at the Energy & Minerals Research Company, EMR, at Exton, Pennsylvania, under the leadership of G.R. Moulder and W.B. Tarpley and supported by the US Department of Energy (3). Their first ultrasonic device was a rotating roller with a capacity between 10 lb/h to 30 lb/h, and it required about 3 kWh/t instead of the 20 kWh/t needed by a hammer mill to obtain a product of 80% finer than 200 Tyler mesh (Illinois #6 and Upper Freeport coals). For micron-size grinding applications, the ultrasonic required 24 kWh/t versus 300 kWh/t, which makes it 12 times less energy intensive. Main weakness of this machine was its low capacity. Then EMR designed and built a cylindrical ultrasonic grinding unit referred as the Auger (4). Capacity was increased by an order of magnitude and energy efficiency still remain in low values. They also noted that wet grinding was more efficient than dry grinding, due to a better conduction of the ultrasonic waves and possible fragmentation by cavitation. Unfortunately, this research was terminated for a variety of reasons and was soon followed by EMR filing to bankruptcy. Most of the technology and know-how developed by EMR was lost.

In a separate study Parekh et al (5) developed a process where electrofracture is combined with ultrasonics to produce fine grinding. Some practical limitations like nonefficient electric contact during electrofracture have to be overcome in order to make it attractive.

In 1988, the US Department of Energy started its own ultrasonic comminution project in the Coal Preparation Division at the Pittsburg Energy and Technology Center, PETC, under the leadership of R.P. Killmeyer and T. Link (6). Experiments were developed in the nip roll grinder recovered from EMR. They were very surprised when testing Illinois #6 coal, the energy consumption was around 400 to 700 kWh/t, that is, two order of magnitude higher that the earliest results. In addition, very little size reduction was achieved. These results led to the termination of that research project after a one year period.

In 1989 part of the nip roll grinder was shipped to the University of Utah Comminution Center in Salt Lake City, where a new project on ultrasonic grinding has been undertaking under the direction of Y.C. Lo and J.A. Herbst. The machine was re-conditioned including new piezoelectric ceramics able to generate strong mechanical vibrations. A matching network was also installed to make efficient energy transfer between the electric power supply and the ultrasonic transducer. With these improvements, extensive experimentation has been done mainly with limestone and Upper Freeport coal (7-8). Total energy consumption has been found in the range 1-10 kWh/t for feed sizes smaller than 8 Tyler mesh and products in the range of 30-50% below 100 Tyler mesh, values comparable to those obtained in a batch ball mill. For feed sizes coarser than 10 Tyler mesh, the ball mill seems to be more efficient (9-10).

In a separate effort, CIMM and the Department of Physics of the University of Santiago in Chile, have also commenced an ultrasonic fracture project in 1990. The emphasis has been put in the development of a high power transducer, especially designed to break materials like ores in beds, initially using the concept of generating a stationary chock wave field along a static particle bed under wet conditions. Results were very poor because of the high attenuating capacity of the particle bed. Additional experiments were conducted by applying a know contact force during the experiment with ultrasonics. With this modification, fines production rate as well as specific energy consumption started to make sense (11). Two conclusions arose from this work: overimposition of compressive and ultrasonic stress fields produce strong synergism which need to be explored, and also, with the available technology it is hard to conceive a high power resonance field in thick bed of particles. Then, design of a future machine should point out to thin active fracture chambers, aspect which could eventually limitate capacity per unit size of the machine.

Chile, as a leader copper producer in the world, is continuously interested in research and development activities which could eventually impact productivity and cost of its mining industry. Thus, CIMM took contact with Dr. R.P. King and Y.C. Lo, from the Comminution Center, who kindly accepted one of our researcher to run some tests in their ultrasonic nip roll grinder with a typical chilean copper ore. Report of the obtained results is the objective of this paper.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

An schematic representation of the Utah ultrasonic roll device is shown in Figure 1. It has a vibrating plate driven by an ultrasonic transducer working in the 10-20 kHz range against a 178 mm in diameter spinning roll. Particles are fed into the gap existing between the roll and a curved plate (grinding shoe). Several breakage events accur due to the overimposed action of ultrasonic vibration and compression stresses between the metallic surfaces. The gap setting (50-250 micrometers) determines the largest opening of the gap (130-700 micrometers) which control the largest particles in the product.

In order to optimize energy transfer between electrical and acoustic systems, appropriate working frequencies were selected. Figure 2 shows the efficiency coefficient with regards to frequency in the range 14-18 kHz. In this work 15.110, 16.494 and 16.764 kHz were selected as the transfer efficiency is largest than 90%.

Three different feed size distributions were prepared with most of the particles in the range 9x14, 20x28 and 35x48 Tyler mesh. These feeds do not correspond to single size fraction in the standard way, thus in the following sections of this paper these will be referred as feed 1, feed 2 and feed 3, respectively.

Batches of about 200 grams each were fed dry and as fast as possible to the grinder. The overall time to pass all the material were recorded to calculate an average throughput. Ground products were collected for size analysis in the standard manner (8).

EXPERIMENTAL RESULT

All the experiments were performed in triplicate in order to increase statistical representativeness of the results. Only average values are here reported. The electric power input was always kept a constant level of 100 Watts. Frequency was carefully adjusted before each experiment in order to assure efficient electrical energy transfer.

Effect of Frequency on Energy Consumption and Product Size Distribution

Figure 3 illustrates that a direct relation exists between frequency and specific energy consumption, but it does not necesarily mean a finer product. Same tendency was observed with the three feed size distributions at the three above-mentioned frequency values.

Effect of Gap Setting on Energy Consumption and product Size Distribution

For a given feed size material, an increase in the gap setting (in the range of 50-130 micrometers), involves a higher energy consumption and a coarser product, as shown in Figure 4 for the coarser feed size under study (feed 1). Finer feed sizes produce finer product size profiles but still energy consumption increases with an increase in the gap opening.

Effect of Feed Size on Product Size Distribution

The gap between the roll and plate was set at 50 micrometers and the three different feed profiles were successively ground. Size analysis of the products are presented in Figure 5. The size variable has been normalized by the maximun size in each case. Product size distributions are sensitive to the feed size, with a shift toward finer sizes for the smaller feed sizes. Fines production is significantly reduced as feed decreases in size.

ANALYSIS OF RESULTS

In order to precise whether the above results are interesting or not , it is necessary to analyse them under comparable conditions with a well-know technology such as the ball milling. Instead of running tests in a small ball mill, in this work it was preferred to perform a scale-down from an industrial ball mill which operates with the same feed ore, to similar conditions used in the lab ultrasonic grinding experiments.

Modeling Using the Specific Selection Function Concept

A sampling triall was conducted at the industrial ball mill circuit in order to get a representative material balance and collect a sample which was later prepared and used in the ultrasonic grinding experiments. Obtained results are shown in Table 1. The simplified version of the kinetic grinding model (12) was used to compute the specific selection function in the form:

$$(1-P_i) = (1-F_i)\left(1+\frac{S_i^E E}{N}\right)^{-N} \tag{1}$$

Where P_i and F_i are product and feed cumulative size distributions in weight fraction, respectively. E is the specific energy consumption in kWh/t, N is the equivalent number of perfect reactor-in-series, usually estimated as the lenght/diameter ratio if no information about RTD is available, and S_i^E is the specific selection function, generally low sensitive to design and operational conditions(10). The resulting S_i^E vector as a function of the particle size is shown in Figure 6.

The simplest way to model the ultrasonic nip roll grinder is assuming that it can also be represented as a kinetic grinding process, where the material is moving down close to plug flow pattern. If the compensation condition also applies (13), then,

$$(1-P_i) = (1-F_i)\exp(-S_i^E \bar{E}) \tag{2}$$

with equivalent meaning of symbols as before.

For a 50 micrometers gap setting in the ultrasonic device, product size distributions is close to the estimated ball mill response for the same specific energy consumption, see Figure 7. In the same figure it has also been included a simulation for same product size, giving an energy consumption of 1.2 kWh/t instead of 1.5 kWh/t for the ultrasonic device.

For larger gap sizes, results are not so promising. Figure 8 illustrates that for a 130 micrometers gap setting, the ultrasonic machine requires about four more times the specific energy required by the ball mill to produce similar product size distributions. It is interesting to note that ultrasonic roll grinding effectively generates more narrow product size profiles as has been previously shown for other materials (7-9).

When the feed size is very fine a low breakage amount is produced, see Figure 9, probably because the applied vibrational stresses are not strong enough to produce fracture.

DESIGN ASPECTS

The experimental device used in this and previous studies of ultrasonic grinding at the Comminution Center, is far to be an optimum design, so definitive conclusions in either way can not be established. The first limitation of this prototype is the small opening of the gap at the top side. throughput measurement is subjeted to a significant error, especially if feed material is above 6 Tyler mesh. This occurs because some particles could eventually plug the gap and stall the vibrations. According to Kientzler (9) this can be avoided if the maximum feed size is smaller than 70% of the opening gap. On the other hand, when particles are too small compared to the upper gap setting, the curved grinding shoe promotes shaking but not breakage of the particles as they do not move down at high speed. Since ultrasonic energy is provided at a constant rate to the vibrating surface, but only part of this surface is actually involved in the grinding process, energy is not efficiently used. Two flat plates could improve this situation as is currently under development at the Comminution Center (4), but always the fine particles will tend to be suspended unless a force obligates them to enter into the grinding area.

FINAL REMARKS

This study has shown that ultrasonic roll milling is also a promising alternative to grind hard materials such as copper ores, in addition to soft materials like coal and limestone previously tested. Generation of sharper product sizes compared to ball milling is also confirmed.

Current ultrasonic device has serious design limitations. Increase in grinding efficiency at large gap opening, both in the rate of fines production as well as in the specific energy consumption have to be overcome in order that real applications make sense.

Great emphasis has been put in matching an effective transfer from electrical energy to ultrasonic energy, but no criteria is available to assure an effective use of the ultrasonic energy in producing fracture in a bed of particles. This is a virgin research field.

Synergism between vibrating and compressive stresses is a key concept in the design of a new ultrasonic prototype. An attractive research goal could be to replace the high contact pressure concept in the Schönert mill by a moderate contact pressure coupled with a radiative energy transfer mechanism like the ultrasonics. This would avoid the heavy duty limitation of the Schönert mill as applied to hard and abrassive materials.

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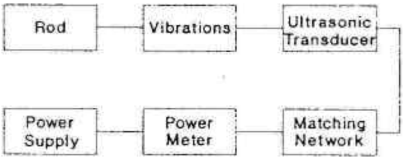

FIGURE 1. Schematic Diagram of The Ultrasonic Nip Roll Grinder at The USA Comminution Center.

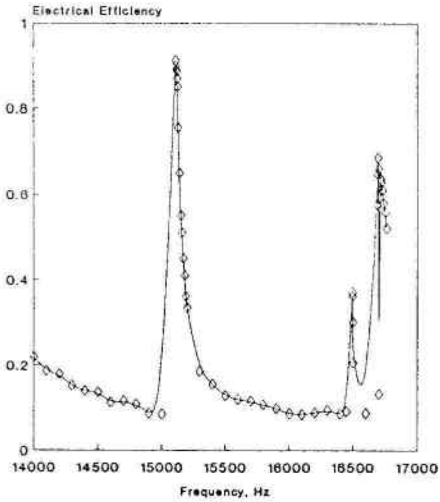

FIGURE 2. Efficiency - Frequency Response Profile.

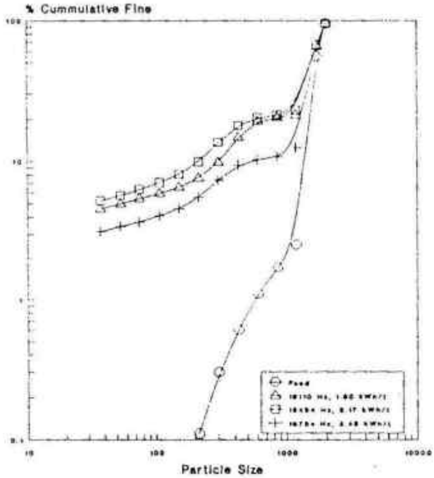

FIGURE 3. Effect of Frequency on Energy Consumption and Product Size Distribution.

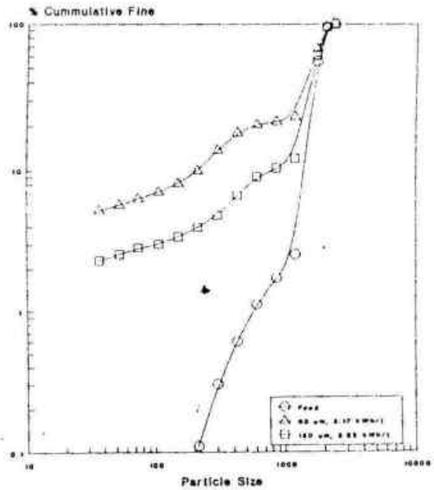

FIGURE 4. Effect of Gap Setting on Energy Consumption and Product Size Distribution.

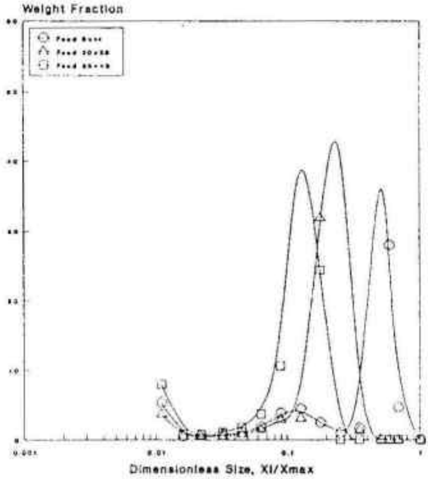

FIGURE 5. Effect of Feed Size on Product Size Distribution with a 50 Micrometers Gap Setting.

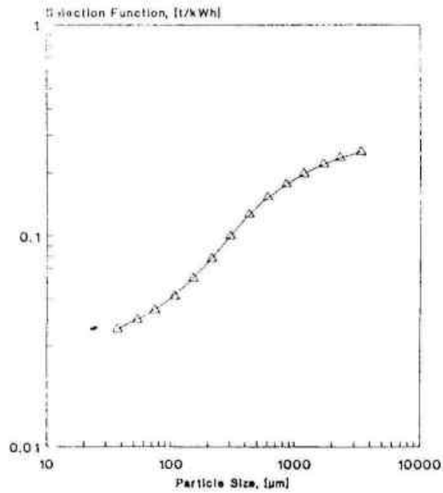

FIGURE 6. Specific Selection Function for a Chilean Copper Ore in a 16'x 24' (DxL) Ball Mill.

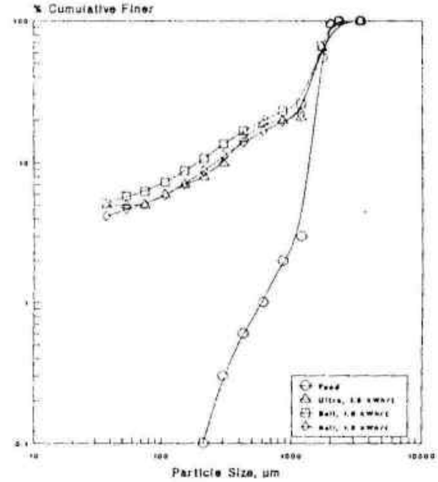

FIGURE 7. Comparison to Scaled-Down Ball Milling and Experimental Ultrasonic Nip Roll Grinder, Gap=50 µm.

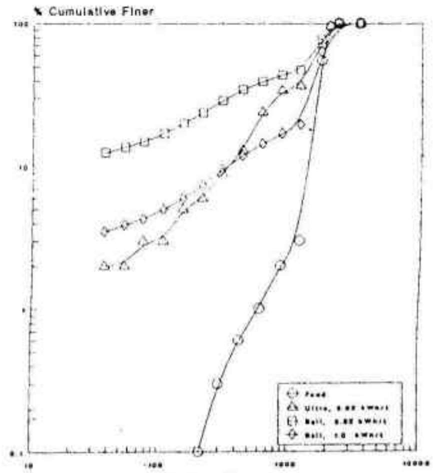

FIGURE 8. Comparison to Scaled-Down Ball Milling and Experimental Ultrasonic Nip Roll, Gap = 130 µm.

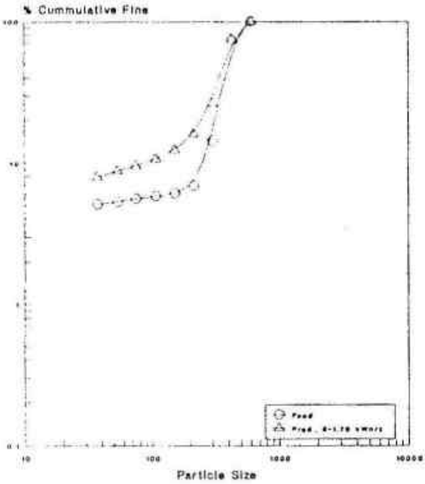

FIGURE 9. Effect of Fine Feed Size
In the Ultrasonic Grinding
Gap = 50 µm.

TABLE 1. [illegible] Industries ball mill and ultrasonic grinding

Gap=50 micrometers			E = 1.5	SE	E = 1.5	E = 1.2
Mesh	Sieve size (µm)	Fi	Ultrasonic	Ball	Ball	Ball
5	3360	1.000	1.00	0.2505	1.00	1.00
8	2360	1.000	1.00	0.2360	1.00	1.00
9	1980	0.943	0.95	0.2210	0.96	0.95
10	1700	0.550	0.55	0.2197	0.57	0.65
14	1180	0.050	0.21	0.1981	0.26	0.22
20	850	0.020	0.20	0.1761	0.23	0.20
28	600	0.010	0.19	0.1529	0.20	0.17
35	425	0.005	0.15	0.1266	0.17	0.14
48	300	0.003	0.10	0.0998	0.14	0.11
65	212	0.001	0.08	0.0779	0.11	0.09
100	150	0.000	0.07	0.0631	0.09	0.07
150	106	0.000	0.06	0.0521	0.07	0.06
200	74	0.000	0.05	0.0445	0.06	0.05
270	53	0.000	0.05	0.0404	0.06	0.05
400	37	0.000	0.05	0.0364	0.05	0.04

Gap=130 micrometers			E = 3.82	SE	E = 3.82	E = 1
Mesh	Sieve size (µm)	Fi	Ultrasonic	Ball	Ball	Ball
5	3360	1.000	1.00	0.2505	1.00	1.00
8	2360	1.000	1.00	0.2360	1.00	1.00
9	1980	0.940	0.96	0.2210	0.97	0.95
10	1700	0.550	0.72	0.2197	0.77	0.63
14	1180	0.030	0.37	0.1981	0.47	0.19
20	850	0.020	0.34	0.1761	0.44	0.17
28	600	0.010	0.24	0.1529	0.40	0.14
35	425	0.006	0.15	0.1266	0.35	0.12
48	300	0.003	0.09	0.0998	0.29	0.09
65	212	0.001	0.06	0.0779	0.24	0.07
100	150	0.000	0.05	0.0631	0.20	0.06
150	106	0.000	0.03	0.0521	0.17	0.05
200	74	0.000	0.03	0.0445	0.15	0.04
270	53	0.000	0.02	0.0404	0.14	0.04
400	37	0.000	0.02	0.0364	0.12	0.04