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Development of an ultrasonic high-pressure roller press

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Abstract

It is widely known that particle size reduction processes have a low energetic efficiency. In this paper, we present experimental results obtained by a new grinding machine using ultrasound to enhance the performance of a roller mill. The required energy consumption for a comminution operation appears to be significantly reduced by careful application of an ultrasonic field in the grinding zone. A lower stress on the shafts and a reduction of the required torque were also observed. The lower mechanical stress should also cause less abrasive wear on the rolls.

Keywords: Grinding; Ultrasound; Roller press; Mill; Wear; Energy

1. Introduction

One of the options to improve the efficiency of comminution is the application of an ultrasonic field in the stressing zone. There are well-known related applications of ultrasonics in drilling and in the destruction of kidney stones. Since the 1950s, many researchers have been exploring the fragmentation effect of ultrasonic fields in suspensions and solids under compression. Gärtner (1959), was probably the first who intentionally tried the application of ultrasonic waves to the fragmentation of particles in suspension. His results were very poor and have little technical interest. Fleischauer and Kröger (1969) used ultrasonic waves to fragment coal in suspension for subsequent solvent extraction. The applied power (400 W) is relevant and the active zone design is still interesting. Graff (1979) arranged many transducers in a multistage stamp mill. Quantitative information about his results is very scarce. Leach and Rubin (1988), studied the fragmentation of drill blocks fixed to an ultrasonic transducer. They observed preferential

fracture at the node and better results with brittle materials. Soft rocks heat up, giving less efficient energy utilisation. Tarpley and Moulder (Tarpley, Howard, & Moulder, 1980) studied the grinding of coal under compression, and developed several devices intended to produce fine particles for combustion. Their reported values of energy consumption were as low as 3 kWh/ton, much lower than the 20 kWh/ton usually required in hammer mills to obtain a product 80% under 75 µm (200 mesh). For grinding below 10 µm, they report 24 kWh/ton, one order of magnitude lower than normal value of 300 kWh/ton. A conical device with an auger spiral was reported to be able to grind 300 lb/h (approx. 135 kg/h) at 5–7 kWh/ton. They designed other devices that finally were not tested. Later, in 1988, other researchers (Link & Killmeyer, 1988) using the same machines were not able to reproduce the previously reported results. Lo and Kientzler (1992, chapter 47) recovered one of the Tarpley and Moulder machines and after redesigning the ultrasonic wave generator, applied the resulting device to grinding of some species. Their results have an energy consumption similar to that of a ball mill, but no better. After identifying some weaknesses in their device, they proposed a new design (Lo, Kientzler, & King, 1993). Yerkovic, Menacho and Gaete (1993) made grinding tests comparing standard

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ore with ultrasonic pre-treated samples in a ball mill. The pre-treated ore exhibited a 32% higher grinding rate.

In most research work, ultrasonic waves have been applied as a means to induce an accelerated fatigue cracking, due to the high frequencies involved. Most devices are composed of a vibrating surface, separated by a gap much smaller than the particle feed size. The amplitude of the vibration is approximately one order of magnitude smaller than the gap size. The process capacities that can be obtained with this design are very limited, in spite of the very low, energy consumption, levels claimed by some authors.

A key point is the influence exerted by the ultrasonic field on the material properties. Blaha and Langenecker (1959) found a decrease in yield point of single metal crystals. The softening effect disappears by switching out the vibration, and comes back when the vibration is restarted. The amount of softening cannot be explained solely by inertial effects on the load and displacement sensors. An energy dissipation mechanism is proposed at crystalline defects, which could cause local heating and a reduction of the slip threshold. Leach and Rubin (1988), mention a 70% reduction of compressive strength of an ore in their experiments. No other data have been found on ultrasonic effect in mineral or ceramic materials.

2. Effect of an ultrasonic field on breakage force of glass balls

An experiment was made on the effect of ultrasound on the breakage of glass balls. A pneumatic press capable of applying up to 390 kPa was fitted with an ultrasonic transducer (Fig. 1). The transducer is of the stepped horn type, resonating at 20.4 kHz. The applied force was measured using a precision pressure gauge.

Three collections, each one formed by 25 glass spheres of 4,5 mm nominal diameter were tested. The experiments consist of breaking each of the 25 balls individually in different conditions. The first group was broken without ultrasonic activation, the second group was broken with an applied ultrasonic power of 35 W, and the last one with an applied ultrasonic power of 70 W.

Fig. 2 shows the experimental results of single ball breakage tests.

The result of tests under static conditions show a mean breakage force of 11.8×10^6 N/kg with standard deviation of 3.3×10^6 (28.2%), whereas the test with ultrasound shows a mean breakage force of 4.8×10^6 N/kg with a standard deviation 1.4×10^6 (29.1%). The relative dispersion is the same for both samples, but the breakage force under ultrasonic vibration is only 40% of the static mean breakage force.

These results suggest that an ultrasonic field reduces the force needed to begin breakage. The main weakness of the high-pressure roll mills is precisely a very high stress imposed on the rolls, which promote rapid wear of their surface

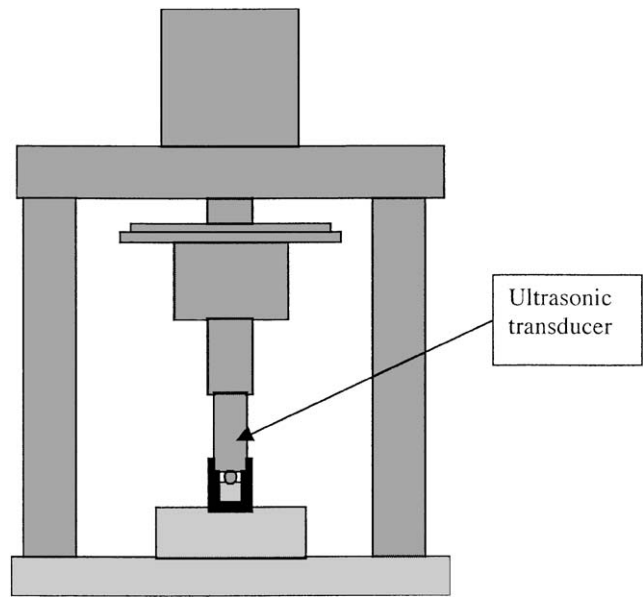


Fig. 1. Diagram of the uniaxial press used for single ball breakage experiments.

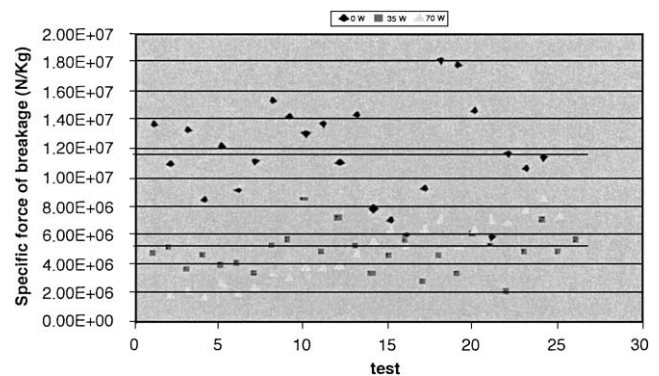


Fig. 2. Influence of ultrasound on the breaking force in single ball breakage experiments.

and some times even fracture. A vibrating roll could help to reduce this problem by prolonging the useful life of the hard face roll and avoiding, or at least reducing, the risk of fracture. It may also be expected that the additional energy spent on ultrasonic vibration could be compensated by the reduced energy requirements for grinding associated with a lower breakage force.

3. Design of an ultrasonic grinding mill

In order to be efficient, the design of a grinding machine must follow some general principles. An efficient grinding device would involve the direct flow of particles to the breakage zone, slow compression loading of particles, and immediate removal of the broken fragments (Lo et al., 1993). Because comminution is a high energy consuming

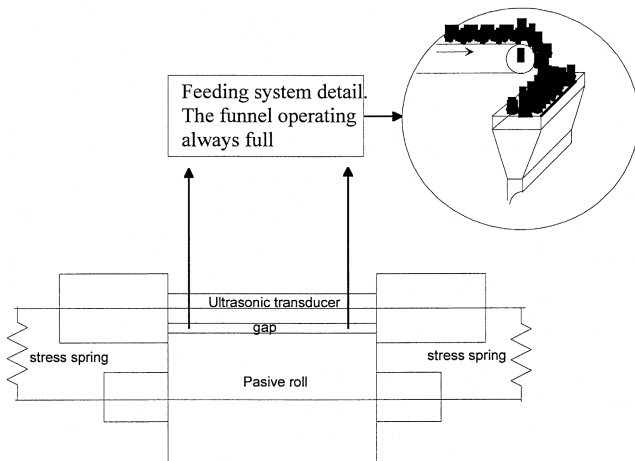


Fig. 3. Schematic view of the ultrasound-assisted roller mill.

process, each stage of the process must be as efficient as possible.

The device that best fulfils the conditions listed above is a high-pressure roll mill which could be redesigned to work under ultrasonic vibration. One requirement for the correct use of ultrasonics is a good coupling between the generator and the grinding material, which is fulfilled by the roller stress. For efficient working, it is necessary that the ultrasonic transducer operate in resonant condition. In other words, it is best that the active parts of an ultrasonic mill oscillate in one of its natural frequencies, and best of all in its first mode which is more efficient for electro-acoustic conversion. It is well known that in this condition the losses in the system decrease and the vibration amplitude is limited only by the internal losses of the system.

To maintain the condition of the free vibration of the roll, that is to say to avoid as far as possible losses other than radiation to the process feed, the system is supported exclusively by its nodal lines. In addition, a special electronic circuit to maintain the frequency in best performance for the whole system was added (Ramos-Fernández, Montoya-Vitini, & Gallego Juárez, 1985). An ultrasonic grinding machine can then be designed in the form of a roller mill constructed over a specially designed ultrasonic transducer, as is shown schematically in Fig. 3.

An active roll, which is itself an ultrasonic transducer, is located in front of a passive roll. The vibration in extensional mode combines compression and shear action of the active roll on the mill feed. The shear of ultrasonic waves are reported to be beneficial to liberation (Revnitvsev et al., 1980). A funnel feeds the material in the gap by gravity. The feed particles are then nipped by the rolls. A spring system furnishes the stress applied to the ore and the stress level can be varied by adjusting the spring tension or by changing the springs. This system also provides a dynamic gap setting, which adjusts automatically with the stress-state of the system. The rotation of the roll is produced by

a variable speed electric motor. The ground ore is collected under the rolls in an iron receiver fed by gravity.

4. Experimental results with the ultrasonic grinding mill

An experimental programme has been performed to assess the real possibilities of the ultrasonic grinding mill. The block diagram of the experimental set-up is shown in Fig. 4. The ultrasonic grinding machine is driven by a 2 HP electric motor coupled with a planetary system that allows the variation of the angular speed. The input power for the drive system was measured with a true power meter. Also the ultrasonic input power was measured at the output of the electronic amplifier.

The experimental system allows in-line measurement of the applied torque, the distance between the two rolls, and the angular speed of the rolls. In each experiment, the process variables are measured and recorded. In addition, particle size analysis of feed and products are made by sieving after sample division by the cone and quartering method.

To eliminate consideration of geometrical factors all experiments are made using the same device. For the reference measurements, the machine is operated as a conventional roller mill by switching off the ultrasonic power. Afterwards, the same test is repeated with the ultrasonic system activated at different levels.

The behaviour of dynamic gap as a function of the applied ultrasonic power is shown in Fig. 5. Because the very nature of the granular material produces large fluctuations in the gap, an average value of different gaps must be taken. It is clear in the figure that two well-defined gap regimes can be distinguished. For less than 100 W of applied power the dynamic gap is approximately 1 mm. Above this value of applied power, the gap value decreases to approximately half of the original. This suggests that in the ultrasonic fracture process there is a threshold for the activation of some special

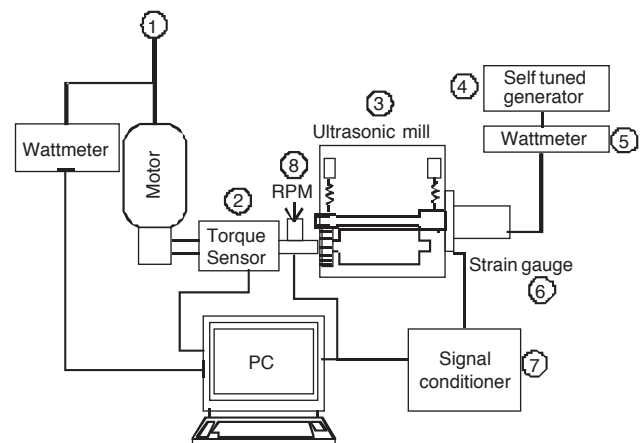


Fig. 4. Experimental grinding machine.

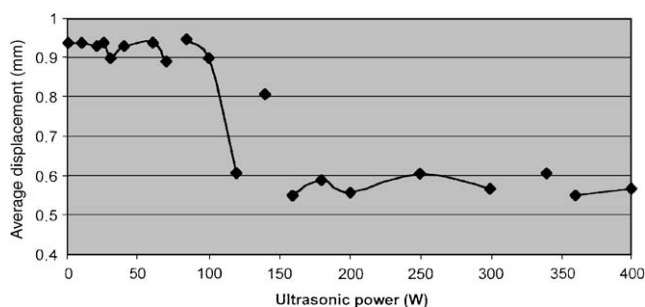


Fig. 5. Behaviour of the dynamic gap as a function of the applied ultrasonic power.

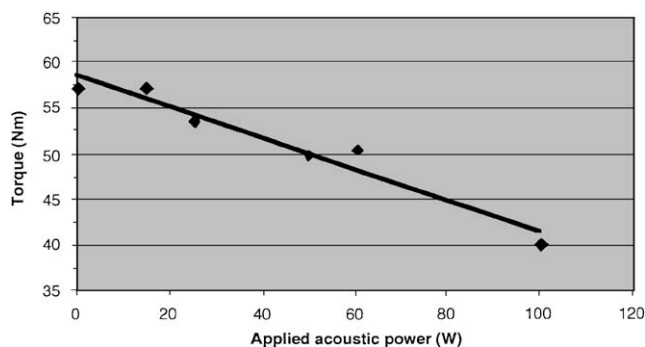


Fig. 6. Example of the influence of the acoustic power on the required torque.

kind of phenomena. The same behaviour was obtained in other experiments for different size feed material.

Although very interesting, this behaviour is out of the scope of this paper and will be considered later in a special research devoted to the basic phenomena of the ultrasonic fracture process.

Fig. 6 shows the curve obtained from a grinding experiment to assess the influence of ultrasonic energy on the total torque in the system. Ore from Minera Pudahuel, Chile were used in these experiments. The machine was operated as a fixed gap machine with a distance between the rolls of 1 mm. The feed is a natural distribution 100%-6# Tyler, that is to say 100% below 3,350 μm .

Fig. 6 clearly shows the drop in torque with the applied ultrasonic power. It should be noted that the flow of material is the same for all ultrasonic power levels. The question now is to assess the energy consumed in the process. That is, is the applied ultrasonic power plus the power used to drive the system lower than the power used for the same grinding task without ultrasonic power? In other words, is the total applied ultrasonic power plus the power used for the system drive lower than the power used to grind the same material to the same degree of fineness with the same machine without ultrasonic power? For the new technology to be successful, it should show improvements in energy efficiency. These improvements can be appreciated in Fig. 7. Here the total energy used in the same grinding task

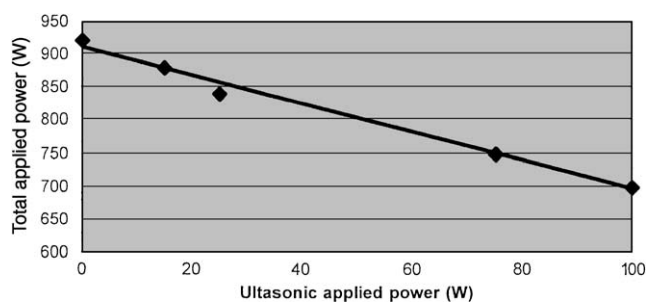


Fig. 7. Example of influence of applied acoustic power on the total required power.

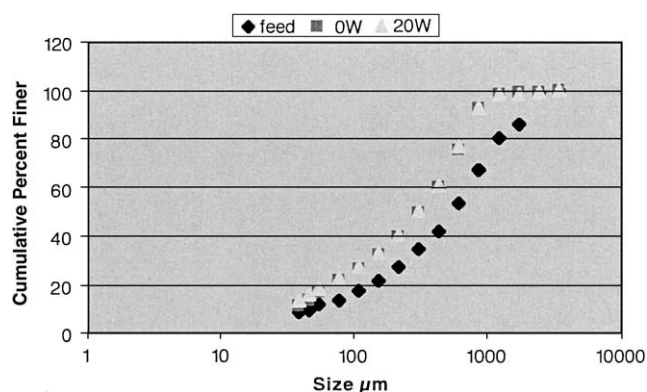


Fig. 8. Influence of ultrasound on the particle size distribution.

is plotted against the applied ultrasonic power. It is clear that the total power requirement for the process is reduced with increasing applied acoustic energy.

A special study was conducted of the particle size distribution obtained with the mill operating with and without ultrasonic energy. For this purpose, ore from the Andina Division of Codelco was ground with the machine operating as a conventional high-pressure roller mill and as an ultrasonic grinding machine. These results are given in Fig. 8 and show that for the same feed, the product particle size is almost the same with and without ultrasound. This is a good result because the whole energy spent in the ultrasonic machine is less for the same product.

There is now some certainty on the processing capacity limits of the machine where the linear velocity is approximately 0.3 m/s, that is, one-third of the limiting velocity of the conventional roll mill. However, our experimental set-up does not allow working beyond 120 rpm because the torque of the motor is not high enough to carry out the experiments with the machine without ultrasound. Operating at 120 rpm, the measured flux shows a processing capacity of 500 kg/h. This figure is very interesting since the machine is a small one, the active part of it can be stored in a 35 cm edge length cube.

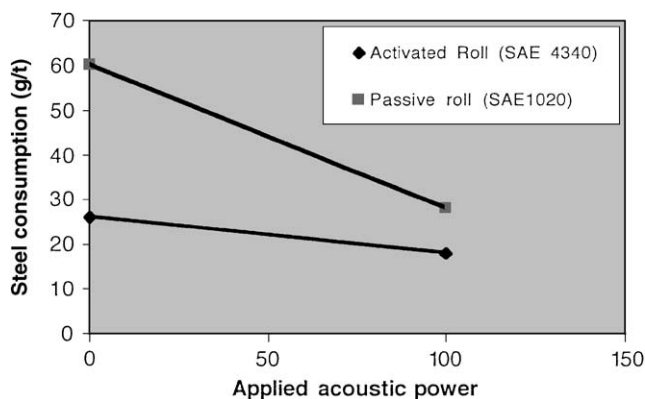


Fig. 9. Abrasive wear tests performed with ore from “Minera Padahuel” 100%-6# Tyler.

5. Wear tests

A special experiment was performed to assess the effect of the ultrasonic field on the response of the grinding surfaces to the abrasive action of the grinding material. However, for a machine made with special SAE 2020 heat-treated hard tool steel, the abrasive effect is negligible over a time scale of 1 h. The experiment, therefore, consists of a new series of grinding tests with the machine fitted with a roll made of a low-resistance steel, without any hardening treatment. Two steels were tested, one was an SAE 1020 structural steel and the other was an SAE 4340 steel. In this way, clear wear signs can be observed after a relatively short time of operation and the influence of the kind of material can be tested. The experiments were planned in such a way that the differences inherent in destructive tests were minimised. A first run was made with the machine ultrasonically activated with an initial input power of 100 W. After 1 h of grinding, the test was continued, keeping the same parameters, but without ultrasonic energy applied to the machine. Afterwards, in a second run, the same experiment was done but starting without ultrasonic energy applied to the machine, and activating the ultrasonic energy after 1 h of grinding and for another hour of grinding. In this way, the only influence that can be noted must be the abrasive effect of the grinding process. Transient phenomena will be masked because both tests, the non-ultrasonically and the ultrasonically activated test will have the same transient stage. Between each experiment, the grinding roll was weighed and the surfaces were examined with an optical microscope. The results of this test are presented in Fig. 9.

From the data collected, it is clear that another beneficial effect of ultrasound is that, in both the passive and active rolls, abrasive wear is less when the grinding is made under ultrasound. Also some differences between the behaviour of different quality of material are detected. The better is the material, the better is the performance even without any treatment to improve the resistance. It is to be noted that each wear tests requires the construction of a machine made

with low-quality material followed by its destruction. For this reason, the wear experiments were done for only two materials. Once the improvement in the wear capabilities of the ultrasonically activated machine were established, this kind of test was abandoned because they are very expensive and time consuming.

6. Conclusions

An ultrasonically assisted roll mill has been developed, in which one of the contact surfaces vibrates at ultrasonic frequency. Grinding tests performed on copper ore show a reduction in the total power required to operate the process when the ultrasonic energy is applied in the active zone.

As is shown in Fig. 8, the same degree of product fineness is obtained with the ultrasonic machine and with a high-pressure roller mill (the machine without ultrasonic activation), but requiring about 6% less energy (see Fig. 7), and with a considerable saving in the grinding medium wear (less steel consumption). This is a very important figure if it is considered that the grinding is the most energy consuming process in a great number of large-scale production processes.

The presence of ultrasonic field brings about a reduction in the shaft torque required compared with the same operation without ultrasonic energy. In addition, the ultrasonic-assisted operation shows less abrasive wear on the grinding surfaces.

These results show that the use of ultrasonic technology is a very promising approach for improving the efficiency of the breakage in different processes. When compared with other approaches in the past, the ultrasonic roll mill does not have the limited process capacity that was characteristic in these developments.

The energy consumption and torque could be even lower than the values we show in this paper. In this research, the power used was that usually employed to evaluate the overall efficiency of a breakage: (Austin, Klimpel, & Luckie, 1984)

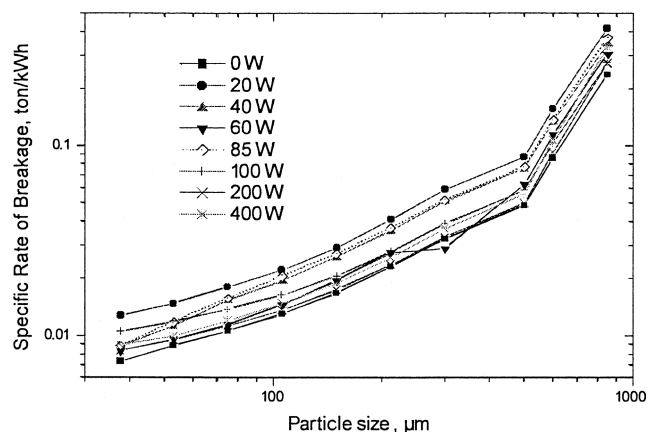


Fig. 10. Copper ore from Andina, CODELCO, Chile. Monosize 1.7 × 1.18 mm sieve feed at the setting gap of 0.2 mm and 120 rpm.

The specific breakage velocity. Curves for this parameter are shown in Fig. 10 which shows that the ultrasonic power, always improves the overall process but that best results are obtained for 20 W of ultrasonic energy. This is the reason why we use this power through all this investigation. Other powers will be considered for different processes in further research, but the data provided in this paper are sufficient to assess the potentiality of this new technology.

The scale up and the optimisation of the process require more basic research in ultrasonic grinding. Further experiments must be done both from the point of view of machine design and of the fracture phenomena.

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