The influence of microwave treatment on the Cerchar abrasivity of igneous rocks

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ABSTRACT: This study investigates the effect of microwave treatment on the Cerchar abrasivity index (CAI) of igneous rocks such as granite, syenite, and gabbro. First the mineral contents and percentages of each rock were determined. Then, microwave treatment was applied on the specimens broken in the indirect tensile strength for 180s at the microwave powers of 2 kW and 6 kW. The evaluation of the test results shows that the CAI values of the specimens decrease with increasing microwave power. The CAI losses increase generally with the increasing surface temperature and the microwave power depending on the mineral contents. Concluding remark is that microwave treatment decreases the CAI values of igneous rocks. However, further study should be carried out to determine the CAI loss for different rock types at different exposure times and microwave powers.

Keywords: Cerchar abrasivity, Igneous rocks, Microwave treatment, Mineral contents.

1 INTRODUCTION

The abrasivity may highly affect the cost and schedule of the projects performed in abrasive rock mass. If the rock is abrasive, the replacement of tools causes considerable downtimes in addition to the high cost due to the cutting tool wear. Therefore, the understanding of wear mechanism of cutting tools and various machine components is important for the planning and cost estimation of excavation projects.

Some researchers have investigated the effects of microwave treatment on the mechanical properties of rocks for possible application in the microwave assisted rock excavation to increase advance rate and decrease tool wear (Satish 2005, Satish et al. 2006, Motlagh 2009, Peinsitt et al. 2010, Nejati et al. 2012, Motlagh 2015, Hassani et al. 2016, Lu et al., 2017, Zheng et al. 2017). However, only one researcher (Motlagh 2009) has investigated the effect of microwave treatment of the abrasivity of rocks. He exposed different hard rocks to microwave illumination at a power level of 800-3000W for the durations ranging from 0 to 240s, and showed that Cerchar abrasivity index (CAI) of almost all tested samples showed a reduction of up to 30% depending on the applied microwave power and exposure duration.

CAI test is widely used in the mechanized rock excavation projects. It is useful estimating cutter consumption and total cutter cost. Additionally, it is helpful for analyzing the wear characteristics of different machine parts, such the screw conveyor of TBMs.

This study investigates the effects of microwave radiation on the CAI of nine different igneous rocks such as granite, syenite, and gabbro. The microwave treatment was applied on the samples broken in the indirect tensile strength for 180s at the microwave powers of 2kW and 6kW.

2 SAMPLING

Six granites, two syenites and one gabbro types were selected for testing in this study. The types and locations of the samples are given in Table 1. The selected granite and syenite types have different mineralogical constitutes and grain sizes.

The NQ (47.6mm) size disc specimens with the thickness of 25-30mm were prepared for the laboratory tests. In order to create the rough surfaces for the CAI tests, 30 disc specimens were cracked by indirect tensile method and 60 semi-disc specimens were obtained. After the preparation, the specimens were allowed to dry in the laboratory for a week.

Table 1. The rock types used in the tests.

Rock code	Rock type	Location
1	Granite (Rosa Well)	Spain
2	Granite (Rosa Minho)	Spain
3	Granite (Steppe Yellow)	Egypt
4	Granite (Nublado)	Spain
5	Granite (Kaman Rosa)	Türkiye
6	Granite(Kozak Granit)	Türkiye
7	Siyenite (Volga Blue)	Ukraine
8	Siyenite (Jungle Green)	Egypt
9	Gabbro (Nero Turka)	Türkiye

3 MINERALOGY

Thin sections were prepared from each rock type to determine the mineral types and percentages under the polarizing microscope. For the rock types with coarse grain size, two thin sections were prepared, and the counted mineral percentages were averaged.

Table 2 presents the mineral types and percentages of the tested rock types. Granitic rocks are composed of quartz, orthoclase, plagioclase and biotite minerals in different amounts. In some granite samples, microcline (Rosa Well, Rosa Minho, Nublado), muscovite (Nublado, Steppe Yellow), amphibole (Steppe Yellow), and pyroxene (Rosa Well, Steppe Yellow) minerals accompany the main mineral composition together with sericite (Rosa Well, Rosa Minho, Nublado), and chlorite (Rosa Well, Rosa Minho, Steppe Yellow) minerals as the secondary alteration products. In granite (Kozak granit) sample, plagioclase, orthoclase, biotite, amphibole and quartz main mineral composition is accompanied by chlorite minerals as alteration product. In syenitic rocks (Volga Blue, Jungle Green), orthoclase, plagioclase, biotite, and pyroxene minerals form the main mineral composition. In addition to these, Synite (Jungle Green) sample contains nepheline, which belongs to feldspathoid group, tourmaline, and granat minerals. Syenitic rocks contain sericite, hydrobiotite, and chlorite as alteration products. Gabbro (Nero Turka) sample is composed of pyroxene, plagioclase, orthoclase, biotite, amphibole, and alteration minerals such as chlorite and epidote.

Table 2. The mineral contents and the percentages of the specimens.

Mineral type	Rock codes and mineral contents (%)								
	1	2	3	4	5	6	7	8	9
Quartz	15	27	23	19	28	12	-	-	-
Orthoclase	45	26	36	28	41	25	70	35	13
Plagioclase	11	12	18	15	18	32	-	8	27
Microcline	4	3	-	15	-	-	-	-	-
Biotite	9	12	8	11	9	16	12	8	7
Hydrobiotie	5	-	-	-	-	-	3	-	-
Muscovite	-	-	-	8	-	-	-	-	-
Amphibole	-	-	3	-	-	13	-	-	4
Sericite	4	9	-	4	-	-	4	3	-
Chlorite	4	8	2	-	4	2	-	2	4
Titanite	2	-	-	-	-	-	-	-	-
Pyroxene	1	-	4	-	-	-	6	-	42
Epidote	-	3	4	-	-	-	-	-	3
Nepheline	-	-	-	-	-	-	-	32	-
Tourmaline	-	-	-	-	-	-	-	6	-
Garnet	-	-	-	-	-	-	-	6	-
Calcite	-	-	2	-	-	-	-	-	-
Pyrite	-	-	-	-	-	-	3	-	-
Magnetite	-	-	-	-	-	-	2	-	-

4 EXPERIMENTAL STUDIES

An industrial microwave oven with 6kW maximum power output at 2.45GHz was used for the irradiation of the specimens. The specimens were exposed to microwaves at 2kW and 6kW powers for the duration of 180s. The surface temperature of the specimens was measured with an infrared gun before and immediately after the irradiation. At least three specimens were tested for each case and the results were averaged.

The Cerchar abrasivity index (CAI) tests were performed using the West type apparatus (Figure 1) by scratching pins of HRC 54-56 loaded with 70N over a distance of 10mm. The tests were carried out on the rough surfaces of broken samples in the indirect tensile strength tests (Figure 2). The tests were repeated at least five times for each case. CAI experiments were carried out on samples that were and were not exposed to the microwave energy.

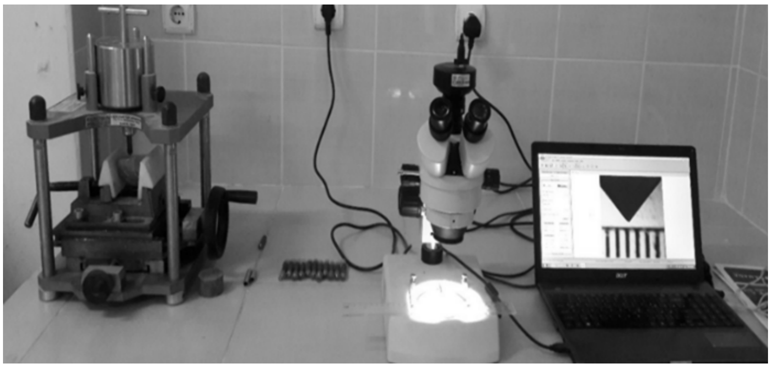

Figure 1. The CAI testing system.

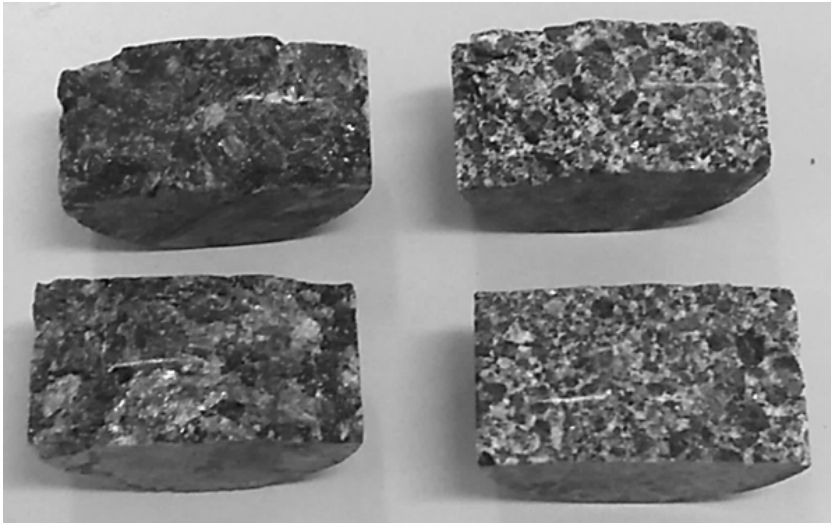

Figure 2. Some samples after the CAI test (Left: Siyenite/Volga Blue, Right: Gabbro/Nero Turka).

5 RESULTS AND DISCUSSION

5.1 Evaluating the surface temperatures of the treated samples

Table 3 lists the average surface temperatures of the specimens before and after the microwave treatment. It should be noted that the measured temperatures are the surface temperatures. Since microwave heats object internally, the inner temperature is higher than the surface temperature. Hartlieb et al. (2012) stated that while the surface temperature of a basalt sample was 250ºC, the internal temperature was 440ºC. The internal temperatures of the specimens are most probably higher than the measured surface temperatures.

Table 3. The surface temperatures of the specimens before and after the microwave treatment.

Rock code	Temperature before microwave treatment (°C)	Temperature after microwave treatment (°C)	
		For 2 kW	For 6 kW
1	8.0	60.9	169.7
2	9.2	52.9	106.1
3	11.9	81.5	200.8
4	9.8	48.2	122.1
5	10.0	51.1	207.4
6	10.9	86.4	341.7
7	9.1	388.6	928.3
8	8.8	72.5	511.9
9	8.2	353.1	645.1

5.2 Evaluating the CAI values of the treated samples

Table 4 presents the CAI values before and after the microwave treatment, and the CAI losses. The CAI values of the untreated specimens range from 3.4 to 4.5. Compared to the untreated specimens, the CAI values of some treated specimens decreased less (Granite/(Rosa Well, Rock Code #1 and Granite/Kozak Granit, Rock Code #6). However, significant reductions were observed on the CAI values of some other treated specimens (Granite/Nublado, Rock Code #4 and Siyenite/Volga Blue, Rock Code #7).

Table 4. Cerchar abrasivity index (CAI) values before and after the microwave treatment.

Rock code	Average CAI of untreated specimens	Average CAI and CAI loss of treated specimens			
		CAI for 2kW	CAI loss for 2kW (%)	CAI for 6kW	CAI loss for 6kW (%)
1	3.5	3.1	11.4	2.9	17.1
2	4.5	3.0	33.5	2.6	42.5
3	4.5	3.5	23.2	3.0	33.4
4	4.0	2.8	31.1	2.0	49.4
5	4.2	3.6	15.6	3.0	27.9
6	3.6	3.4	4.7	3.2	10.6
7	3.7	2.0	45.7	1.2	66.7
8	4.2	3.5	18.0	2.6	38.8
9	3.4	2.7	18.7	2.3	32.4

In order to make a visual comparison between the CAI losses of the tested rocks, Fig. 3 was plotted. Syenite (Volga Blue, Rock Code #7) has the highest CAI loss. As indicated in Table 3, the average surface temperature of the Volga Blue specimens reached about 900^{o}C at 6kW powers due to the content of metallic minerals such as pyrite and magnetite. This high temperature led to crackings and local meltings on the specimens, and thus weakening the strength of the mineral structure and rock. Therefore, the highest CAI loss was observed in this rock type. Syenite (Jungle Green, Rock Code #8) and gabbro (Nero Turka, Rock Code #9) rocks have also significant the CAI losses due to high surface temperatures caused by the constitutes of microwave absorber minerals.

Among the granite specimens, Rosa Minho (Rock Code #2) and Nublado (Rock Code #4) have high CAI losses. Although the temperatures of these specimens are low compared to the other granite specimens, the CAI losses are high. This is probably due to the fact that the internal temperatures of these specimens are much more than their surface temperatures. As explained above, the interior temperatures of the specimens may be approximately two times of their surface temperatures (Hartlieb et al., 2012).

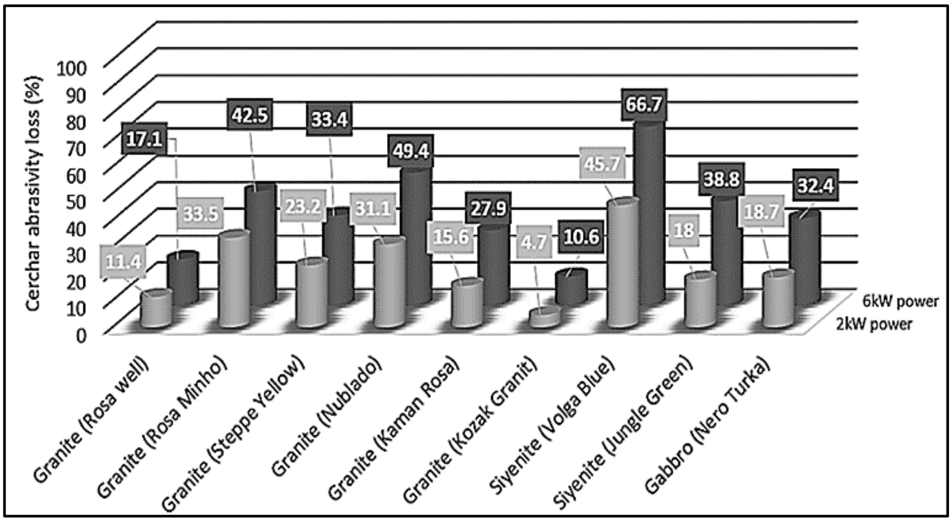

Figure 3. The CAI losses of all tested rocks for 2 and 6kW powers.

Because the applied powers and exposure times are different in this study and the study Motlagh (2009), only a general comparison can be made between the two studies. Motlagh (2009) stated that the CAI of almost all tested samples indicated a decrement of up to 30% as the power level and exposure time increases. In this study, the decrements in the CAI values vary from 10.6% to 66.7% for 6kW power as shown in Table 4 and Figure 3. All CAI losses are greater than 28% except two values. It can be said that there is a general consistency between the two studies.

6 CONCLUSIONS

The effect of microwave energy was investigated on the CAI of igneous rocks. The heating degrees and the CAI losses of the specimens were evaluated by considering the mineralogical contents. The conclusions that can be drawn from the study are:

- The surface temperature of the specimens rises with increasing microwave power.
- The role of the mineral constituents is very important for microwave heating of rocks. The metallic minerals or the minerals with metallic ions cause the specimen to heat rapidly.
- The CAI values of the specimens reduce with increasing microwave power.
- The loss in the CAI of the specimens declines generally with the increasing surface temperature and the applied microwave energy depending on the mineral constituents.

It is concluded that microwave energy reduces the CAI values of igneous rocks depending on the applied power and the mineralogical contents of the specimens. The CAI loss of different rock types should be further investigated by applying at different microwave powers and exposure times. Another research to be carried out is the effect of the internal temperatures on the abrasivity of the specimens.

ACKNOWLEDGEMENTS

This paper was partially prepared from a TUBITAK (The Scientific and Technological Research Council of Turkey) project. The authors thank TUBITAK for the support of the project (Project No. 216M003).

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