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Investigating the Efficiency of Microwave Treatment in Mine-to-Mill Operations: An Energy-Based Analysis

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ABSTRACT

Mining is one of the most energy-intensive industries, accounting for almost 10 percent of worldwide energy consumption. This study investigates microwave treatment as a rock pre-conditioning method to improve energy efficiency in mine-to-mill operations. A novel energy-based data analysis is used to evaluate the application of the method, considering the input microwave energy and its corresponding effect on the mining processes. The results show that microwave treatment provides advantageous outcomes such as reducing the strength of rocks, specific crushing energy, field penetration index, and increasing cutter life cycle. The energy-based analysis emphasizes the significance of optimizing microwave power and exposure time as major design criteria. The results show that applying microwave energy can influence multiple mine-to-mill operations simultaneously, which exponentially improves the efficiency of the method. This understanding showcases the potential of microwave treatment in field applications, leading to more energy efficient and sustainable mining.

Keywords: microwave treatment, mine-to-mill operations, energy efficiency, sustainable mining

NONMENCLATURE

Abbreviations	
UCS	Uniaxial Compressive Strength
ECS	Specific Crushing Energy
CLP	Cutter Life Parameter
FPI	Field Penetration Index
TEP	Treatment Efficiency Parameter
VHN	Vickers Hardness Number
RQD	Rock Quality Designation
Symbols	
P	Power
t	Exposure Time
M	Mass
E_M	Input Microwave Energy

1. INTRODUCTION

Mining is among the top energy-consuming industries, demanding around 10% of the worldwide energy consumption. As a result of the global environmental movement, new innovative methods are introduced in different mining operations to improve energy efficiency and achieve lower carbon emissions. Currently, the mining sector has committed to pursuing more environmentally friendly practices, necessitating the adoption of a diverse array of energy-efficient procedures [1]. The energy used in mining is consumed in different mine-to-mill operations such as fragmentation, excavation, comminution, and separation, some of which are highly energy intensive [2]. For instance, Klein et al. showed that the energy efficiency of traditional methods for reducing particle size can be as low as 0.1%. Therefore, researchers have been investigating novel technologies to improve the energy efficiency of mining operations, one of the most important of which is microwave treatment [3].

The significance of microwave treatment in the mining industry is due to the variation of minerals within the rocks. Minerals can absorb or reflect microwave irradiation, the former of which can be observed in the form of heating in the material. Based on the thermal expansion, the heated minerals expand and apply stress to their surroundings, eventually damaging the rock. The damages in the form of cracks and fractures can facilitate different mining operations [4].

Over the past two decades, many studies have evaluated the effect of microwave treatment in different mine-to-mill operations. Their results showed that microwave treatment could benefit the mining industry in different processes, such as reducing the UCS of rocks [5] and improving mineral recovery and work index [6]. The main drawback of these studies is their focus on the

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outcome of the microwave treatment without considering the input microwave energy, which is a of microwave treatment on mode I fracture toughness for Basalt. They showed that increasing the microwave exposure time at constant power can reduce the fracture toughness value. However, if the input microwave energy is taken into account in the data analysis, the reduction in the fracture toughness value as a result of microwave treatment is the most efficient at the shortest exposure time. Furthermore, to evaluate the efficiency of microwave treatment, studies focused on only one of the mining operations and neglected the subsequent side effects in their analysis. For instance, reducing the strength of rocks before the excavation not only increases the cutter life cycle but also provides materials with more cracks for subsequent operations (e.g., crushing and liberation), which has the potential to exponentially increase the efficiency of the microwave treatment. This research addresses the knowledge gap in this field by investigating how implementing microwave treatment in one of the mine-to-mill sections can affect its subsequent and sidelong processes. The results are gathered using a novel energy-based analysis to provide feedback on the efficiency of the methodology for potential field applications.

2. METHODOLOGY

2.1 Materials

Basalt and Kimberlite rocks are used in this study to evaluate the effect of microwave treatment on rock characteristics. The samples are cut, ground, and crushed in different shapes and sizes for different experiments (e.g., cylinders for UCS and particle-sized for crushing experiments).

determinative factor in evaluating the efficiency of the method. For example, Deyab et al. [7] studied the effect

The prepared samples are treated with microwave irradiation using an industrial microwave system with a frequency of 2.45 GHz. A power control system embedded in the equipment makes it possible to change the applied microwave power from 0 up to 15 kW. The samples are treated with different powers and exposure times to investigate the effect of power density and energy dosage. For each experiment, the total input energy can be calculated as follows:

$$E_M = P \times t \tag{1}$$

2.3 Evaluation criteria

Various interconnected parameters are chosen to evaluate the effect of microwave treatment on the characteristics of the rocks. First, UCS is used as a criterion to assess the strength of rocks, which can be measured using cylindrical shaped samples [8]. Furthermore, using empirical relationships that are derived based on experimental and field investigations, an estimate of the cutter life cycle and FPI during excavation can be provided as follows [9,10]:

$$CLP = -756.0 \ln\left(VHN\left(\frac{UCS}{100}\right)\right) + 5605.6 \tag{2}$$

$$FPI = e^{(0.008UCS + 0.015RQD + 1.384)} \tag{3}$$

CLP represents the volume of the rock that can be excavated before a cutter replacement is needed. Equations (2) and (3) have been shown to predict CLP and FPI with reliable accuracy, depicting a regression

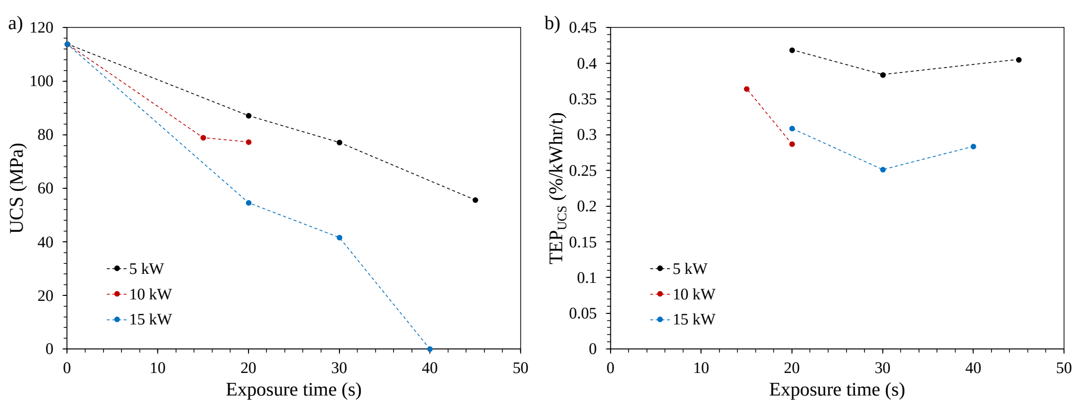

Fig. 1 Effect of microwave treatment on the UCS of Kimberlite at different powers and exposure times based on a) traditional approach and b) energy-based approach.

2.2 Microwave treatment

coefficient of 0.810 and 0.785, respectively [9,10].

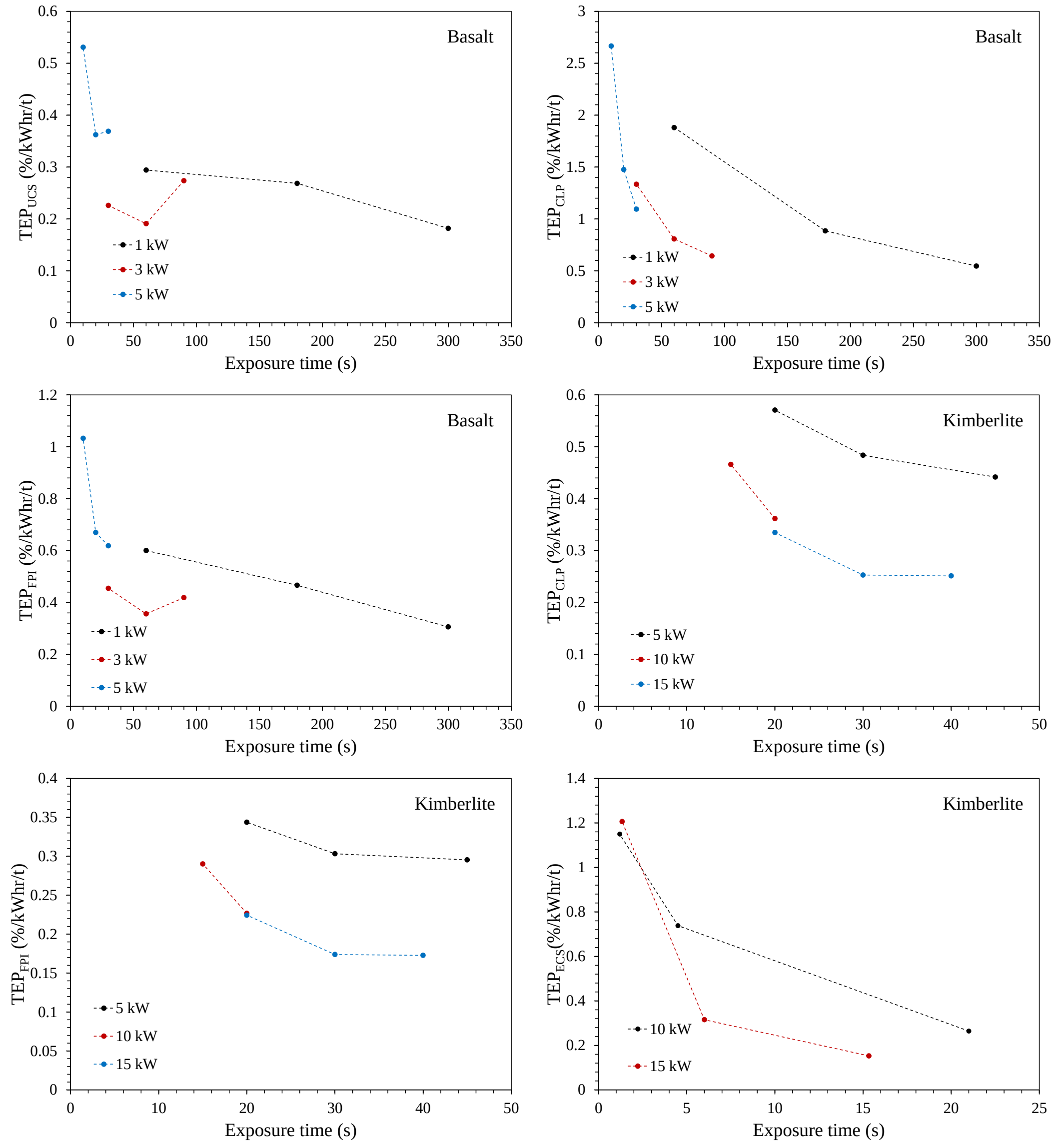

Fig. 2 Effect of microwave treatment on UCS, CLP, FPI and specific crushing energy for Basalt and Kimberlite rocks and different powers and exposure times.

One of the essential parts of the mining industry is comminution. Since rock crushing is one of the most energy-intensive parts of comminution, ECS is used as a representative to evaluate the effectiveness of microwave treatment on the comminution aspect of mining. This parameter is calculated based on the required energy to crush a certain sample mass using a roller crusher and is reported in energy per mass.

2.4 Energy efficiency analysis

An energy-based approach is used for evaluating the efficiency of microwave treatment. In this approach, the analysis of any changes to the parameters introduced in 2.3 is investigated considering the input microwave energy. This evaluation is based on the percentage of change achieved through microwave treatment for each parameter per input energy in a certain mass as follows:

$$\mathrm{TEP}_X = \frac{\Delta(X)/X_{initial} \times 100}{\mathrm{E}_M/mass} \tag{4}$$

Where X can be any of the parameters introduced in 2.3.

3. RESULTS AND DISCUSSION

Available raw data in the literature are used to investigate the effect of microwave treatment according to energy-based analysis, including UCS of Basalt in Lu et al. [5], UCS of Kimberlite in Deyab et al. [11], and ECS of Kimberlite in Rasyid et al. [4]. First, a comparison is made between the traditional and the novel energy-based approaches. Figure 1.a shows that the UCS of the samples decreases when the exposure time increases. The decrease of UCS with exposure time occurs with a higher intensity for higher microwave powers. Moreover, using the energy-based analysis in Figure 1.b shows that increasing the exposure time in some cases can decrease the efficiency of microwave treatment.

Figure 2 shows the results for the TEP at different microwave powers and exposure times for the four evaluation criteria. The results show that in many cases, such as CLP or FPI for Kimberlite samples, increasing the exposure time decreases the efficiency of the microwave treatment. For some charts, such as the FPI of Basalt, the trend is irregular, which can be related to the heterogeneous nature of the rocks and inconsistency in microwave treatment.

The results shown in Figure 2 depict that microwave energy reduces the UCS of rocks, which can be as high as 0.5 %/kWhr/t. This value might not significantly influence the energy efficiency in the mining industry. However, the results show that a reduction in UCS can substantially improve the CLP, FPI, and ECS. In other words, applying microwave energy in one of the mine-to-mill operations leads to a combination of multiple effects on the rocks that can exponentially increase the efficiency of microwave treatment in mining on a more global scale and make it an applicable method for field investigations.

4. CONCLUSIONS

This research studied the microwave treatment as a rock pre-conditioning method with a novel approach based on energy efficiency analysis. The results showed that, unlike the general perception, increasing the microwave energy dosages does not always provide more efficient treatment, which makes optimizing the power and exposure time a critical design consideration. Furthermore, analyzing different mine-to-mill operations showed that since these operations are very intertwined, using microwave energy in one of them can affect the others, leading to an exponential increase in the energy efficiency of the method. These achievements emphasize the importance of energy-based analysis and how microwave treatment can be a promising tool for a more efficient and sustainable mining in the future.

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