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Investigating the effect of cooling/lubricant fluids on the amperage draw of disc cutting machines for hard rocks

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Abstract

One of the most crucial steps in producing dimension rocks is the rock cutting process, which incurs a high cost. The amperage draw of rock cutting machines is a major cost factor of this production process. Determining the effect of factors, such as the machine's operating configurations, mechanical and physical characteristics of the rock, and type of cooling/lubricant fluid, on the cutting machine's performance can significantly reduce operational costs. This study evaluates the electrical current consumption of a disc cutting machine during the cutting of hard rocks for producing dimension rocks under different operating conditions and using different fluids for cooling/lubrication. For this purpose, a number of cutting tests were performed under different operating conditions (cutting depths of 0.5, 0.7, 1, and 1.3 cm and feed rates of 45, 60, 75, and 90 cm/min) with five cooling/lubrication fluids, including tap water, soap water with a ratio of 1:40 and 1:20, and a commercial cutting power (Abtarash) with a ratio of 30:10 and 15:10. After examining the relationship between operating parameters and the amperage draw of the cutting machine in the presence of five fluids, several linear and nonlinear multivariate statistical models were developed to predict the amperage draw of the cutting machine. The developed models were evaluated using the t-test and F-test statistical methods. The results showed that using the developed models, the amperage draw of the cutting machine can be accurately predicted from the properties of the cooling/lubrication fluid, including viscosity and pH.

Keywords:

dimension rock; disc cutting machine; energy consumption; statistical model; lubricant fluid

1. Introduction

Given the economic and environmental implications of poor energy efficiency and improper technical management of energy consumption in industrial processes, energy consumption evaluation and optimisation is of paramount significance. Achieving this goal requires carefully examining these processes to find solutions for reducing energy consumption and production costs. This also applies to the rock-cutting industry, which employs over sixty thousand people in Iran. Iranian rock mining and processing units need to use advanced technologies and tools to achieve higher production outputs, enhanced quality, and better competitiveness in global markets. This cannot be done without extensive knowledge of the cutting equipment and process and identifying all the influential parameters. Today, rock-cutting discs are commonly applied in factories that produce dimension rocks. Knowing how to use these tools properly and measuring their performance can significantly increase the efficiency of the cutting process and the quality of processed rocks. Over the years, many studies on both industrial and laboratory scales have been done on the energy consumption of rock-cutting machines. In 2011, Mikaeil et al. studied the cutability of carbonate dimension rocks from the perspective of energy consumption using fuzzy AHP, Delphi, and TOPSIS algorithms. In another study, Mikaeil et al. investigated the relationship between the amperage draw of a disc cutting machine and the brittle-

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ness of rock samples (**Mikaeil et al., 2011c**). Ataei et al. studied the cutability of dimension rocks from the energy consumption perspective and the relationship between mechanical rock characteristics and the operational features of the cutting machine (**Ataei, et al., 2012a**). In 2013, Sadegheslam et al. investigated the relationship between rock strength parameters and the amperage draw of the cutting machine during the cutting of dimension rocks using multivariate analyses. The results showed that the machine's amperage draw increases with the rock's strength properties (i.e. the cutting power of diamond bits decreases by increasing grain boundary strength and rock matrix strength). Ultimately, they used the t-tests and F-tests to check the statistical significance of these relationships. The results showed that the amperage draw of the cutting machines can be predicted, with an appropriate level of reliability and a high correlation coefficient, using the rock strength properties (**Sadegheslam et al., 2013**).

In 2015, Yurdacol studied the effect of cutting parameters, including cutting mode, cutting depth, and feed rate, on the cutting machine's power consumption. This study used a semi-hard granite rock for its cutting tests. For this purpose, two rows of disk cutters were used to run the tests in 12 different cutting modes. These tests were conducted using 1200 mm saws with feed rates of 10, 13, 15, and 17 m/min and cutting depths of 3, 6, and 9 mm at a constant peripheral speed of about 35 m/s. The effect of cutting mode, cutting depth, and feed rate on the cutting performance (represented by energy consumption) was then analysed. The results showed that in the forward-cutting mode with cutting depths of 3, 6, and 9 mm, the machine's power consumption increases with increasing feed rate. Power consumption also changed with the change in cutting depth when the feed rate was kept constant. The results showed that power consumption also increases with increasing cutting depth in the back-cutting mode. Finally, after comparing the results of forward-cutting and back-cutting modes, it was concluded that the latter is preferable in terms of power consumption (**Yurdakul, 2015**). In the study conducted by Ariafar and Mikaeil, they investigated whether it is possible to predict the amperage draw of disk cutting machines during cutting dimension rocks with artificial neural networks (**Aryafar and Mikaeil, 2016**). In 2017, Almasi et al. studied the cutability of dimension rocks with diamond cutting wires. In their studies, the amperage draw of the machine, as a parameter affecting the performance of the cutting process, was examined (**Almasi et al., 2017a; Almasi et al., 2017b**). In 2017, Akhiani et al. investigated the efficiency of a diamond cutting machine using the artificial bee colony algorithm. This study aimed to use the algorithm to forecast the efficiency of a circular cutting disc in hard rocks. Through the laboratory experiments, 14 hard rock varieties were cut under various circumstances and the parameters, including the uniaxial compressive strength, Schmiazek factor, Mohs hardness, and Young's modulus, were measured. Based on the results, the artificial bee colony method correctly predicted how well the disc cutting machine would work based on the mechanical parameters of the rock (**Akhyani et al., 2017**).

In another study, Akhiani et al. investigated the impact of brittleness indices on the amperage draw and wear rate of disc cutting machines. They employed simple and multiple regression analyses to determine how the four brittleness indices (B1, B2, B3, and B4) were related to the amount of amperage and the rate of wear. Also, the validity of the developed models was assessed by the F-test and the t-test. The correlation coefficient between the measured and estimated values was also calculated to select the most accurate model. Based on the amperage draw and brittleness index, the results showed that the wear rate of diamond disc cutting tools can be accurately forecasted (**Akhyani et al., 2018**). In 2018, Mikaeil et al. studied the energy consumed during the process of cutting dimension rocks. For this purpose, they conducted several tests on seven carbonate rocks under different operating conditions (cutting depth, feed rate, and peripheral speed). They used SPSS software to produce statistical models for predicting energy consumption. The results demonstrated that cutting depth and feed rate are directly related to energy consumption, probably because energy consumption is a function of the cutting mechanism and ease of cutting (**Mikaeil et al., 2018a**). In 2020, Hosseini et al. created a precise model to forecast how cooling and lubrication fluids will affect cutting performance, emphasizing power consumption as one of the most crucial indicators of cutting effectiveness (**Hosseini et al., 2020**). In 2021, Piri et al. studied the simultaneous impact of some mechanical parameters and tool characteristics (i.e. coating) on the noise of the cutting process through statistical analysis in SPSS (**Piri et al., 2021**). **Table 1** shows a list of notable studies conducted in this field and the physical and mechanical parameters that they have investigated (**Mikaeil et al., 2021; Mikaeil et al., 2022; Shaffiee Haghshenas et al., 2022**). Most of these studies have been performed on disc cutting machines and diamond cutting wire, and strength, hardness, and abrasion parameters have been among the physical and mechanical parameters most widely investigated by researchers in this field.

The cutting process and the electrical current consumed by the cutting machine have been the subject of several studies, but the impact of coolant and lubrication fluids on both the quality of the cutting procedure and the performance of the cutting machine has not been investigated comprehensively. There is no doubt that the lubricating fluid affects the cutting process, and thorough, well-planned research could lead to significant cuts in the amount of energy consumption and the number of cutting tools used in the stone-cutting industry. Hence, the main goal of this study is to determine the

Table 1: An overview of research on the functional of stone cutting machines (**Mikaeil et al., 2021**)

Researchers	Year	Physical and Mechanical Characteristics										
		UCS	BTS	YM	IS	SS	BS	H	A	D	Gs	Qc
Burgess	1978										●	●
Clausen et al.	1996										●	●
Wei et al.	2003	●						●	●			●
Eyuboglu et al.	2003	●	●	●				●				
Ersoy and Atici	2004	●	●	●	●	●	●	●	●	●	●	●
Kahraman et al.	2004	●	●		●			●	●			
Gunaydin et al.	2004	●	●		●							
Ozcelik et al.	2004	●	●	●				●		●		●
Buyuksagis and Goktan	2005	●	●					●	●			●
Ersoy et al.	2005	●	●	●	●	●	●		●	●		●
Delgado et al.	2005							●				●
Kahraman et al.	2005					●						●
Fener et al.	2007	●	●		●			●	●			
Kahraman et al.	2007	●	●							●		●
Ozcelik	2007	●	●					●				●
Tutmez et al.	2007	●	●		●			●	●			
Buyuksagis	2007	●	●				●	●	●	●		●
Mikaeil et al.	2008	●										●
Kahraman and Gunaydin	2008							●		●		
Ataei et al.	2011	●	●					●	●			
Mikaeil et al.	2011a	●	●	●				●	●		●	●
Mikaeil et al.	2011b	●	●					●	●			
Mikaeil et al.	2011c	●	●									
Mikaeil et al.	2011d	●	●	●				●	●		●	●
Ataei et al.	2012	●	●					●	●		●	●
Yurdakul and Akdas	2012	●	●				●	●	●	●		
Ghaysari et al.	2012										●	
Mikaeil et al.	2012	●	●	●				●	●		●	●
Mikaeil et al.	2013a	●	●									
Mikaeil et al.	2013b	●	●	●				●	●		●	●
Sadegheslam et al.	2013	●		●					●			●
Mikaeil et al.	2014	●	●									
Tumac	2015							●	●			
Mikaeil et al.	2015	●	●	●				●	●		●	●
Aryafar and Mikaeil	2016	●	●	●				●	●		●	●
Tumac	2016	●	●						●	●		
Almasi et al.	2017	●	●	●				●	●		●	●
Almasi et al.	2017	●	●	●				●	●		●	●
Almasi et al.	2017	●	●	●				●	●		●	●
Kamran et al.	2017	●	●	●				●	●		●	●
Akhyani et al.	2017	●	●	●				●	●		●	●
Akhyani et al.	2017	●	●	●				●	●		●	●
Mikaeil et al.	2017	●		●				●	●		●	●
Mikaeil et al.	2018a	●	●	●				●	●		●	●
Aryafar et al.	2018	●	●	●				●	●		●	●
Mohammadi et al.	2018	●		●				●			●	●
Dormishi et al.	2018	●	●	●				●	●		●	●
Tumac et al.	2018	●	●		●			●		●		
Zhang et al.	2018						●	●		●		
Mikaeil et al.	2019	●	●	●				●	●		●	●
Dormishi et al.	2019	●	●	●				●	●		●	●
Haghshenas et al.	2019	●	●	●				●	●		●	●
Hosseini et al.	2020	●	●	●				●			●	●
Piri et al.	2021	●	●	●				●			●	●

effect of operating parameters and fluid type on the energy consumption of a disc cutting machine to produce dimension hard rocks. After studying the relationship between operational parameters and amperage draw in the presence of five fluids, several linear and nonlinear multivariate statistical models are developed to predict the amperage draw of the cutting machine, and the results are discussed in more detail.

2. Method

In this study, ten rock types were collected from several Iranian quarries. Then, field and laboratory investigations were performed to examine the effects of parameters of interest on cutting performance using statistical analyses. Laboratory investigations included measuring the properties of cooling and lubricant fluids, building a laboratory-scale disc cutting machine capable of measuring and recording amperage draw, and conducting cutting tests in different operating conditions with five cooling and lubricant fluids. For this purpose, after preparing the samples for laboratory research, four physical and mechanical properties of stones are evaluated and quantified: uniaxial compressive strength, Mohs hardness, Schimazek's F-abrasiveness factors, and Young's modulus. Then, five different coolant and lubricant fluids are used to find out how much electricity the disk cutting machine uses at its peak. Finally, several multivariate statistical models are constructed to estimate the cutting machine's required current. More comprehensive explanations for each step of this study are given in the following sections. The flowchart of this study is shown in **Figure 1**.

3. Laboratory investigations

In this study, different rock types were chosen as the testing materials, including granite, syenite, diabase, tuff, basalt and diorite. Ten cylindrical specimens were cut and prepared smooth according to the ISRM standard (**Fairhurst and Hudson, 1999**) to perform the experimental tests and measure physical and mechanical rock properties (see **Figure 2**). The uniaxial monotonic tests (see **Figure 3**) were conducted on the prepared specimens under a constant axial stress rate of 1 MPa/s (**Mikaeil et al., 2018b**). After conducting the tests and analyzing the recorded stress-strain curves, the rocks' uniaxial compressive strength (UCS) and Young's modulus

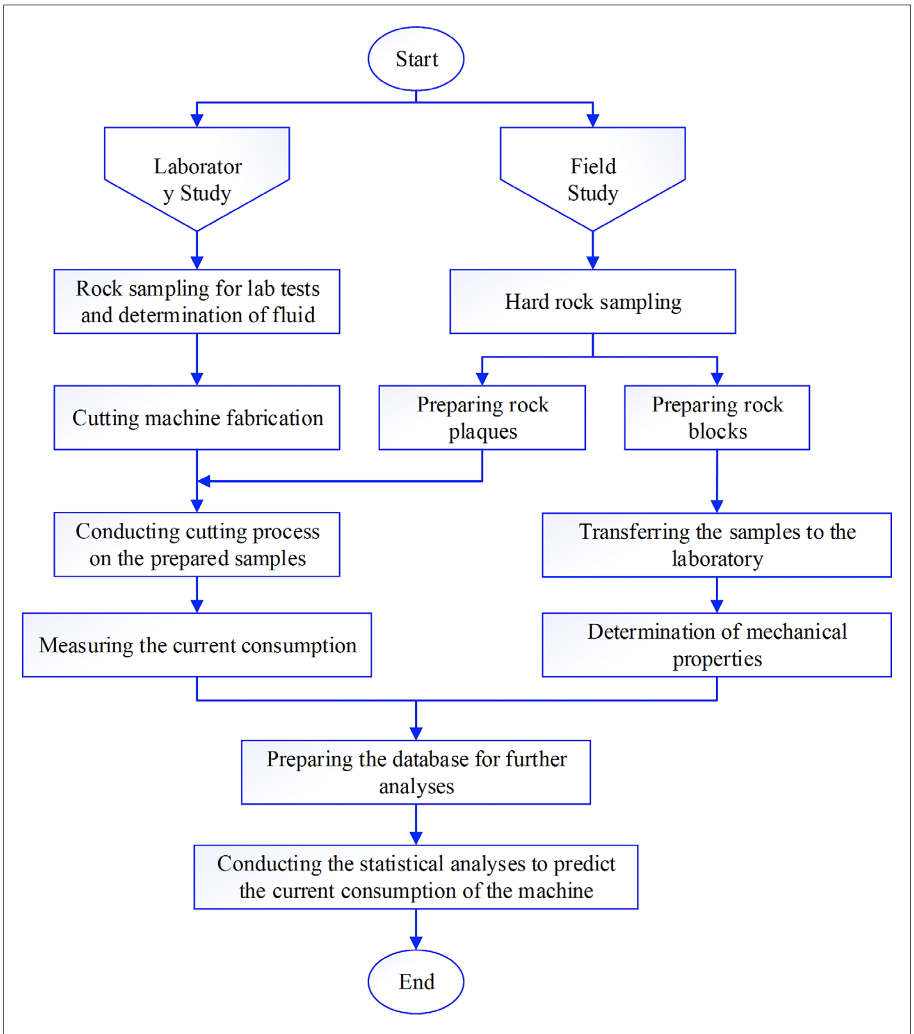


Figure 1: Procedure followed in this study

Figure 2: Sample preparation for experimental tests

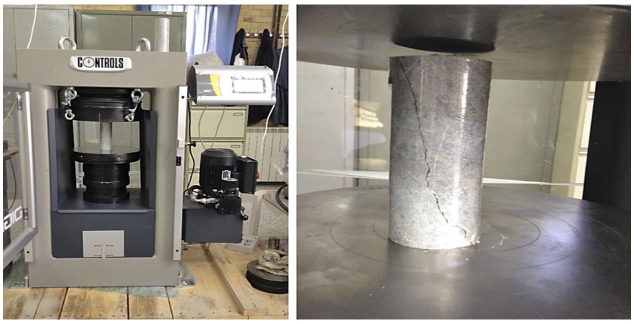
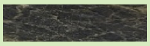
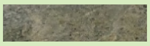
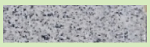
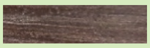
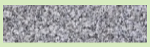
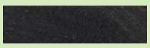


Figure 3: Determination of uniaxial compressive strength (UCS) of studied rock types

Table 2: Physical and mechanical properties of the rock specimens

	Rock type	Trade Name	UCS (MPa)	YM (GPa)	Mh	SF-a (N/mm)
	Granite	Khorram Darreh	133	28.9	5.65	10.42
	Syenite	Birjand Forest Green	239	52	6.4	28.3
	Diabase	Naein Green Shadab	279	56	6.1	8.352
	Granite	Birjand Kahuei Green	110	37	6.3	4.284
	Granite	Natanz White	150	43	5.7	46.63
	Granite	Nehbandan White	145	35.5	5.95	24.25
	Tuff	Isfahan Red	182	46.5	6	1.872
	Basalt	Yazd Red	142	43.6	6.1	14.24
	Granite	Mashhad Morvarid	125	31.2	5.6	8.5
	Diorite	Chyghan Black	173	48.6	6.6	7.6

(YM) were determined. Furthermore, the other physical parameters, including the Schmiazek abrasivity factor (SF-a) and Mohs hardness (Mh) of different rock types, were measured through laboratory investigations (**ISRM 1981**). The results of these measurements are summarized in **Table 2**. According to Table 2, the UCS of rocks varies within the range of 110 to 279 MPa, classifying them as hard rocks. Then, plaques of 40×40 cm were prepared for cutting tests with the disk cutting machine.

Feed rate (Fr) and cutting depth (Dc) are two operational variables of cutting machines that, because of their combined effect on the cutting process, are generally evaluated together. Therefore, the cutting tests were carried out under different operational conditions with varying cutting depths of 0.5, 0.7, 1, and 1.3 cm and varying feed rates of 45, 60, 75, and 90 cm/min with the fixed rotation of 3400 rounds/min of the disk. The disc's diameter and width were also set to 25 (cm) and 5 (mm), respectively, as critical experimental parameters. Eighteen diamond segments with the size of 35 (mm) × 2.5 (mm) × 6.0 (mm) along with a spindle motor with a maximum power of 4 kilowatts (kW) were employed in this study. The disk cutting machine utilized for the data collection can be observed in **Figure 4**.

The cutting tests were performed in five stages with five fluids: tap water, soap water with a ratio of 1:40 and 1:20, and a commercial cutting powder (Abtarash) with a ratio of 30:10 and 15:10. The properties of these fluids, according to the relevant tests (see **Figure 5**), were listed in **Table 3**. At each test stage, the prepared rock block

Figure 4: The disk-cutting machine used in this study

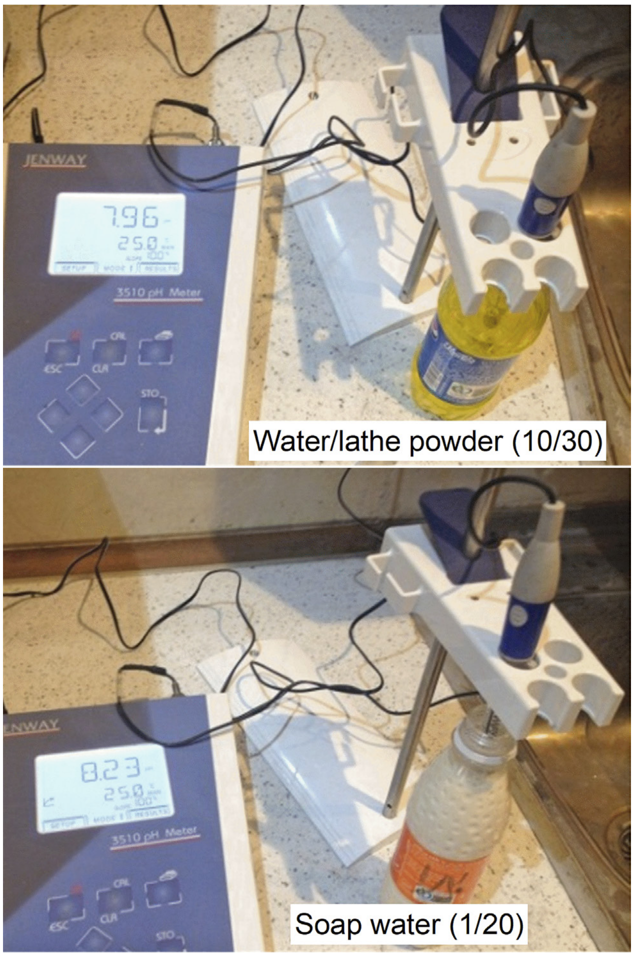


Figure 5: Determining the hardness of fluids

(e.g. Birjand forest green granite in specific dimensions) was fixed on a table and cut with the operating conditions given in **Table 4**. The results of 80 tests (16 tests per fluid) were recorded. The variation in amperage draw by changing the cutting depth (Dc) and feed rate (Fr) was recorded for each test. The results of the undertaken cutting tests for Birjand forest green granite are listed in **Table 4**.

Table 3: Characteristics of fluids studied in tests

No.	Fluid	Hardness (pH)	Viscosity (mPa·s)
1	Water	7.68	1.069
2	Soap water with a ratio of 1/40	7.87	0.9851
3	Soap water with a ratio of 1/20	8.23	0.9754
4	Water /lathe powder with a ratio of 10/30	7.96	1.839
5	Water /lathe powder with a ratio of 10/12	8.1	1.158

4. Results and discussion

To investigate the relationship between operating parameters (i.e. feed rate and cutting depth), characteristics of the cooling/lubricant fluid (i.e. hardness and viscosity), and amperage draw, statistical analysis was conducted in SPSS and Excel using univariate and multivariate linear/nonlinear regression. **Figures 6 to 13** show the correlation between the amperage draw of the cutting machine and the changes in operating parameters and cooling/lubricant fluid for the Birjand forest green granite.

According to **Figure 6**, it is observed that for Dc=50 (mm), the increase in the feed rate from 45 to 90 (cm/min) results in a significant increase in the amount of electrical current consumption when the samples are cut using water and soap water with the ratio of 1:20. This is while the tests with the other two fluids (i.e. water mill powder with the ratios of 10/30 and 10/15) did not show considerable change. Although the variation in maximum current consumption for the soap water with the ratio of 1/20 with the advance rate is not notable, its consumed energy is relatively higher than the two types of water mill powder.

In the next step, the tests are repeated by increasing the value of Dc from 0.5 to 0.7 and 1 (mm). According to **Figures 7 and 8**, the results had a relatively similar trend to that of **Figure 6**. It is evident that the samples with water and soap water with the ratios of 1:20 and 1:40 showed the largest variations in the amount of energy consumption when Dc (70 mm) was kept constant, and the feed rate was increased from 45 to 90 (cm/min). These changes were also negligible in the test with two powder lubricants.

According to **Figure 9**, for Dc=1.3 mm, the electrical current consumption increased with an increase in the advance rate. However, the highest amount of current consumption was observed for tests with water lubricant, which varies from 7.6 to 13.8 amps. When the samples were tested with soap water lubricant with ratios of 1 to 20 and 10 to 40, the consumed current energy increased, following an approximately similar trend. Moreover, the cutting machine consumed the least amount of energy by using two water lathe powder lubricants.

Table 4: The cutting test results for Birjand forest green granite under different operational conditions

No.	Cutting operational specifications			water	Soap water with a ratio of 1/20	Soap water with a ratio of 1/40	Water lathe powder with a ratio of 10/30	Water /lathe powder with a ratio of 10/15
	Dc (cm)	Fr (cm/min)	Ps (rpm)	Current consumption (amps)				
1	0.5	90	3400	8.3	6.7	6.1	5.1	7.3
2	0.7	90		10.2	7.3	7.4	5.6	7.6
3	1	90		11.2	8.5	8.3	5.9	7.5
4	1.3	90		13.8	9.5	9.6	6.4	8.8
5	0.5	75		7.6	6.2	6	5	6.7
6	0.7	75		9.1	7.1	6.9	5.5	6.1
7	1	75		10.2	7.7	7.8	5.6	6.5
8	1.3	75		12.6	8.8	8.6	6.2	8.7
9	0.5	60		6.5	5.8	5.9	5	5.3
10	0.7	60		7.4	6.3	6.4	5.3	5.9
11	1	60		7.8	6.8	7.2	5.6	6.1
12	1.3	60		8.7	7.6	7.9	6.1	8.7
13	0.5	45		5.7	5.3	5.6	5	5.2
14	0.7	45		6.5	6	6.2	5.2	5.8
15	1	45		7.1	6.1	7	5.2	7
16	1.3	45		7.6	6.8	7.4	5.5	7.9

In the following tests, the cutting depth increased by keeping the advance rate constant at 45 cm/min, and the samples were tested with five lubricants. According to **Figure 10**, all the samples during the cutting procedure with all different lubricants experienced increased electrical current consumption. The highest electrical current consumption was observed for water and soap water lubrication, with a ratio of 1 to 20. Also, the lowest amount of energy consumption was obtained for the abrasive powder, with a ratio of 10 to 15.

According to **Figure 11**, the feed rate value increased from 45 to 75 (cm/min), which was kept constant during this test. The values of Dc were increased, and the samples were cut again with five different lubricants and coolants. In all the tests, an increase in the amount of current consumption was observed, while the highest value was recorded for water.

In the next test, by keeping the feed rate constant at 75 (cm/min) and increasing the amount of Dc, it was observed that the cutting machine needs more energy to cut stones compared to feed rates of less than 75 (cm/min) (see **Figure 12**). These amperage changes were specifically evident in cutting with water lubrication, where the lowest value of amperes consumed at a depth of 5 (mm) was equal to 7.6 (amps), and the highest value of amperes consumed at a depth of 13 mm was 12.6 (amps). This increasing trend was also observed for the feed rate of 90 (cm/min). On the other hand, **Figure 13** shows the largest value of changes with water lubricant.

According to the trends shown in **Figures 6** to **13**, at a constant disk rotational speed (3400 rpm), the amperage draw of the cutting machine increased with cutting depth and feed rate. The slope of this change also increased with an increase in feed rate and cutting depth, reaching a maximum at the highest applied feed rate and cutting depth. This relationship between amperage draw and feed rate and cutting depth can be attributed to the intensification of process forces, including normal and shear forces and increased thermal stresses, where the rock surface comes in contact with the diamond grains of the cutting machine.

As the feed rate and cutting depth increase, the cutting power of diamond grains and the thickness of removed chips also increase. Aside from increasing the forces and stresses of the process, this also leads to the creation and propagation of lateral and radial cracks. The formation and propagation of these cracks in the rock cause secondary cutting. In other words, as the cutting depth of diamond grains increases, the role of secondary cutting in the cutting process intensifies, which finally results in a significant portion of the formed cuttings. Overall, for a constant volume of cuttings removed (cutting rate), the amperage draw of the machine decreases with an increase in the process forces and stresses. The interesting point is the increased disk wear rate and machine vibration, which will lead to increased repair and maintenance costs. The best solution to this problem is to reduce the process forces and thermal stresses in the cutting envi-

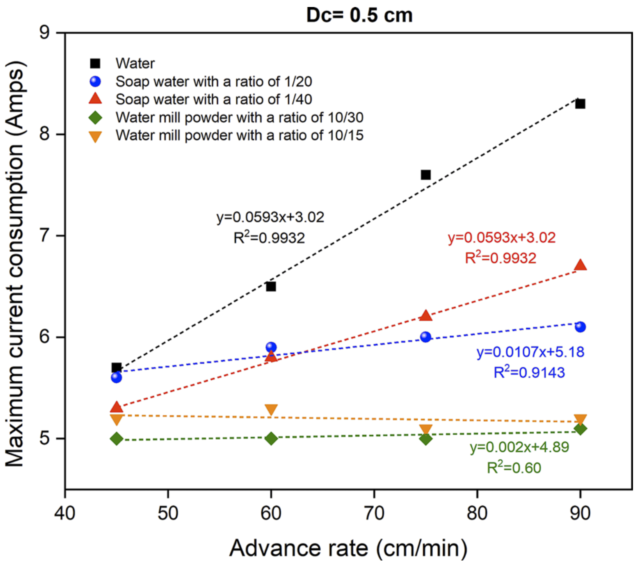


Figure 6: The relationship between maximum current consumption and the advance rate at a cut depth of 0.5 cm

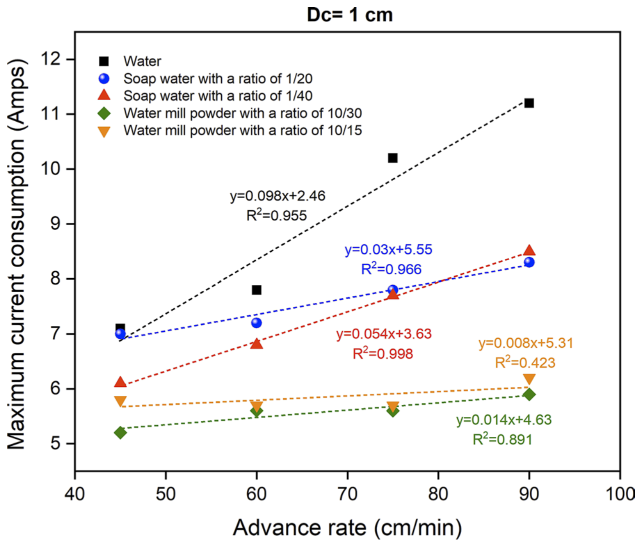


Figure 8: The relationship between maximum current consumption and the advance rate at a cut depth of 1 cm

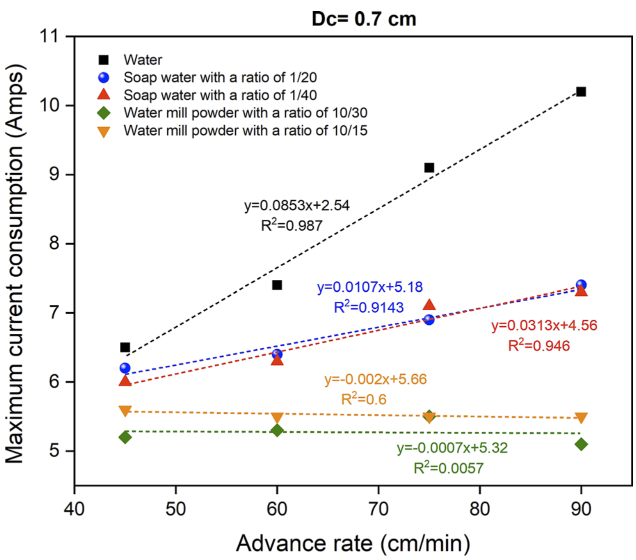


Figure 7: The relationship between maximum current consumption and the advance rate at a cut depth of 0.7 cm

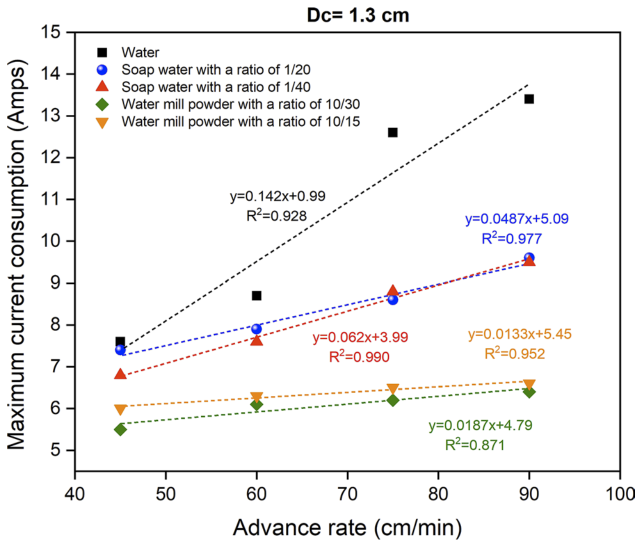


Figure 9: The relationship between maximum current consumption and the advance rate at a cut depth of 1.3 cm

ronment by using a cooling/lubricant fluid. A proper cooling/lubricant fluid can significantly reduce the process forces and thermal stresses by reducing the coefficient of friction of the environment and removing the cuttings. As shown in **Figures 6** to **13**, changing the fluid from tap water to a proper cooling/lubricant fluid decreased the amperage draw of the cutting machine. At high cutting rates (maximum cutting depth and feed rate), the amperage draw of the cutting machine was reduced by 14% on average.

In most cases, using commercial cutting powder (Abtarash) with a ratio of 30:10 had a better impact on the results than using other fluids. The relationship between the amperage draw of the cutting machine and properties of the rock and cooling/lubricant fluid and operating parameters was investigated using linear and nonlinear multivariate regression. The following statistical models express the relationship between amperage draw and operating parameters for different cooling/lubricant fluids (**Equations 1** to **10**).

$$I_{Max} = 2.528D_c + 0.026F_r - 1.834PH - 0.213Vis + 17.734 \quad (1)$$

$$I_{Max} = 2.528D_c + 0.026F_r - 1.834PH - 0.213Vis + 0.001UCS + 0.202Mh - 0.002SF - a + 0.002YM + 17.35 \quad (2)$$

$$I_{Max} = 2.528D_c + 0.026F_r - 1.834PH - 0.213Vis + 0.001UCS + 17.511 \quad (3)$$

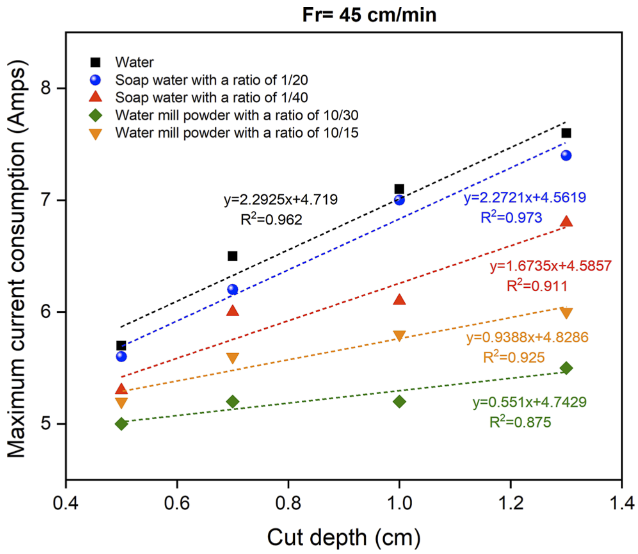


Figure 10: The relationship between maximum current consumption and cut depth at an advance rate of 45 cm/min

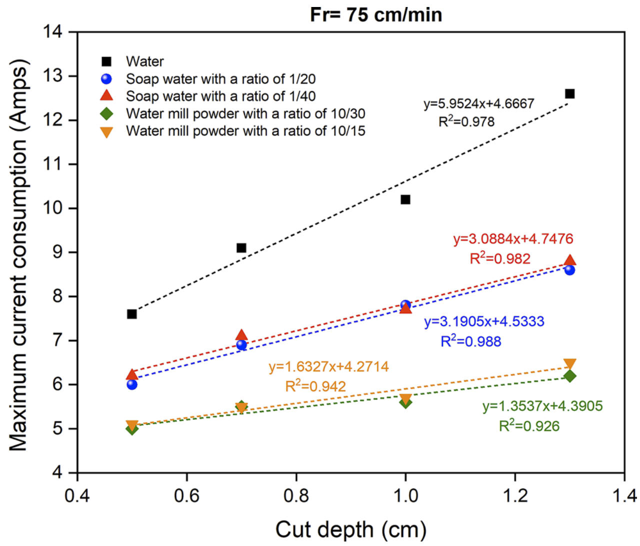


Figure 12: The relationship between maximum current consumption and cut depth at an advance rate of 75 cm/min

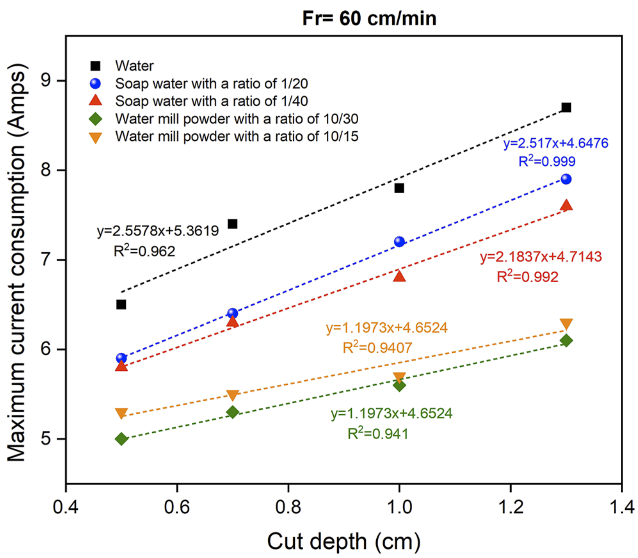


Figure 11: The relationship between maximum current consumption and cut depth at an advance rate of 60 cm/min

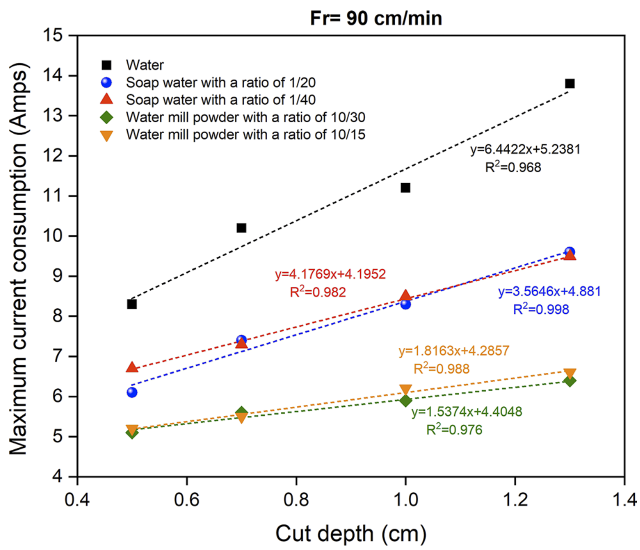


Figure 13: The relationship between maximum current consumption and cut depth at an advance rate of 90 cm/min

$$I_{Max} = 2.528D_c + 0.026F_r - 1.834PH - 0.213Vis + 0.281Mh - 0.001SF - a + 16.055 \quad (4)$$

$$I_{Max} = 2.528D_c + 0.026F_r - 1.834PH - 0.213Vis + 0.293Mh + 15.964 \quad (5)$$

$$I_{Max} = \frac{D_c^{0.302} \times F_r^{0.235} \times 10^{2.222}}{PH^{1.989} \times Vis^{0.043}} \quad (6)$$

$$I_{Max} = \frac{D_c^{0.302} \times F_r^{0.235} Mh^{0.109} \times YM^{0.064} \times 10^{2.099}}{PH^{1.989} \times Vis^{0.043} \times UCS^{0.029} \times SF - a^{0.002}} \quad (7)$$

$$I_{Max} = \frac{D_c^{0.302} \times F_r^{0.235} \times UCS^{0.019} \times 10^{2.181}}{PH^{1.989} \times Vis^{0.043}} \quad (8)$$

$$I_{Max} = \frac{D_c^{0.302} \times F_r^{0.235} \times Mh^{0.221} \times 10^{2.051}}{PH^{1.989} \times Vis^{0.043} \times SF - a^{0.002}} \quad (9)$$

$$I_{Max} = \frac{D_c^{0.302} \times F_r^{0.235} \times Mh^{0.226} \times 10^{2.046}}{PH^{1.989} \times Vis^{0.043}} \quad (10)$$

In all models, the maximum amperage draw of the cutting machine was considered the dependent variable, and the rock properties, fluid characteristics, and the machine's operating parameters were defined as independent variables. The statistical significance of the models was checked using the t-test and F-test. The F-test was used to check the significance of the model, and the t-test was used to control the significance of each independent variable. The results of the t-test and F-test are presented in **Tables 5** and **6**.

Table 5: Results of linear multivariate regression analysis to forecast the current intensity

	Parameters	Coefficients	Standard error	F	F Table	t	t Table	R
Model 1	Constant	17.734	1.101	339.98	3.78	16.11	2.58	0.794
	D_c	2.528	0.085			29.77		
	F_r	0.026	0.002			16.94		
	pH	-1.834	0.136			13.46		
	Vis	-0.213	0.08			2.67		
Model 2	Constant	16.35	1.266	174.49	2.208	12.91	2.58	0.799
	D_c	2.528	0.084			29.99		
	F_r	0.026	0.002			17.01		
	pH	-1.834	0.135			-13.56		
	Vis	-0.213	0.079			-2.69		
	UCS	0.001	0.001			0.49		
	Mh	0.202	0.127			1.59		
	SF-a	-0.002	0.002			-0.89		
	YM	0.002	0.008			0.29		
Model 3	Constant	17.511	1.1	275.4	3.319	15.92	2.58	0.796
	D_c	2.528	0.085			29.89		
	F_r	0.026	0.002			17.01		
	pH	-1.834	0.136			-13.51		
	Vis	-0.213	0.079			-2.68		
	UCS	0.001	0.001			2.63		
Model 4	Constant	16.055	1.206	232.2	3.017	13.31	2.58	0.798
	D_c	2.528	0.804			29.99		
	F_r	0.026	0.002			17.07		
	pH	-1.834	0.135			-13.56		
	Vis	-0.213	0.079			-2.69		
	Mh	0.281	0.083			3.38		
	SF-a	-0.001	0.002			-0.64		
Model 5	Constant	15.694	1.198	278.7	3.319	13.33	2.58	0.798
	D_c	2.528	0.084			30		
	F_r	0.026	0.002			17.08		
	pH	-1.834	0.135			-13.56		
	Vis	-0.213	0.079			-2.69		
	Mh	0.293	0.081			3.61		

As mentioned earlier, linear and nonlinear regression models can be used to describe the linear and nonlinear relationships between independent and dependent variables. The multivariate linear and nonlinear regression analyses were conducted in this study using SPSS software, and the results were listed in **Tables 5 and 6**. In these analyses, the regression coefficient for each independent parameter was found automatically by the software using the least square error (LSE) technique to minimize the prediction error. The models built with these coefficients can show their efficiency in the t-test and F-test. As a result, these two tests were used to evaluate all of the regression-based models. The correlation coefficient (R) values in **Tables 5** and **6** can also be used for further evaluation of the models.

The F value derived from all models is lower than the number in the F-distribution table, with a confidence level of 99%. The null hypothesis, i.e. no linear relationship between the dependent variable (maximum amperage draw of the cutting machine) and the independent variables (characteristics of the rock, fluid, and machine), was disproved, and it was determined that at least

Table 6: Results of nonlinear multivariate regression analysis to predict the current intensity

	Parameters	Coefficients	Standard error	F	F Table	t	t Table	R
Model 6	Constant	2.222	0.13	395.8	3.78	17.13	2.58	0.816
	D_c	0.302	0.009			32.42		
	F_r	0.235	0.013			18.13		
	pH	-1.989	0.142			-14.05		
	Vis	-0.043	0.014			-2.98		
Model 7	Constant	2.099	0.142	202.7	2.802	14.78	2.58	0.82
	D_c	0.302	0.009			32.65		
	F_r	0.235	0.013			18.26		
	pH	-1.989	0.141			-14.16		
	Vis	-0.043	0.014			-2.99		
	UCS	-0.029	0.023			-1.23		
	Mh	0.109	0.094			0.247		
	SF-a	0.002	0.004			-0.522		
	YM	0.064	0.038			1.69		
Model 8	Constant	2.181	0.132	317.7	3.319	16.47	2.58	0.817
	D_c	0.302	0.009			32.45		
	F_r	0.235	0.013			18.14		
	pH	-1.989	0.141			-14.07		
	Vis	-0.043	0.014			-2.98		
	UCS	0.019	0.012			1.52		
Model 9	Constant	2.051	0.139	269.4	3.017	14.77	2.58	0.819
	D_c	0.302	0.009			32.63		
	F_r	0.235	0.013			18.25		
	pH	-1.989	0.141			-14.15		
	Vis	-0.043	0.014			-2.99		
	Mh	0.221	0.065			3.39		
	SF-a	-0.002	0.004			-0.397		
Model 10	Constant	2.046	0.138	323.6	3.319	14.8	2.58	0.819
	D_c	0.302	0.009			32.65		
	F_r	0.235	0.013			18.26		
	pH	-1.989	0.141			-14.15		
	Vis	-0.043	0.014			-2.99		
	Mh	0.226	0.064			3.15		

one of the regression coefficients is not zero. After checking the overall significance of the model with the F-test, the significance of each independent variable was checked with a t-test. This test was used to check the hypothesis that each coefficient of the independent variables is zero. Since only some of the t-values obtained for independent variables were smaller than the relevant value in the t-distribution table for 99% confidence level, the hypothesis that the coefficients of independent variables are zero was rejected. Therefore, models 2, 4, 7, 8, and 9 were discarded. In statistical analyses, especially those aimed to produce statistical models, it should be noted that coefficients must be logically justifiable, or in other words, the model must conform to the nature of the modelled process. In the context of this research, we can always expect an increase in the amperage draw of the machine with an increase in the rock's strength, hardness, or abrasiveness under constant operating conditions. Also, we can expect the amperage draw for a given rock to rise with an increase in the machine's operating parameters. Therefore, any model that suggests otherwise would be unacceptable. Based on this ration-

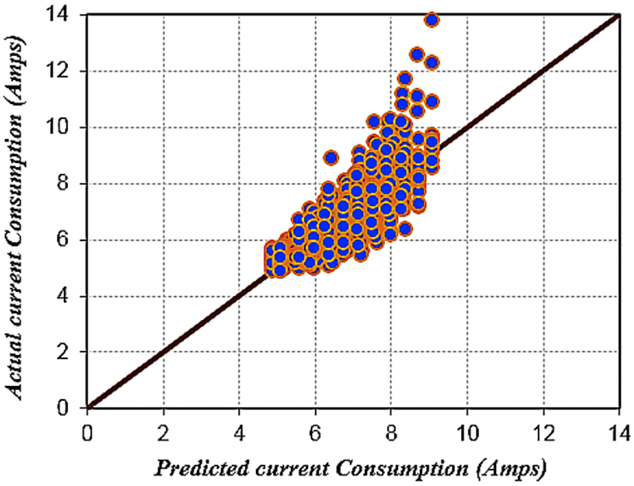


Figure 14: Dispersion of predicted and actual points relative to the 1: 1 half-line for model 1

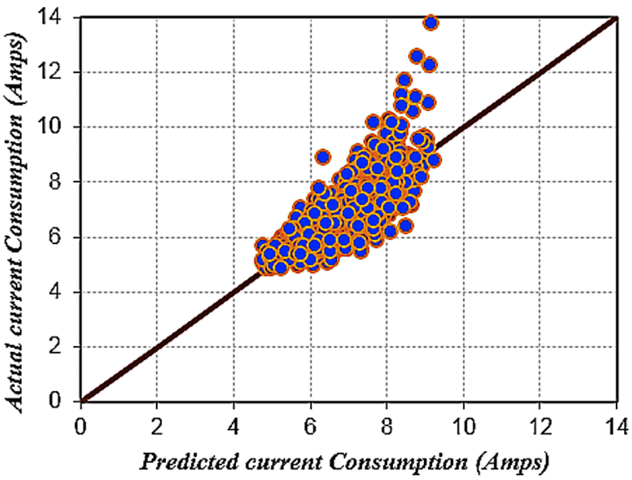


Figure 15: Dispersion of predicted and actual points relative to the 1: 1 half-line for model 3

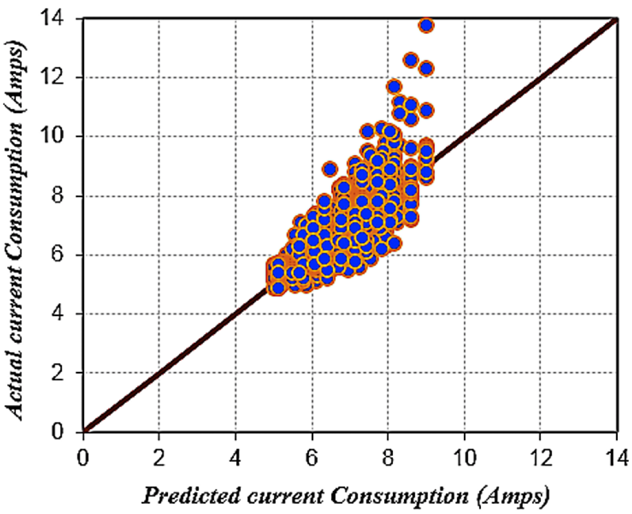


Figure 16: Dispersion of predicted and actual points relative to the 1: 1 half-line for model 5

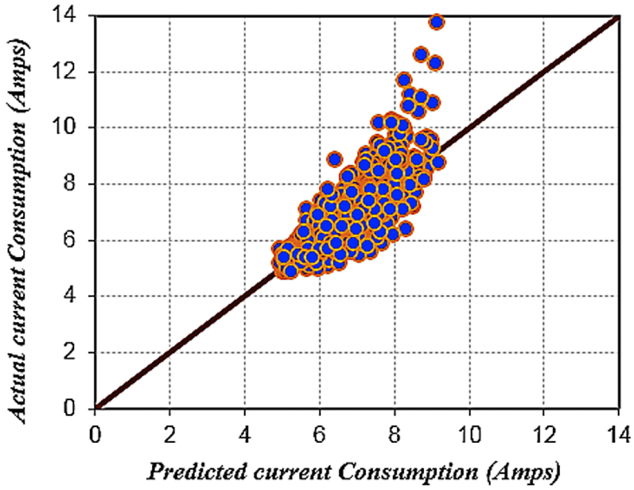


Figure 17: Dispersion of predicted and actual points relative to the 1: 1 half-line for model 6

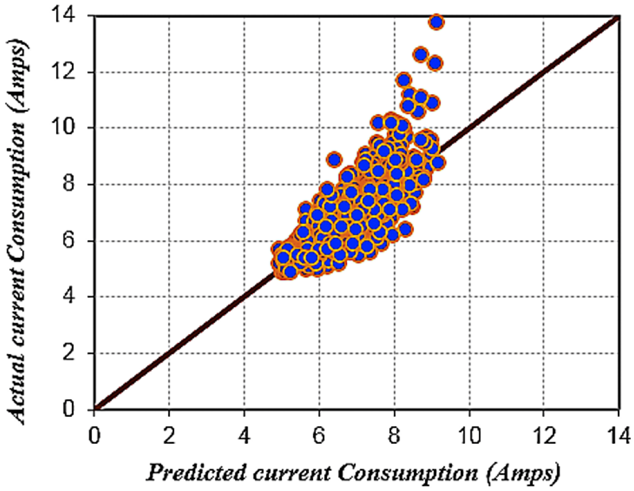


Figure 18: Dispersion of predicted and actual points relative to the 1: 1 half-line for model 10

ale, models 2, 4, 7, and 9 were unacceptable as they predict the amperage draw to decrease with increasing abrasivity. Finally, models 1, 3, 5, 6, and 10 with correlation coefficients of respectively 0.794, 0.796, 0.798, 0.816, and 0.819, were identified as suitable models for predicting the amperage draw of the cutting machine according to the properties of the fluid and rock and the machine's operating parameters.

Another method to assess statistical models is to check the dispersion of their predictions versus observations relative to the 1:1 bisector line. The higher the density of these points around the bisector, the more accurate the model. In other words, forecasts are seen to be accurate when the frequency of observations is almost equal to the frequency of predictions. A complete match between experimental and prediction values is therefore attained for a location located on the bisector line. On the other hand, the prediction value gives a safe prediction when a point is on the bisector line. **Figures 14** to **18** show the dispersion of the predicted values of the current consumption by models 1, 3, 5, 6, and 10 versus the actual measurements. In these scatter plots, whenever the data points are closer to the diagonal line (line 1:1), the difference between the measured and predicted values decreases, representing a higher prediction accuracy. As can be observed from **Figures 14** to **18**, all five models almost have similar dispersion, and the data points have perfectly concentrated around the diagonal line. This shows that the regression models can estimate the performance of the cutting machine with high accuracy.

5. Conclusions

The relationship between the amperage draw of a rock cutting machine and rock properties, different cooling/lubricant fluids, and the machine's operating parameters was investigated in this study using experimental and statistical approaches. The experimental tests were performed on ten hard rock types to measure the uniaxial compressive strength, Mohs hardness, Schmiazek abrasivity factor, and modulus of elasticity, representing the strength, hardness, abrasivity, and elasticity-plasticity characteristics of rocks, respectively. The cutting tests were completed using a laboratory-scale disk cutting machine with different operating conditions using five fluids: tap water, soap water with a ratio of 1:40 and 1:20, and a commercial cutting power (Abtarash) with a ratio of 30:10 and 15:10. The compiled experimental datasets were then analysed by statistical tests. The results of simple fitting showed that as the operating parameters (i.e. cutting depth and feed rate) increase, the amperage draw of the cutting machine also increases. However, the slope of these changes varies depending on the cooling/lubrication fluid. In general, the best results were observed for Abtarash cutting powder with a ratio of 30:10. In most cases, the use of this cooling lubricant significantly reduced the amperage draw of the machine. By analyzing the experimental data in SPSS, ten linear and nonlinear multivariate statistical models were developed for predicting the amperage draw of the cutting machine. The t-test and F-test were then utilised to examine the statistical significance of the models and their coefficients. Ultimately, five models were selected as the best models for predicting the amperage draw of the cutting machine. The statistical tests conducted at a 99% confidence level showed that these five models are acceptably accurate, with a correlation coefficient of about 0.8 in estimating the amperage draw of the cutting machine operating using the tested fluids as the cooling lubricant.

6. References

Akhyani, M., Sereshki, F., Mikaeil, R. and Taji, M. (2017): Evaluation of cutting performance of diamond saw machine using artificial bee colony (ABC) algorithm. International Journal of Mining and Geo-Engineering, 51, 2, 185-190.

Akhyani, M., Sereshki, F. and Mikaeil, R. (2018): An investigation of the effect of toughness and brittleness indexes on ampere consumption and wear rate of a circular diamond saw. Rudarsko-geološko-naftni zbornik, 33, 4, 85-93.

Akhyani, M., Mikaeil, R., Sereshki, F. and Taji, M. (2019): Combining fuzzy RES with GA for predicting wear performance of circular diamond saw in hard rock cutting process. Journal of Mining and Environment, 10, 3, 559-574.

Almasi, S.N., Bagherpour, R., Mikaeil, R. and Ozcelik, Y. (2017a): Developing a new rock classification based on the abrasiveness, hardness, and toughness of rocks and PA for the prediction of hard dimension stone sawability in quarrying. Geosystem engineering, 20, 6, 295-310.

Almasi, S.N., Bagherpour, R., Mikaeil, R. and Ozcelik, Y. (2017b): Analysis of bead wear in diamond wire sawing considering the rock properties and production rate. Bulletin of Engineering Geology and the Environment, 76, 4, 1593-1607.

Almasi, S.N., Bagherpour, R., Mikaeil, R., Ozcelik, Y. and Kalhori, H. (2017c): Predicting the building stone cutting rate based on rock properties and device pullback amperage in quarries using M5P model tree. Geotechnical and Geological Engineering, 35, 4, 1311-1326.

Aryafar, A. and Mikaeil, R. (2016): Estimation of the ampere consumption of dimension stone sawing machine using of artificial neural networks. International Journal of Mining and Geo-Engineering, 50, 1, 121-130.

Aryafar, A., Mikaeil, R., Haghshenas, S.S. and Haghshenas, S.S. (2018): Application of metaheuristic algorithms to optimal clustering of sawing machine vibration. Measurement, 124, 20-31.

Ataei, M., Mikaeil, R., Hoseinie, S.H. and Hosseini, S.M. (2011): Fuzzy analytical hierarchy process approach for ranking the sawability of carbonate rock. International Journal of Rock Mechanics and Mining Sciences, 50, 83-93.

Ataei, M., Mikaiel, R., Sereshki, F. and Ghaysari, N. (2012): Predicting the production rate of diamond wire saw using statistical analysis. Arabian Journal of Geosciences, 5, 6, 1289-1295.

Burgess, R. and Birle, J. (1978): Circular sawing granite with diamond saw blades. Paper presented at the Proceedings of the fifth industrial diamond seminar, Tokyo, Japon. 3-10.

Buyuksagis, I. and Goktan, R. (2005): Investigation of marble machining performance using an instrumented block-cutter. Journal of materials processing technology, 169, 2, 258-262.

Buyuksagis, I. (2007): Effect of cutting mode on the sawability of granites using segmented circular diamond sawblade. Journal of materials processing technology, 183, 2-3, 399-406.

Clausen, R., Wang, C. and Meding, M. (1996): Characteristics of acoustic emission during single diamond scratching of granite. Industrial Diamond Review, 56, 570, 96-99.

Dormishi, A., Ataei, M., Khalokakaei, R. and Mikaeil, R. (2018): Energy consumption prediction of gang saws from rock properties in carbonate rocks cutting process. International Journal of Mining and Mineral Engineering, 9, 3, 216-227.

Dormishi, A., Ataei, M., Mikaeil, R., Khalokakaei, R. and Haghshenas, S.S. (2019): Evaluation of gang saws' performance in the carbonate rock cutting process using feasibility of intelligent approaches. Engineering Science and Technology, an International Journal, 22, 3, 990-1000.

Ersoy, A. and Atıcı, U. (2004): Performance characteristics of circular diamond saws in cutting different types of rocks. Diamond and Related Materials, 13, 1, 22-37.

Ersoy, A., Buyuksagic, S. and Atici, U. (2005): Wear characteristics of circular diamond saws in the cutting of different hard abrasive rocks. Wear, 258, 9, 1422-1436.

Eyuboglu, A., Ozcelik, Y., Kulaksiz, S. and Engin, I. (2003): Statistical and microscopic investigation of disc segment wear related to sawing Ankara andesites. International Journal of Rock Mechanics and Mining Sciences, 40, 3, 405-414.

Fener, M., Kahraman, S. and Ozder, M. (2007): Performance prediction of circular diamond saws from mechanical rock properties in cutting carbonate rocks. Rock Mechanics and Rock Engineering, 40, 5, 505-517.

ISRM (1981): Rock characterization testing and monitoring: Brown, E., Ed., Pergamon Press, Oxford, 211 p.

Ghaysari, N., Ataei, M., Sereshki, F. and Mikaiel, R. (2012): Prediction of performance of diamond wire saw with respect to texture characteristics of rock. Archives of Mining Sciences, 57,4, 887-900.

Gunaydin, O., Kahraman, S. and Fener, M. (2004): Sawability prediction of carbonate rocks from brittleness indexes. Journal of the Southern African Institute of Mining and Metallurgy, 104, 4, 239-243.

Haghshenas, S.S., Faradonbeh, R.S., Mikaeil, R., Haghshenas, S.S., Taheri, A., Saghatforoush, A. and Dormishi, A. (2019): A new conventional criterion for the performance evaluation of gang saw machines. Measurement, 146, 159-170.

Hosseini, S.M., Ataei, M., Khalokakaei, R., Mikaeil, R. and Haghshenas, S.S. (2020): Study of the effect of the cooling and lubricant fluid on the cutting performance of dimension stone through artificial intelligence models. Engineering Science and Technology, an International Journal, 23, 1, 71-81.

Kahraman, S., Fener, M. and Gunaydin, O. (2004): Predicting the sawability of carbonate rocks using multiple curvilinear regression analysis. International Journal of Rock Mechanics and Mining Sciences, 41, 7, 1123-1131.

Kahraman, S., Altun, H., Tezekici, B. and Fener, M. (2005): Sawability prediction of carbonate rocks from shear strength parameters using artificial neural networks. International journal of rock mechanics and mining sciences, 43, 1, 157-164.

Kahraman, S., Ulker, U. and Delibalta, M. (2007): A quality classification of building stones from P-wave velocity and its application to stone cutting with gang saws. Journal of the Southern African Institute of Mining and Metallurgy, 107, 7, 427-430.

Kahraman, S. and Gunaydin, O. (2008): Indentation hardness test to estimate the sawability of carbonate rocks. Bulletin of Engineering Geology and the Environment, 67, 4, 507-511.

Kamran, M.A., Khoshsirat, M., Mikaeil, R. and Nikkhoo, F. (2017): Ranking the sawability of ornamental and building stones using different MCDM methods. Journal of Engineering Research, 5, 3, 124-149.

Mikaiel, R., Ataei, M.A. and Hoseinie, H. (2008): Predicting the production rate of diamond wire saws in carbonate rock cutting. IDR. Industrial diamond review, 68, 3, 28-34.

Mikaeil, R., Ataei, M. and Yousefi, R. (2011a): Application of a fuzzy analytical hierarchy process to the prediction of vibration during rock sawing. Mining Science and Technology (China), 21, 5, 611-619.

Mikaeil, R., Yousefi, R. and Ataei, M. (2011b): Sawability ranking of carbonate rock using fuzzy analytical hierarchy process and TOPSIS approaches. Scientia Iranica, 18, 5, 1106-1115.

Mikaeil, R., Ozcelik, Y., Ataei, M. and Yousefi, R. (2011c): Correlation of specific ampere draw with rock brittleness indexes in rock sawing process. Archives of Mining Sciences, 56, 4, 777-788.

Mikaeil, R., Yousefi, R., Ataei, M. and Farani, R.A. (2011d): Development of a new classification system for assessing of carbonate rock sawability. Archives of Mining Sciences, 56, 1, 59-70.

Mikaeil R., Ataei M. and Yousefi, R. (2012): Evaluating the Power Consumption in Carbonate Rock Sawing Process by Using FDAHP and TOPSIS Techniques. Effi cient Decision Support Systems: Practice and Challenges – From Current to Future / Book 2. ISBN 978-953-307-441- 2, 478.

Mikaeil, R., Ataei, M. and Yousefi, R. (2013a): Correlation of production rate of ornamental stone with rock brittleness indexes. Arabian Journal of Geosciences, 6, 1, 115-121.

Mikaeil, R., Ozcelik, Y., Yousefi, R., Ataei, M. and Hosseini, S.M. (2013b): Ranking the sawability of ornamental stone using Fuzzy Delphi and multi-criteria decision-making techniques. International Journal of Rock Mechanics and Mining Sciences, 58, 118-126.

Mikaeil, R., Ataei, M., Ghadernejad, S. and Sadegheslam, G. (2014): Predicting the relationship between system vibration with rock brittleness indexes in rock sawing process. Archives of Mining Sciences, 59, 1, 139-154.

Mikaeil, R., Abdollahi Kamran,.M., Sadegheslam, G. and Ataei, M. (2015): Ranking sawability of dimension stone using PROMETHEE method, 6, 2, 263-271.

Mikaeil, R., Shaffiee Haghshenas, S., Ozcelik, Y. and Shaffiee Haghshenas, S. (2017): Development of intelligent systems to predict diamond wire saw performance. Journal of Soft Computing in Civil Engineering, 1, 2, 52-69.

Mikaeil, R., Sohrabian, B. and Ataei, M. (2018a): The study of energy consumption in the dimension stone cutting process. Rudarsko-geološko-naftni zbornik, 33, 4, 65-71.

Mikaeil, R., Haghshenas, S.S., Ozcelik, Y. and Gharehghesh-lagh, H.H. (2018b): Performance evaluation of adaptive neuro-fuzzy inference system and group method of data handling-type neural network for estimating wear rate of diamond wire saw. Geotechnical and Geological Engineering, 36, 6, 3779-3791.

Mikaeil, R., Ozcelik, Y., Ataei, M. and Shaffiee Haghshenas, S. (2019): Application of harmony search algorithm to evaluate performance of diamond wire saw. Journal of Mining and Environment, 10, 1, 27-36.

Mikaeil, R., Esmailzadeh, A., Aghaei, S., Haghshenas, S. S., Jafarpour, A., Mohammadi, J., & Ataei, M. (2021). Evaluating the sawability of rocks by chain-saw machines using the promethee technique. Rudarsko-geološko-naftni zbornik, 36, 1, 25-36.

Mikaeil, R., Mokhtarian, M., Shaffiee Haghshenas, S., Careddu, N., & Alipour, A. (2022): Assessing the system vibration of circular sawing machine in carbonate rock sawing process using experimental study and machine learning. Geotechnical and Geological Engineering, 40, 1, 103-119.

Mohammadi, J., Ataei, M., Kakaei, R.K., Mikaeil, R. and Haghshenas, S.S. (2018): Prediction of the production rate of chain saw machine using the multilayer perceptron (MLP) neural network. Civil Engineering Journal, 4, 7, 1575-1583.

Ozcelik, Y., Polat, E., Bayram, F. and Ay, A. (2004): Investigation of the effects of textural properties on marble cutting with diamond wire. International Journal of Rock Mechanics and Mining Sciences, 41, 228-234.

Özçelik, Y. (2007): The effect of marble textural characteristics on the sawing efficiency of diamond segmented frame saws. Industrial Diamond Review, 2, 65-70.

Piri, M., Mikaeil, R., Hashemolhosseini, H., Baghbanan, A. and Ataei, M. (2021): Study of the effect of drill bits hardness, drilling machine operating parameters and rock mechanical parameters on noise level in hard rock drilling process. Measurement, 167, 108447.

Sadegheslam, G., Mikaeil, R., Rooki, R., Ghadernejad, S. and Ataei, M. (2013): Predicting the production rate of diamond wire saws using multiple nonlinear regression analysis. Geosystem engineering, 16, 4, 275-285.

Sanchez Delgado, N., Rodríguez-Rey, A., Suarez del Rio, L., Díez Sarriá, I. and Calleja, L. (2005): The influence of rock microhardness on the sawability of Pink Porrino granite (Spain). International journal of rock mechanics and mining sciences (1997), 42, 1, 161-166.

Shaffiee Haghshenas, S., Mikaeil, R., Esmaeilzadeh, A., Careddu, N., & Ataei, M. (2022): Statistical Study to Evaluate Performance of Cutting Machine in Dimension Stone Cutting Process. Journal of Mining and Environment, 13, 1, 53-67.

Tumac, D. (2015): Predicting the performance of large diameter circular saws based on Schmidt hammer and other properties for some Turkish carbonate rocks. International Journal of Rock Mechanics and Mining Sciences, 75, 159-168.

Tumac, D. (2016): Artificial neural network application to predict the sawability performance of large diameter circular saws. Measurement, 80, 12-20.

Tumac, D. and Shaterpour-Mamaghani, A. (2018): Estimating the sawability of large diameter circular saws based on classification of natural stone types according to the geological origin. International Journal of Rock Mechanics and Mining Sciences, 101, 18-32.

Tutmez, B., Kahraman, S. and Gunaydin, O. (2007): Multifactorial fuzzy approach to the sawability classification of building stones. Construction and Building Materials, 21, 8, 1672-1679.

Wei, X., Wang, C. and Zhou, Z. (2003): Study on the fuzzy ranking of granite sawability. Journal of materials processing technology, 139, 1-3, 277-280.

Yurdakul, M. and Akdas, H. (2012): Prediction of specific cutting energy for large diameter circular saws during natural stone cutting. International Journal of Rock Mechanics and Mining Sciences, 53, 38-44.

Yurdakul, M. (2015): Effect of cutting parameters on consumed power in industrial granite cutting processes performed with the multi-disc block cutter. International Journal of Rock Mechanics and Mining Sciences, 76, 104-111.

Zhang, H., Zhang, J., Dong, P. and Sun, Q. (2018): Investigation of the sawing performance of a new type of diamond frame saw machine. Diamond and Related Materials, 84, 11-19.

SAŽETAK

Istraživanje utjecaja tekućina za hlađenje/podmazivanje na veličinu struje reznih strojeva s diskom za tvrde stijene

Jedan od najvažnijih koraka u obradi arhitektonsko-građevnoga kamena jest proces rezanja, koji uzrokuje visoku cijenu proizvodnje. Veličina električne struje kod strojeva za rezanje glavni je faktor troškova ovoga proizvodnog procesa. Određivanje radnih čimbenika, kao što su radne konfiguracije stroja, mehaničke i fizičke karakteristike stijene te vrsta tekućine za hlađenje/podmazivanje, na performanse stroja za rezanje može znatno smanjiti operativne troškove. Ovo istraživanje procijenilo je potrošnju električne struje reznoga stroja s diskom tijekom rezanja tvrdih stijena pri obradi arhitektonsko-građevnoga kamena u različitim radnim uvjetima i pri korištenju različitih tekućina za hlađenje/podmazivanje. Proveden je niz ispitivanja rezanja u različitim radnim uvjetima (dubine rezanja od 0,5, 0,7, 1 i 1,3 cm te brzine rezanje od 45, 60, 75 i 90 cm/min) s pet tekućina za hlađenje/podmazivanje, uključujući vodu iz slavine, sapunicu omjera 1 : 40 i 1 : 20 te komercijalni prah za rezanje (Abtarash) u omjeru 30 : 10 i 15 : 10. Nakon ispitivanja odnosa između radnih parametara i veličine struje reznoga stroja uz upotrebu pet tekućina razvijeno je nekoliko linearnih i nelinearnih multivarijantnih statističkih modela kako bi se predvidjela veličina struje reznoga stroja. Razvijeni modeli procijenjeni su statističkim metodama t-testa i F-testa. Rezultati su pokazali kako se pomoću razvijenih modela može točno procijeniti veličina struje stroja za rezanje iz svojstava tekućine za hlađenje/podmazivanje, uključujući viskoznost i PH.

Ključne riječi:
arhitektonsko – građevni kamen; rezni strojevi s diskom; utrošak energije; statistički model; tekućina za podmazivanje

Author's contribution

Reza Mikaeil (Associate Professor, Urmia University of Technology): supervised the project and contributed to the writing and editing of the paper. **Mostafa Piri** (PhD, Lorestan University) contributed to the literature review, writing and editing of the paper. **Sina Shaffiee Haghshenas** (PhD Candidate, University of Calabria) completed the literature review and contributed to the writing and editing of the paper. **Akbar Esmaeilzadeh** (Assistant Professor, Urmia University of Technology): contributed to conducting the experimental tests and data analysis. **Payam Rjabzadeh Kanafi** (MSc, Islamic Azad University) contributed to reviewing and editing the paper. **Roohollah Shirani Faradonbeh** (Assistant Professor, Curtin University) contributed to writing, reviewing and editing the paper. **Seyed Mehdi Hosseini** (PhD, Shahrood University of Technology) performed the field studies standard tests and measured the physical and mechanical properties of rocks. Mojtaba Mokhtarian Asl (Assistant Professor, Urmia University of Technology) reviewed and edited the paper.