ROMANIAN CARBONATE ROCKS CUTTABILITY ASSESSMENT USING LINEAR CUTTING TESTER

Andrei ANDRAȘ^{1*}, Florin Dumitru POPESCU²

¹ University of Petroșani, Petroșani, Romania, andrei.andras@gmail.com

² University of Petroșani, Petroșani, Romania, fpopescu@gmail.com

DOI: 10.2478/minrv-2021-0034

Keywords: microwave, excavation, carbonate rocks, point attack picks, mechanical properties, linear cutting test

Abstract: The paper presents the state-of-the-art on the microwave assisted mechanical rock cutting by presenting actual findings and tendencies in the field in international literature, and the activities performed during the intermediate stage and the results obtained by the team from the University of Petroșani as partner within the ERAMIN-ERANET-MIWACUT research project.

1. Introduction

In general, mechanical excavation, hard rock cutting and drilling and blasting are the most common methods / technologies when it comes to rock mass extraction. Mechanical cutting or excavation is more advantageous as compared to the classic drilling and blasting for a number of reasons: continuous exploitation versus cyclic one, less effect on the surrounding rock mass, better safety and less environmental impact. However, the technical limitation of the mechanical machines in certain geotechnical conditions is the biggest disadvantage. With the scope of overcoming these limitation, as well as production increase, excavation tools wear reduction or replacement of the drill and blast method, there are numerous approaches researched today.

One of these is the use of microwave treatment of the rocks prior to excavation / cutting. Rock absorbs the microwaves thus the electromagnetic energy is converted to heat, which leads to cracks and changes of the rock mass properties. Microwave treatment is proved to decrease the strength of rocks [1-3]. Research on various types of rocks was conducted [4], such as basalt [5], granite [6]. Experimental research as well as numerical approaches on the topic of microwave-induced fracturing of rocks was conducted by scholars worldwide [7-11]

Microwave-assisted mechanical rock cutting is still in laboratory and experimental phases, with the proposed schema as shown in Figures 1 and 2.

Fig.1. Schematic diagram of microwave-assisted mechanical rock cutting [12]

* Corresponding author: Andraș Andrei, assoc.prof. Ph.D. eng., University of Petrosani, Petrosani, Romania, (University of Petrosani, 20 University Street, andrei.andras@gmail.com)

Fig.2. Schematic view of the microwave heating system [13]

2. Experimental work carried out

2.1 Previous work conducted within the project

In the precedent stages of the research, samples of carbonate rocks (Ruschița Marble, Bășchioi and Podeni limestone) were prepared for both UCS and BTS test as well as linear cutting tests both for abroad partners in the project as well as in-house testing at Petroșani. Their mineralogical, petrographic and physical mechanical characteristics were established using standard testing methods in the laboratories of University of Petroșani.

2.2 Test carried out within current stage of the project

In the present stage, linear cutting tests were performed in the laboratory of the University of Petroșani, using rectangular samples from all three locations of sampling. The tests were performed using point attack bits (Figure 3), without microwave assistance, using an in-house force measurement solution developed using 1-D load cells (Figure 4), based on technology presented in [14].

Results from this testing will be compared to test carried out by consortium partners in the project in the next stage, as well as with results of numeric simulation to be carried out.

Fig.3. Point attack bits used

Fig.4. Measurement solution proposed [14]

With this system, samples of marble and limestone were subjected to cuts at different depths of cut, and the tangential, normal and lateral components (F_x , F_y și F_z) of the force were recorded. F_x is the tangential force and is acting in the direction of the pick movement, F_y , is the normal force, acting perpendicular to the cutting plane and F_z , is the lateral force, acting in a direction perpendicular to the first two.

To make an initial estimate of the cutting forces, the Evans [15] model of the tangential cutting force was used, according to the relation:

$$F_t = \frac{16 \cdot \pi \cdot \sigma_{rc}^2 \cdot h_0^2}{\cos(\alpha)^2 \cdot \sigma_{rt}} \quad (1)$$

where:

σ_{rc} is the uniaxial compressive strength, N / m²

σ_{rt} is the splitting tensile strength, by the Brazilian method, N / m²

h_0 is the cutting depth, m

α is the point attack pick angle.

The results obtained for values of cutting depth between 1 mm and 15 mm for the three types of rocks are presented in the Table 1.

Table 1. Cutting test results

h_0 (mm)	F_t (kN)		
	Rușchița Marble	Bășchioii Limestone	Podeni Limestone
1	0.086	0.091	0.024
2	0.342	0.363	0.094
3	0.77	0.816	0.213
4	1.369	1.451	0.378
5	2.14	2.267	0.59
6	3.081	3.264	0.85
7	4.193	4.443	1.157
8	5.477	5.803	1.511
9	6.932	7.344	1.913
10	8.558	9.067	2.361
11	10.355	10.971	2.857
12	12.324	13.057	3.4
13	14.463	15.323	3.99
14	16.774	17.772	4.628
15	19.256	20.401	5.313

The highlighted values in the Table, correspond to the depth of 10 mm (1 cm) and represent the average value of the specific cutting resistance, A , expressed in kN/cm.

Table 2. Specific cutting resistance obtained by regression formulae in [16]

Rock type	σ_{rc}	σ_{rt}	A
	(MPa)	(MPa)	(kN/cm)
Marble Rușchița	86	9.57	9.2
Limestone Bășchioii	77	9.35	8.53
Limestone Podeni	16.3	2.2	3.5

In order to stay under the value of force offered by the LCM ($F_t < 10$ kN), for the samples of Rușchița marble and Bășchioii limestone it was decided to limit the tests to the value h_0 of 1 cm, and for samples of Podeni limestone, to 1.5 cm.

There are empirical coefficients presented in literature for the correlation of the specific resistance A with σ_{rc} and σ_{rt} that are determined based on experimental tests.

Thus, in [16] for similar rocks and values of σ_{rc} and σ_{rt} , the values of 9.2, 8.53, respectively 3.5 kN/cm result for A , as presented in Table 2. The differences are due to the imperfection of the Evans model.

3. Results and discussion

The results of recorded measurements for all samples tested are presented in Figures 5 to 7.

Fig. 5. Recorded measurements F_x , Ruschita marble, $h_0=3\text{mm}$

Fig. 6. Recorded measurements F_x , Bășchioi limestone, $h_0= 3 \text{ mm}$

Fig. 7. Recorded measurements F_x , Podeni limestone, $h_0= 5 \text{ mm}$

The results were further processed statistically to highlight average measured values and the regression line.

Fig. 8. Average values obtained by measurement, and the regression line for Rușchița marble

Fig. 9. Average values obtained by measurement, and the regression line for Bășchioi limestone

Fig. 10. Average values obtained by measurement, and the regression line for Podeni limestone

Based on the data obtained, the average values of specific cutting resistance and specific cutting energy consumption of the three rock types, summarized in the Table 3, were determined.

Table 3. Average values determined

Rock type	Specific cutting resistance (kN/cm)	Specific cutting energy	
		kWh/m ³	J/cm ³
Marble Rușchița	8,499	8,53	30,708
Limestone Bășchioi	7,075	7,788	28,037
Limestone Podeni	3,01	2,771	9,976

4. Conclusions

On the basis of data for three types of rocks under study, using the inhouse built linear cutting system, the average values of cutting resistance and specific energy consumptions were determined.

The results are in line with literature, obtained for similar type of rocks, using similar or slightly different methods of measurement or / and estimation.

These are results of stage two of this research, and will serve as basis for comparison with values obtained by Consortium partners, in their tests, and further interpretation for the development of the microwave assisted linear cutting machine of carbonate rocks.

Acknowledgements

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS/CCCDI - UEFISCDI, project number ERANET-ERAMIN-MIWACUT, within PNCDI III.

References

- [1] **Lu G.M., Li Y.H., Hassani F., Zhang X.W.**, 2016
Review of theoretical and experimental studies on mechanical rock fragmentation using microwave-assisted approach. Chinese Journal of Geotechnical Engineering, 38(8), pp. 1497-1506.
- [2] **Zheng Y.L., Ma Z.J., Zhao X.B., He L.**, 2020
Experimental investigation on the thermal, mechanical and cracking behaviours of three Igneous rocks under microwave treatment. Journal of Rock Mechanics and Rock Engineering.
- [3] **Hassani F., Nekoovaght P.M., Gharib N.**, 2016
The influence of microwave irradiation on rocks for microwave-assisted underground excavation. Journal of Rock Mechanics and Geotechnical Engineering, 8(1), pp. 1-15.
- [4] **Santamarina, J.C. (ed.)**, 1989
Rock excavation with microwaves: a literature review, Evanston, IL (etc.): Publ by ASCE.
- [5] **Hartlieb P., Leindl M., Kuchar F., Antretter T., Moser P.**, 2012
Damage of basalt induced by microwave irradiation. Special Issue - Physical Separation, Minerals Engineering, 31, pp. 82–89.
- [6] **Toifi M., Hartlieb P., Meisels R., Antretter T., Kuchar F.**, 2017
Numerical study of the influence of irradiation parameters on the microwave-induced stresses in granite. Minerals Engineering, 103-104(4), pp. 78-92.
- [7] **Hassani F., Nekoovaght P.M., Radziszewski P., Waters K.E.**, 2011
Microwave assisted mechanical rock breaking. Proceedings of the 12th ISRM International Congress on Rock Mechanics, Beijing: International Society for Rock Mechanics, pp. 2075-2080.
- [8] **Ali A.Y., Bradshaw S.M.**, 2011
Confined particle bed breakage of microwave treated and untreated ores. Minerals Engineering, 24(14), pp. 1625-1630.

[9] **Lu G.M.**, 2018

Experimental study on the microwave fracturing of hard rock. Thesis, Northeastern University.

[10] **Kahraman S., Canpolat A.N., Fener M.**, 2020

The influence of microwave treatment on the compressive and tensile strength of igneous rocks. International Journal of Rock Mechanics and Mining Sciences, 129, 104303.

[11] **Kahraman S., Canpolat A.N., Fener M., Kilic C.O.**, 2020

The assessment of the factors affecting the microwave heating of magmatic rocks. Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 6(4), pp. 1-16.

[12] **Lindroth D.P., Morrell R.J., Blair J.R.**, 1991

Microwave assisted hard rock cutting. US5003144 Patent.

[13] **Lu G., Zhou J.**, 2021

Experimental Investigation on the Effect of Microwave Heating on Rock Cracking and Their Mechanical Properties, Microwave Heating - Electromagnetic Fields Causing Thermal and Non-Thermal Effects. Gennadiy I. Churyumov, IntechOpen, DOI: 10.5772/intechopen.95436. Available from: <https://www.intechopen.com/chapters/75087>

[14] **Kang H., Cho J.W., Park J.Y., Jang J.S., Kim J.H., Kim K.W., Rostami, J., Lee, J.W.** 2016.

A new linear cutting machine for assessing the rock-cutting performance of a pick cutter. International Journal of Rock Mechanics and Mining Sciences, 88, pp. 129–136. DOI:10.1016/j.ijrmms.2016.07.021.

[15] **Evans A.**, 1984

Theory of the cutting force for point attack picks. International Journal of Mining Engineering, 2(1), pp. 63-71.

[16] **Bilgin N., Demircin M.A., Copur H., Balci C., Tuncdemir H., Akcin N.**, 2006

Dominant rock properties affecting the performance of conical picks and the comparison of some experimental and theoretical results, International Journal of Rock Mechanics & Mining Sciences, 43, pp. 139–156.

This article is an open access article distributed under the Creative Commons BY SA 4.0 license. Authors retain all copyrights and agree to the terms of the above-mentioned CC BY SA 4.0 license.