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# The effect of microwave pretreatment on impact breakage of copper ore

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ABSTRACT

It has been shown that very short exposures to a high level of microwave power lead to reductions in ore strength. In this paper, the influence of modulated microwave power on copper ore breakage has been investigated. This approach to power delivery is applied to ascertain whether the strength of porphyry copper ore can be reduced with lower average modulated power levels than using continuous power. Changes in resistance to breakage of the treated and untreated ore were quantified by comparative drop weight tests. Mineralogical investigation for the ore was carried out with the Mineral Liberation Analyser (MLA) for surface identification of minerals and X-ray tomography for volumetric analysis. The comparative drop weight tests showed that material treated for 5 s at 5 kW of modulated power was weaker than untreated material. However, for this particular low grade ore, the degree of breakage which was achieved could be achieved with substantially less mechanical energy. It is possible that by using much higher level of microwave power, better liberation might be achieved than using conventional methods.


## 1. Introduction

Inducing fracture in rocks has always been important in comminution, but achieving fracture along mineral boundaries is even more important. One of the ways to perform this type of fracturing is a thermal shock method caused by microwave heating of ore fragments. It is a way of introducing an intergranular fracture, which is a fracture that follows the grains of the material. In this case, a grain boundary crack is associated with differential stress which is occurring between grains of different mineral phases.

The primary reason is differential volumetric expansion of heterogeneous solids in the process of heating. For the simplified linear case, thermal stress ($\sigma_t$) is defined as:

$$\sigma_t = \alpha \Delta T E \tag{1}$$

where in Eq. (1), $\alpha$ is linear thermal expansion coefficient, $\Delta T$ is temperature difference under heating and $E$ is the Young's modulus, by Didenko et al. (2005). It can be seen that mineral grains, which have a high thermal expansion coefficient and high values of Young's modulus, should induce high stress.

The basic principle in achieving fracture is the ability of microwaves to heat individual phases with a faster heating rate within the matrix of the ore. Heat is generated by molecular friction inside the material lattice of the phases which respond to electromagnetic field oscillation and then transferred by thermal conduction into other surrounding phases.

The degree of interaction of microwaves with a material depends on both the dielectric and the magnetic properties of the medium and these are described in terms of the complex permittivity ($\varepsilon$) and the complex permeability ($\mu$), respectively. For the experiment which this paper describes, the influence of the magnetic properties has not been investigated and only the complex permittivity has been considered (as the material has very low content of ferro-magnetic components).

Earlier work by Kingman et al. (2004) showed promising results in achieving reductions in ore strength using microwave energy. Two particle sizes $-53+45$ and $-37+31$ mm were tested with continuous microwave exposure using power levels from 5 to 15 kW and exposure times up to 1 s. Simulations conducted by Salsman et al. (1996) and Jones et al. (2007) demonstrated that the magnitude of fracture in ores with microwave absorbing phases is increased when the power density is increased and the microwave exposure time is kept to a minimum. Both studies demonstrated that much better effect for achieving breakage will be applying pulsed microwave power.

This paper investigates the influence of modulated microwave power. This approach should induce stress between mineral phases. It has been established by Walkiewicz et al. (1988) that most sulphides, arsenides, sulphosalts, and sulphoroarsenides heat strongly and that they have high heating rates. This is of a great importance because exposure to modulated power carries less energy than continuous exposure. The aim of this experiment is: to use less microwave energy, and still induce necessary thermal stress between mineral species of copper bearing ore and to investigate any changes in the ore strength under impact breakage relative to microwave untreated ore.

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Pulse-width modulation of a signal or power source involves the modulation of its duty cycle, to control the amount of applied microwave power sent to the ore fragments. Many different wave forms can be used for modulation. Most common functions which are used to describe these wave forms are: sine, square, triangle and sawtooth functions.

For the experiment in this paper, a square wave has been used. The pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a square waveform $f(t)$ with a low value $y_{\min}$, a high value $y_{\max}$ and a duty cycle $D$ (see Fig. 1). The duty cycle is the proportion of time during which a component, device, or system is operated. In this case how long the load will be exposed to a high value of power. The average value of the waveform is given by the following equation:

$$\bar{y} = \frac{1}{T}\int_0^T f(t)dt \tag{2}$$

As $f(t)$ is a pulse wave, its value is $y_{\max}$ for $0 < t < D * T$ and $y_{\min}$ for $D * T < t < T$.

In order to calculate average value of the waveform the expression $f(t)$ is integrated over the domain of integration from 0 to $T$ leading to the following equation:

$$y = Dy_{\max} + (1 - D)y_{\min} \tag{3}$$

## 2. Experimental

### 2.1. Equipment

A microwave heater manufactured by Sairem from France was used to expose these samples prepared for drop weight testing (DWT) described by Napier-Munn et al. (1996) to a range of microwave energies. A schematic of the apparatus is shown in Fig. 2.

The apparatus consists of an electromagnetic wave applicator, a power supply and a water-cooled 2.45 GHz magnetron. The applicator included a tube with an internal diameter of 52-mm mounted on the broad face of a WR340 waveguide. The length of the applicators components was chosen to create standing wave and enable positioning one of the modes with maximum of electric field in the middle of the tube. This enabled to expose ore particles to the maximum strength of electric field. The apparatus also included an automatic E–H tuner to match the impedance of the generator to the impedance of the applicator, ensuring a minimum amount of reflected power.

### 2.2. Drop weight testing

In the drop weight test (DWT), a known mass falls through a given height onto a single particle providing an event that allows characterisation of the ore under impact breakage. Although the test is physically simple, it is supported by detailed data analysis. For each drop weight test, five size fractions were tested at three levels of energy inputs. In Table 1 we can see parameters used for standard drop weigh testing and Fig. 3 shows the drop weight testing device.

The standard drop weight test as in Napier-Munn et al. (1996) was modified, because the two upper sizes 63 × 53 and 45 × 37.5 usually used in testing were too large to fit in the applicator tube and should not be properly exposed to the electric field.

Kingman et al. (2004) found that if the recommended energy levels were used, there would not be discrimination between treated and untreated material, despite the appearance of significant visible fracture in the microwave treated samples. Therefore, the energy levels used in this investigation were half of those recommended in the standard method as suggested by Kingman.

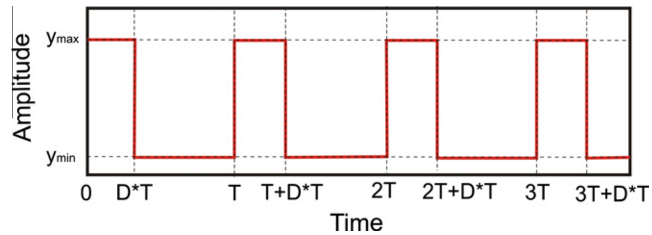


**Fig. 1.** Square waveform function $f(t)$.

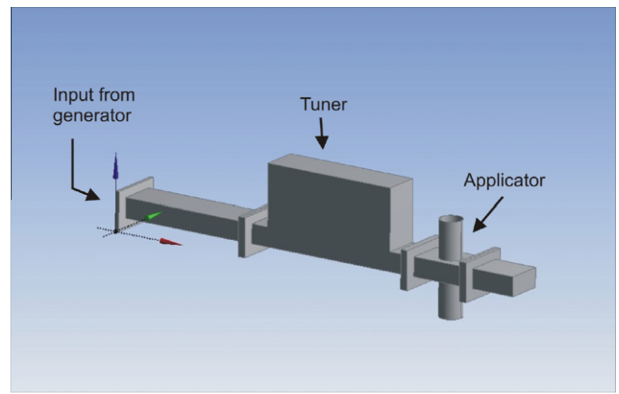


**Fig. 2.** Microwave apparatus used in this experiment.

**Table 1**
Particle sizes, numbers of particles broken per energy level and energies used in standard DWT (after Napier-Munn et al., 1996).

| Particle size (mm) | Number of particles per energy level | Energy 1 (kW h/t) | Energy 2 (kW h/t) | Energy 3 (kW h/t) |
|---|---|---|---|---|
| 63 × 53 | 10 | 0.40 | 0.25 | 0.10 |
| 45 × 37.5 | 15 | 1.0 | 0.25 | 0.10 |
| 31.5 × 26.5 | 30 | 2.5 | 1.0 | 0.25 |
| 22.4 × 19.0 | 30 | 2.5 | 1.0 | 0.25 |
| 19.0 × 16.0 | 30 | 2.5 | 1.0 | 0.25 |

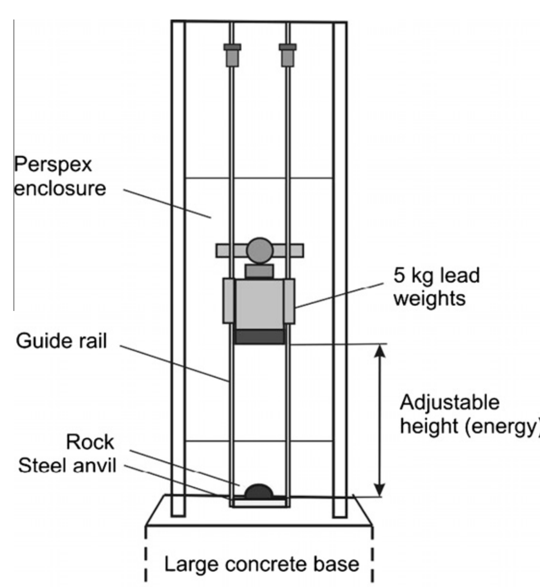


**Fig. 3.** The JKMRC drop weight-testing device (after Napier-Munn et al., 1996).