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TRANSFORMING POWER DRAW TREND OF ORE CRUSHING BY APPLYING MICROWAVE HEATING

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ABSTRACT

Microwave irradiation, as a heating source, has potential applications in mining industry. Microwave irradiation makes physical impacts on brittle rock particles that transform its power draw trend during comminution. This potentially improves the raw material supply. In this research, an instantaneous power draw analysis is applied to detect the microwave heating impact on the particle breakage mechanism during single-roll crushing. Microwave energy is reducing the duration of high resistance zone of crushing trend, which provides shorter crushing time as well as lower crushing energy saving.

Keywords: microwave heating, crushing, power draw, energy, kimberlite ore.

NOMENCLATURE

Abbreviations	
AC	Alternating current
GHz	Gigahertz
kJ	Kilojoule
kW	Kilowatt
kWh/t	Kilowatt-hour/ton
mm	millimeter
s	second
XRD	X-ray diffraction

1. INTRODUCTION

In general, raw materials from mines are sent to mineral processing plants to concentrate target minerals. Mineral processing can be categorized into two operation types: comminution and separation. To have an ideal separation between the target mineral and gangue minerals, it is necessary to first liberate the target mineral from other ones by breaking them, which is called as comminution and consists of crushing and grinding (Wills & Finch, 2016a). Crushing operation highly requires energy consumption and has small energy efficiency (Napier-Munn et al., 1996). Therefore, 10-40% of total production cost in a typical mineral processing plant relates to the crushing operation.

Crushing will reduce the size of run-of-mine ore that usually has coarse size distribution. Crushing can be in single stage or multiple stage, depending on ore characteristics. There are several types of crushers based on its mechanism such as jaw, cone, and roll crushers (Wills & Finch, 2016b). In this research work, breakage mechanism by compressive forces inside a roll crusher applies. Fig. 1 is showing the typical breakage of a brittle ore particle inside the crusher (Jiménez-Herrera et al., 2018).

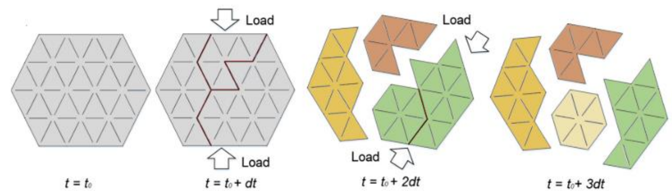

Fig. 1. Typical breakage of a brittle particle inside the crusher (Jiménez-Herrera et al., 2018)

The energy consumption in crushing operation is called as specific energy. It is defined as the amount of energy consumption for one ton of crushed materials (kWh/t). To determine the specific energy, it is necessary to measure the crusher power draw. There are different methods for measuring the power draw that most of them considering the average power draw and not instantaneous power draw (Napier-Munn et al., 1996).

Microwaves are defined as electromagnetic energy, which can react with absorbent materials that known as dielectrics. The microwave irradiation alters the dipoles of a dielectric material, and heating made by stored internal energy (Kingman & Rowson, 1998). The interactions between microwaves and materials can be generalized as dielectric, conductive and magnetic losses. These interactions are the cause for dielectric, Joule and induction heating, respectively (Sun et al., 2016). Microwave irradiation selectively heat the components of a heterogenous material. Thermal shock made by the difference in temperature can physically damage the material and create cracks. For a brittle rock, the crack density made by microwave irradiation is bigger in the boundaries among the mineral grains compared to inside of grains. Some research works and reviews were published about the microwave-assisted crushing (Ali & Bradshaw, 2011; Buttress et al., 2017; Lovás et al., 2011; Somani et al., 2017). However, the understanding on how the microwave-induced cracks affect the crushing of rocks which impact the raw-material production is still lacking.

In this research work microwave-assisted crushing of a kimberlite ore is studied by a single-roll crusher at lab scale. The instantaneous power draw data is applied to verify how the microwave heating transforms the particle breakage for the single-roll crusher.

2. MATERIAL AND METHODS

2.1 Materials

The material used in this research is kimberlite rock which is a primary source of natural diamond. The rock samples were delivered to McGill University's Geomechanics Laboratory from the Gahcho Kué Mine, Northwest Territories, Canada. Based on XRD results, the samples contained few amounts of magnetite which is a good microwave absorbance, while majority is silica-based minerals which are poor microwave absorbance. The rock samples were jaw crushed and screened. After the samples were mixed and homogenized, representative 500-gram individual samples were prepared with the same particle size distribution of the bulk sample, which is smaller than 31 mm but larger than 16 mm. Sample's weight variability of each size fractions and in total were less than 5% to increase reproducibility.

2.2 Methods

The whole experimental work was done at Geomechanics Laboratory of McGill University. The work divided into two steps: microwave test and crushing test. The microwave used in this work is a 15-kW industrial microwave with single mode cavity, operating at 2.45 GHz. For each test, the rock sample is placed 6 cm under the microwave antenna on a non-microwave absorbing plate. The microwave power was varied between 5 to 15 kW to observe the impact of microwave power density on crack generation. The microwave energy input is adjusted indirectly through setting up the exposure time of the microwave. Thirteen samples were not treated by microwave to be used as reference ("untreated" samples).

All the treated and untreated samples were individually crushed in a lab-scale single-roll crusher. The crusher has 110 voltage configurations, installed in parallel with a digital 100-Ampere power-meter logger with AC split core transformer for power draw reading.

The crushing sequence started when the whole 500-g sample was fed from the top of the crusher directly into the crushing chamber as illustrated in Fig. 2. The particles were crushed by the rotating roll, preferably starts from the largest size and hardest ones down, broken into smaller and smaller fractions while keep being subjected to compression force until the particles are small enough to pass the discharge gap, which was determined by the shorter gap size between the roll and the static plate (6 mm).

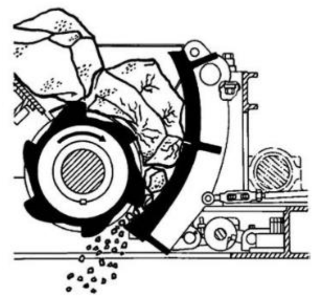

Fig. 2. Cross-sectional view inside a single-roll crusher (Wills & Finch, 2016b)

To measure the power draw, the reading on the power-meter was recorded in a thirty frame-per-seconds video during the whole sequence of crushing test. The power draw of the crusher under no-load condition was measured in the beginning of each crushing test for multiple times prior to sample feeding to get the baseline average of power draw. The second-by-second instantaneous power data collected in the video was then extracted to a spreadsheet to be processed. The instantaneous net power draw is calculated by:

$$P_{net,i} = P_i - P_{UL} \quad \text{(Eq. 1)}$$

where $P_{net,i}$ is the instantaneous net power at crushing time *i* second, P_i is the instantaneous power at time *i* second (from measurement), and P_{UL} is the average unloaded power when crushing runs in empty condition before feeding, all in the unit of Watts. The $P_{net,i}$ was then plotted against time for analysis of power draw trends. The average numbers from multiple samples of the same condition (microwave-treated or untreated) were taken.

3. RESULTS AND DISCUSSIONS

3.1 Power Draw Trend Zones of Untreated Samples

The power trend can be defined into three different zones which physically correspond to specific phase of breakage of samples in a batch system. The three zones are the particle accumulation zone, resistance zone, and gradual reduction zone as illustrated in Fig. 3.

Particle accumulation zone (blue) is when rock particles just entered the crushing chamber at the early phase of the crushing sequence (at the first four seconds). Particles with varied sizes rearrange themselves randomly under the increasing compression force between the roller and the static plate until they interlock each other, thus rapidly increasing the resistance of crushing. This happened in noticeably short duration in the first three seconds.

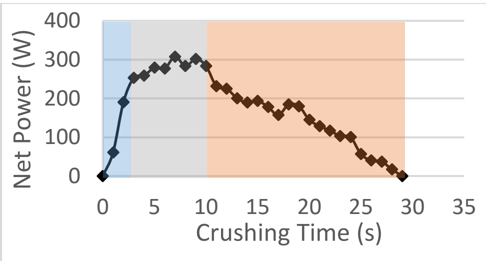

Fig. 3. Crushing power draw of untreated samples

The resistance zone (gray) signifies the range of maximum net power draw. A higher net power duration indicates a harder properties of rock samples, particularly the largest particles since they are preferentially subjected to the force first. A longer resistance zone time also indicates longer residence time of the samples as the smallest size particle generated from breakage has not leave the crushing chamber.

The gradual declining zone (orange) is when the progenies particle smaller than 6 mm starts leaving the system while the rest of bigger size particles still provide resistance against the crushing act. The gradient of the declination of this zone determines characteristic of breakage stages of particles. Flatter declining gradient indicates resistance from intermediate sizes is more prevalent than the production rate of particle smaller than 6 mm.

3.2 Comparisons between Untreated and Microwave-treated Sample

The effect of microwave power level on crushing power trends is given by Fig. 4 for long microwave exposure time (equals 250 kJ microwave energy input) and Fig. 5 for short microwave exposure time (equals 20 to 30 kJ microwave energy input). All three microwave power shows transformation on the zone structures of the typical untreated sample.

1) It shortens the accumulation zone. The microwave-induced cracks on the large particles are contributing to faster particle interlocking. That is because cracks inside the bigger particles can be easily broken early in crushing sequence during the accumulation zone.

2) Duration of resistance zone is shorter too. This indicates the microwave treatment has lowered the strength of the biggest particles which are crushed first after particles interlock each other.

3) It changes the declining zones. For longer microwave exposure (Fig. 4), the decline rates are divided into two: they decline sharply in the first five to six seconds, then decline slowly afterwards. This could be happened because at longer microwave exposure the excessive heating might have transformed mineral phases or melted them. These might increase the hardness of the progenies from the bigger particles broken in the accumulation and resistance zone. There is no notable difference between samples after irradiated by three different microwave power levels at longer exposure time.

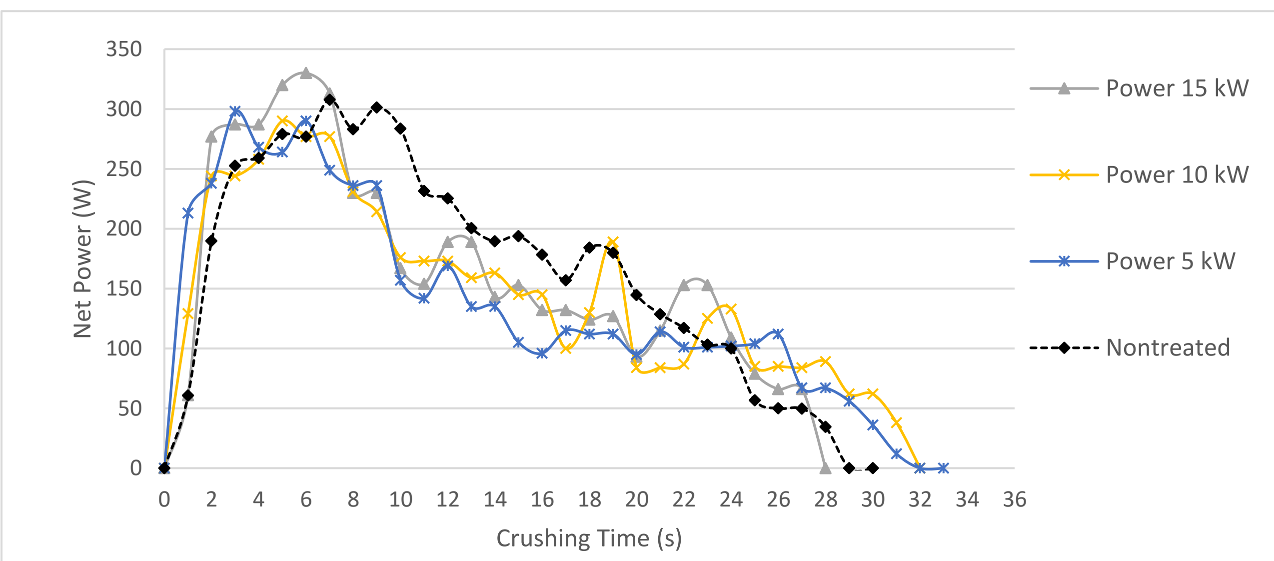

Fig. 4. Crushing power draws of samples microwaved at different power levels (long microwave time)

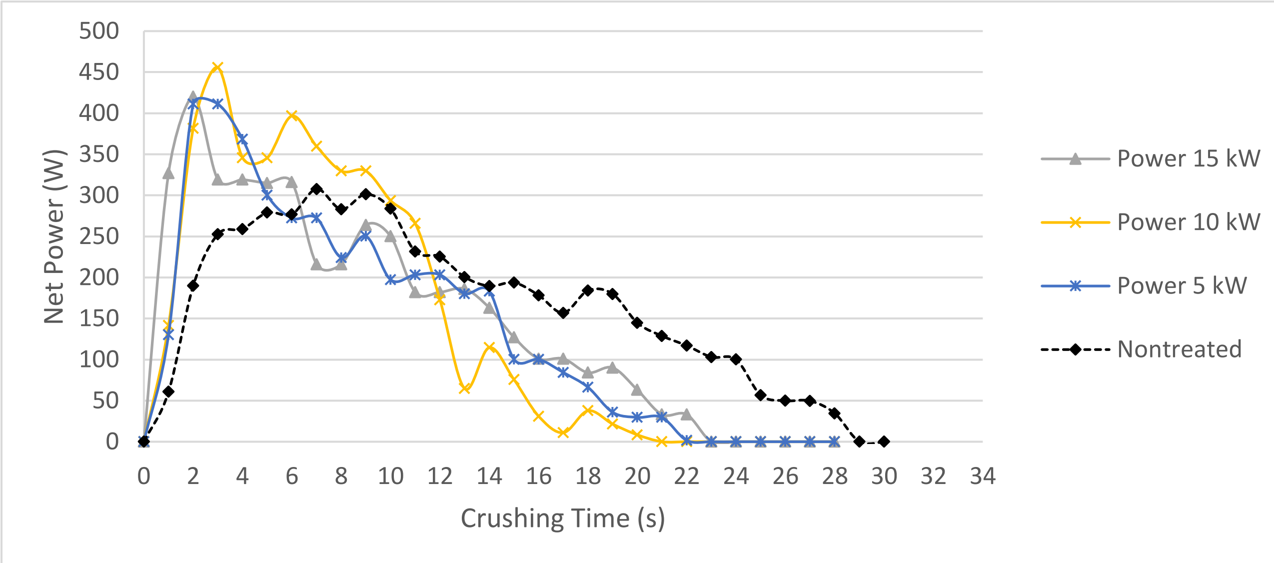

Fig. 5. Crushing power draws of samples microwaved at different power levels (short microwave time)

4) For short microwave exposure Fig. 5, the declining rates are significantly higher, thus ending the crushing faster for all power levels. These suggest the impact of microwave in reducing the overall strength of particles. However, the magnitude of net power of the resistance zone is surprisingly higher than the untreated samples. The nature of this is still under investigation.

3.3 Implications on Specific Crushing Energy

The power draw trends discussed before is undeniably affecting the energy being consumed by the crusher (E_C). It is the net crushing energy being consumed to crush the sample is the area under the power versus time curves. It can be calculated using integration of instantaneous net power ($P_{net,i}$) over the time (Δt_i) until the crusher coming back to the original unloaded condition (the net power coming back to zero at *n* seconds). These can be expressed as:

$$E_C\ [kW.h] = \sum_{i=1}^{n} [(\frac{P_{i-1} + P_i}{2})(t_i - t_{i-1}) - P_{NL}(t_i - t_{i-1})$$

(Eq.2)

The specific crushing energy (E_{CS}), therefore can be calculated as follows:

$$E_{CS}\left[{kW.h}/{tonne}\right] = \frac{E_C[kW.h]}{m[gram]} x \frac{10^6\ [gram]}{[ton]}$$

(Eq.3)

Using those calculations on the power draw data, the E_{CS} results for those sample is summarized in Table 1.

Table 1. Summarized specific crushing energy

MW treatment	E_{CS} (kWh/t)	E_{CS} decrease (%)
Untreated	2.778	-
Power 5 kW – prolonged exposure	2.588	6.9
Power 10 kW – prolonged exposure	2.679	3.6
Power 15 kW – prolonged exposure	2.605	6.3
Power 5 kW – short exposure	2.406	13.4
Power 10 kW – short exposure	2.298	17.3
Power 15 kW – short exposure	2.272	18.2

The specific crushing energy of microwave treated samples are reduced by 3-7% for prolonged exposure samples and 13-18% for short exposure time. This energy savings results are in line with the results from previous studies on microwave-assisted crushing (Ali & Bradshaw, 2011; Buttress et al., 2017; Hassani et al., 2020; Lovás et al., 2011; Somani et al., 2017). These savings are attributed to the existence of microwave-induced cracks generated by microwave treatment.

4. CONCLUSION

In this research work first the power draw trend of the single-roll crusher is classified into three zones, which each zone is representative for specific breakage mode during crushing. This is an innovative approach for better understanding about the breakage mechanism by using the instantaneous power draw data. Also, the power trend data for treated sample is showing that microwave heating is positively reducing the duration of high resistance zone which means the material is crushed with smaller specific crushing energy (ECS) at shorter time (up to 18% reduction in ECS). This physical impact by microwave can be explained by making cracks inside the brittle particle, which significantly reduce the duration of high resistance zone. This will potentially increase the throughput rate of the process. Also, the calculated specific energy using the power draw data are showing crushing energy saving at lower microwave exposure time.

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