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Statistical Study to Evaluate Performance of Cutting Machine in Dimension Stone Cutting Process

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Abstract

Predicting the amperage consumption of cutting machines could be one of the critical steps in optimizing the energy-consuming points for the dimension stone cutting industry. Hence, the study of the relationship between the operational characteristics of cutting machines and rocks with focusing on the machine's energy-consuming is unavoidable. For this purpose, in the first step, laboratory studies under different operating conditions at different cutting depths and feed rates are performed on 12 soft and hard rock samples. In the continuation of the laboratory studies, the rock samples are transferred to the rock mechanics laboratory in order to determine the mechanical properties (uniaxial compressive strength and modulus of elasticity). The statistical studies are performed in the SPSS software in order to predict the electrical current consumption of the cutting machine according to the mechanical characteristics of the rock samples, cutting depth, and feed rate. The statistical models proposed in this work can be used with a high reliability in order to estimate the electrical current consumed in the cutting process.

1. Introduction

Low productivity and undesirable technical management in energy consumption in some industrial processes, on the one hand, and the adverse environmental effects involved therein have further emphasized the requirement to optimize energy consumption in the industries and carry out various projects in this regard. Achieving this end demands a careful consideration of the industries to seek ways in order to optimize energy consumption and minimize the final production cost [1, 2]. One of the most prominent aspects of urban development is constructing urban structures for the housing, economic or service purposes. The dimension stones are among the most widely used building materials due to the requirement of construction instructions and their significant impact on the beauty of cities, and the improvement of their appearance standards. In light of the discussion above, there is an ever-growing demand for the consumption of construction stones whose ornamental stone quarries and stone-crusher plants must meet. One of the rather major steps in preparing the dimension stones is the cutting process. Due to a high volume of stones being demanded, a very high amount of cutting is required. Owing to its inherent features, the process of cutting stone is time-consuming and, of course, an energy-intensive process due to its small size and bag, as given the high volume of energy consumed in different stages of cutting, the main energy consumption in quarries and dimension stone processing plants is easily attributed to sawing [3]. Therefore, a proper management and a high efficiency at this stage can

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play an essential role in minimizing energy consumption, and thus reducing the final cost of the final product. In fact, the results of some studies show that the portion of cost of energy consumption is almost over 30% out of the final cost of the final product such as the costs of water, workers, and maintenance [4, 5]. The first step to meet such a goal is to comprehend the cutting process in-depth and the parameters influencing it. Today, stone-cutting discs are widely used in building the stone factories. A full knowledge of the building stones and evaluation of the operating capacity of cutting machines in the processing plants lead the designers and production planners to improve the processing speed and increase production [6]. The need for more production, excellent quality, and effective competition in global markets necessitates an advanced technology and the instruments in stone quarrying and processing.

On the one hand, the efficient application of such devices, and an accurate examination of their performance, on the other hand, can significantly contribute to the improved efficiency and quality of the processed stones. So far, relatively good studies have been conducted on various industrial and laboratory scales on the capacity to cut rocks. The relevant studies in this area include the taxonomy systems and statistical relationships. Moreover, some researchers have studied the parameters of the stones and the specifications of the cutting plane, and the others have examined the operational parameters in the field of the cutting process. Table 1 and Figure 1 indicate some important studies over four decades and the frequency of parameters in the previous studies, respectively.

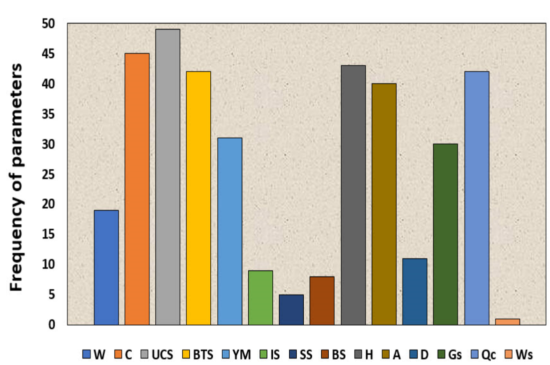

Figure 1. Frequency of parameters in previous studies.

According to Figure 1, among all the factors influencing the stone-cutting process, the physical and mechanical properties of the stones have been among the most important parameters studied in most of the studies. In this work, we use the statistical studies in order to investigate the relationship between the mechanical properties of stones and the operational characteristics of the cutting machines with the electrical current consumed by the cutting machines. Despite the fact that there are some useful research works on this scenario, this type of analysis has never been applied before.

The rest of this paper is laid out as what follows. Section 2 provides a comprehensive overview on the methodology. Section 3 describes the statistical analysis, and then the results will be discussed. Section 4 concludes with a summary of the findings and the suggestions for the future research works.

2. Methodology

In order to study the energy consumption in the cutting process, it is necessary to know the cutting mechanism and its parameters. The stone cutting process is an abrasion process, in that the cutting of stone with the help of diamond segments can be considered by the abrasion of the particles that make up the stone by passing diamond grains on the surface of the stone. In general, the process of cutting stones using diamond equipment can be summarized as the following two steps. The first stage of the stone-cutting process is achieved as a result of the movement of diamond segments on the cutting surface, followed by the formation of stone chips as a result of the penetration of diamond grains into the stone. During this process, the diamond grains form a chip by scratching and splitting the cutting surface, creating a new surface for the next diamond grain. When a diamond cutting device cuts a stone, the mechanical interaction between the device and the stone generates the forces of the process, which is mainly due to the factors such as the change of elastic and plastic shape in the stone and friction between the diamond grain and the matrix with stone and chips as the result of cutting. These changes in the input force, the varying elevation of the rock surface, irregularities in the thickness of the chips, the breaking and layering of the chips, and the friction between the surfaces, among others, cause ever-changing cutting conditions [68-70]. Figure 2 shows a schematic view of a diamond grain in the process of cutting and the interaction of the existing forces between the diamond grain and the scratched surface of the stone.

Table 1. Literature review of saw ability studies.

Researchers	Year	Saw type		Physical and mechanical properties											
		W	C	UCS	BTS	YM	IS	SS	BS	H	A	D	Gs	Qc	Ws
Burgess [7]	1978		●										●	●	
Wright and Cassapi [8]	1985		●	●	●					●	●			●	
Birle and Ratterman [9]	1986		●							●					
Jenning and Wright [10]	1989		●	●	●					●				●	
Clausen *et al.* [11]	1996		●										●	●	
Ciccu *et al.* [12]	1999	●				●				●					●
Agus *et al.* [13]	2003	●								●			●	●	
Wei *et al.* [14]	2003		●	●						●	●			●	
Eyuboglu *et al.* [15]	2003		●	●	●	●				●					
Ersoy and Atici [16]	2004		●	●	●	●	●	●	●	●	●	●	●	●	
Kahraman *et al.* [17]	2004		●	●	●		●			●	●				
Gunaydin *et al.* [18]	2004		●	●	●		●								
Ozcelik *et al.* [19]	2004	●		●	●	●				●		●		●	
Buyuksagis and Goktan [20]	2005		●	●	●					●	●			●	
Ersoy *et al.* [21]	2005		●	●	●	●	●	●	●		●	●		●	
Delgado *et al.* [22]	2005		●							●				●	
Kahraman *et al.* [23]	2005		●					●						●	
Cai *et al.* [24]	2007	●		●		●	●		●			●			
Fener *et al.* [25]	2007		●	●	●		●			●	●				
Kahraman *et al.* [26]	2007		●	●	●							●		●	
Ozcelik [27]	2007	●		●	●					●				●	
Tutmez *et al.* [28]	2007		●	●	●		●			●	●				
Buyuksagis [29]	2007		●	●	●				●	●	●	●		●	
Mikaeil *et al.* [30]	2008	●		●										●	
Kahraman and Gunaydin [31]	2008		●							●		●			
Mikaeil *et al.* [32]	2011a		●	●	●										
Ataei *et al.* [33]	2012		●	●	●					●	●				
Ataei *et al.* [34]	2012	●		●	●					●	●		●	●	
Yurdakul and Akdas [35]	2012		●	●	●				●	●	●	●			
Ghaysari *et al.* [36]	2012	●											●		
Mikaeil *et al.* [37]	2013		●	●	●	●				●	●		●	●	
Sadegheslam *et al.* [38]	2013	●		●		●					●			●	
Careddu and Cai [39]	2014	●	●												
Careddu and Lanceni [40]	2015	●	●												
Tumac [41]	2015		●							●	●				
Mikaeil *et al.* [42]	2016		●	●	●	●				●	●		●	●	
Aryafar and Mikaeil [43]	2016		●	●	●	●				●	●		●	●	
Tumac [44]	2016		●	●	●						●	●			
Almasi *et al.* [45]	2017a	●		●	●	●				●	●		●	●	
Almasi *et al.* [46]	2017b	●		●	●	●				●	●		●	●	
Almasi *et al.* [47]	2017c	●		●	●	●				●	●		●	●	
Kamran *et al.* [48]	2017	●		●	●	●				●	●		●	●	
Akhyani *et al.* [49]	2017		●	●	●	●				●	●		●	●	
Mikaeil *et al.* [50]	2017	●		●	●	●				●	●		●	●	
Yilmazkaya *et al.* [51]	2018	●		●		●	●	●	●		●		●	●	
Tumac and Shaterpour [52]	2018		●			●	●	●					●	●	
Aryafar *et al.* [53]	2018a		●	●	●	●				●	●		●	●	
Aryafar *et al.* [54]	2018b		●	●	●	●				●	●		●	●	
Akhyani *et al.* [55]	2018		●	●	●										
Mikaeil *et al.* [56]	2018a		●	●	●	●				●	●		●	●	
Mikaeil *et al.* [57]	2018b		●	●	●	●				●	●		●	●	
Careddu *et al.* [58]	2018	●		●					●		●	●			
Careddu *et al.* [59]	2019	●		●					●		●	●			
Akhyani *et al.* [60]	2019		●	●	●	●				●	●		●	●	
Mohammadi *et al.* [61]	2019		●	●	●	●				●	●		●	●	
Dormishi *et al.* [62]	2019a		●	●	●	●				●	●		●	●	
Dormishi *et al.* [63]	2019b		●	●	●	●				●	●		●	●	
Mikaeil *et al.* [64]	2019a		●	●	●	●				●	●		●	●	
Haghshenas *et al.* [65]	2019		●	●	●	●				●	●		●	●	
Hosseini *et al.* [66]	2019		●	●	●	●				●	●		●	●	
Hosseini *et al.* [67]	2020a		●	●	●	●				●	●		●	●	
Hosseini *et al.* [68]	2020b		●	●	●	●				●	●		●	●	

W, Diamond wire saw; C, Circular saw, Frame saw and Chain saw; UCS, Uniaxial compressive strength; YM, Young's modulus; BTS, Indirect Brazilian tensile strength; IS, Impact strength; SS, Shear strength; BS, Bending strength; H, Hardness; A, Abrasivity; D, Density; Gs, Grain size; Qc, Quartz content; Ws, Wave speed.

In general, the parameters affecting the stone-cutting process can be analyzed in three main parts:

A) Stone specifications,

B) Cutting specifications including the operational parameters and cutting design specifications, and

C) Management specifications such as the operator skills and the work environment conditions.

Among these parameters, the operational parameters and the cutting design specifications are considered controllable or the related parameters, and the related parameters related to the rock characteristics as the uncontrollable or independent parameters in the stone-cutting process. Each one of these parameters has a unique role in the efficiency and production capacity of the cutting process. The rock properties are one of the key parameters in the cutting process, especially in the chip formation. As the host of cutting operations, the stone has a pivotal role in the cutting and production process. The stone specifications determine the conditions, quality, and quantity of the interaction between the stone and the machine. Therefore, forming the chips and advancing the tool vastly affects it. Due to the wide range of geo-mechanical characteristics of stone, in order to facilitate the analysis and study of these parameters, they are mostly divided into three characteristics: physical, mechanical, and structural. At first, by examining the rock mass and intact rock, the parameters affecting the cutting process were determined and categorized. Then the characteristics of the intact rock that affect the cutting process are considered because the cracked, fissured, and discontinuous samples are not used for testing. Finally, among the studied parameters of intackt rock, four strength parameters of rock are selected that have the greatest impact on the rock cutting process. In the following sections, the characteristics of the samples of rock, testing the samples of rock, and the specifications of the cutting machine are discussed, respectively [63-68]. Figure 3 shows the parameters affecting the stone-cutting process [67-68].

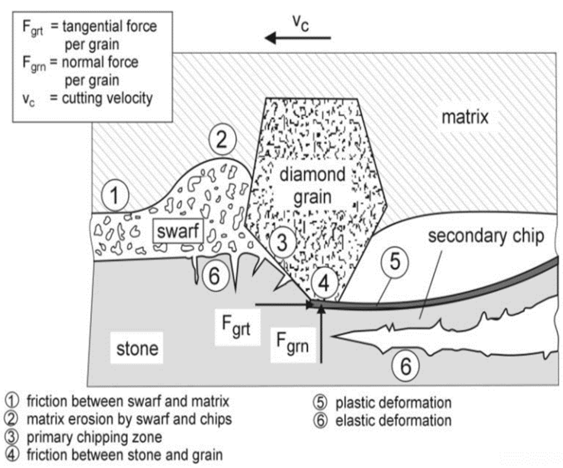

Figure 2. Interaction of existing forces between diamond grain and stone scratched surface [69].

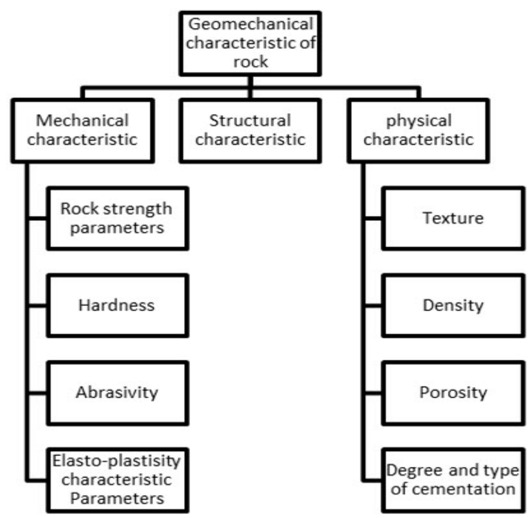

Figure 3. Effective parameters of rock profile in stone-cutting process.

2.1. Rock mechanical characteristic

The ability to deform and the manner and the type of rock break are subject to its elasticity and plasticity. Depending on how the rock will be deformed as a function of the stresses generated by static loads, the rocks can be divided into three groups:

A) Brittle elastic or those that follow the Hooke's law.

B) Brittle plastics that have a plastic deformation before breaking.

C) Extremely plastic or porous with no definite elastic deformation.

Most of the minerals in the rocks have an elastic brittleness, and thus follow the Hooke's law. The elastic properties of the rocks are determined by their elastic modulus. In some rocks, fractures and breaks occur after plastic deformation; this occurs when the stresses exceed the elastic limit. Some researchers have used the elastic modulus in their studies, while the others have used rock crushing indicators in order to study and analyze the cutting process. Due to the change in the mechanism of formation and growth of lateral cracks in the stone and, consequently, the formation of secondary chips, the ability to cut the stone also changes by changing the elastic modulus and the crisp indicators of the stone. Moreover, studies show that by improving the elastic modulus and brittleness indices of the stone, the stone's cutting capacity decreases. Some researchers have studied the brittleness of rock and elastic modulus in their studies of stone cutting capability [10, 13, 16, 19, 30, 70-73]. For a more comprehensive study of the contact mechanics, refer to the relevant references [74-80].

Under the influence of single-axis pressures, the rocks have two types of behavior: ductile and brittle. A brittle rock sample's stress and strain diagram consist of an almost straight section that leads to the breakpoint at the moment of failure. The diagram corresponding to the ductile-type minerals has two parts: a straight line for an elastic behavior (up to the elastic breakpoint) and plastic (or soft). Examining the types of stress-strain curves of rocks under the influence of an single-axis pressure, it is evident that basalt, quartzite, diabase, dolomite, and some other limestone rocks have an elastic straight-line stress-strain curve (that ends in the breakpoint of the stone). The area enclosed below the straight line between the origin and every point of the curve in the position of ultimate strength of rock represents the equivalent energy density stored in the rock before the fracture point. Figure 4 shows the energy density equal to that stored in the rock before the breakpoint. The equivalent energy density stored in the rock before the fracture point can be calculated from Equation 1.

$$E = \frac{UCS^2}{2YM} \tag{1}$$

2.2. Laboratory and field studies

In order to examine the behavior of the sample minerals in different operating conditions (machining), a cutting machine was made on a laboratory scale. In order to devise and present a statistical model for predicting the intensity of the current consumption of the cutting machine, various tests were performed in different operating conditions on 12 samples of building stone. The statistical data was collected in two parts: laboratory and field. The specifications of the cutting machine and the specifications of the stone and the cutting tool are presented in the following sections.

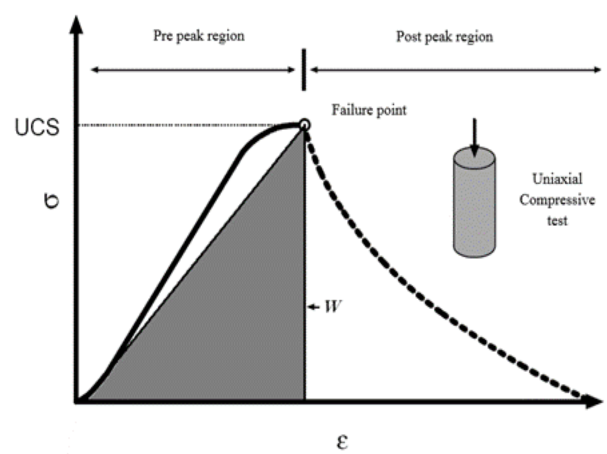

Figure 4. Stored equivalent energy density in the rock before the Failure point

2.2.1. Piecework characteristic

The second part of the laboratory studies was performed on the studied rock samples in order to investigate the relationship between the hardness of rock samples, cutting depth, and feed rate with energy consumption. For this purpose, a total of 12 samples of construction stone including 5 samples of hard rock and 7 samples of soft rock available in the country were collected, and the amount of energy consumption in different operating conditions was measured and recorded in the laboratory. The samples with an average size of 30 × 40 × 30 cm and an approximate weight of 50 kg were selected in order to determine the mechanical properties. The samples were transferred to the laboratory to perform the mechanical stone experiments. All experiments were performed with a high accuracy according to the standards of the International Society for Rock Mechanics (ISRM) suggested methods [81]. The results of the undertaken studies are given in Table 2.

Table 2. Results of laboratory tests of samples.

Mine	Stone	UCS (MPa)	YM (GPa)	E (MJ/m^3)
Ghaleh Khargush	Red granite	142	43.6	0.231
Chayan	Black granite	173	48.6	0.308
Nehbandan	White granite	145	35.5	0.296
Khosh-tinat	Khoramdarreh choclate granite	133	28.9	0.306
Khatam Granite	Morvarid granite	125	31.2	0.25
Zulfiqar Ali	Harsin crème marble	71.5	32.5	0.079
Gol sang	Anarak pink marble	74.5	33.6	0.083
Azar shahr	Red travertine	53	20.7	0.068
Haji abad	Travertine	61.5	21	0.09
Darreh bokhari	Travertine	63	23.5	0.084
Salsali	Marmarite	73	31.6	0.084
haftuman	Pink marble	74.5	35.5	0.078

YM: Modulus of elasticity, UCS: Uniaxial Compressive Strength, E: energy density stored until before the breakpoint.

2.2.2. Cutting machine characteristics

The cutting machine was designed and built in such a way that the parameters of the machine such as the cutting depth and feed rate are adjustable with minor changes therein. The various components of this device include the device bed (consisting of two guide rails for the moving table of the device), the upper part of the chassis (location of the main axis of the device), and the lower part of the chassis (for collecting muds, water and cut chips, Figure 5). The movable part of the device has a flat surface on which the stone pieces for cutting operations are fixed. The machine desk is moved by a wheel and chain mechanism installed on a hydraulic motor on the machine rail. Using a hydraulic system allows one to control and adjust the velocity of the desk, which is also known as the forward speed. Power is transmitted to the main shaft by a pole and a rubber belt. The cutting disc is installed and fastened between two cast iron washers by a bolt and nut mechanism. The throat part is fixed on a steel bed attached to the main bearing bed. The bearing of the throat bed is such that it allows a very limited rotational movement of approximately 0.8. The main spindle motor with a power of 7.5 kW is installed on top of the bed. A vertical movement is performed by a hybrid mechanism that employs a hydraulic motor. This mechanism, which is based on the screws and bolts, provides the ability to adjust the cutting depth with an accuracy of 0.01 mm. A hydraulic unit is employed in order to start the drive motors of the desk (horizontal movement) and the throat bed (vertical movement). This system allows the operator to control the movement velocities. The device's electrical circuit is such that it is possible to control the device's feed-in three modes: manual, semi-automatic, and fully automatic. Electronic counter-measures the velocity. During the test, the current consumption intensity of the device is measured by a precise ammeter in different machining conditions including different feed rates (100, 200, 300, and 400 cm/min) and different cutting depths (15, 22, 30, and 35 mm). In all experiments, the cutting process was done in the parallel state (moving in line with the rotation of the disk), and the water was used as the cooling fluid.

Figure 5. Scheme of cutting machine.

2.2.3. Cutter tool characteristics

In the cutting experiments, two hard and soft metal discs with a diameter of 41 cm and a thickness of 2.7 mm were used. 28 diamond segments with dimensions of 3×10×40 mm are soldered around the steel body. The artificial diamond grains in the octagonal cubic crystals with 40/50 mesh for hard disk and 30/40 mesh for soft disk and weight percentages of 25-30 and 30-40, respectively, for the two soft-cutting and hard-cutting disks are distributed on the metal bands. The specifications of the disks used in the cutting experiments are given in Table 3.

Table 3. Specifications of discs used in cutting experiments.

Disc type	Percent of used diamond in the band	Mesh size of diamond crystals
Hard cutter	30-40 %	40-50
Soft cutter	25-30%	30-40

Thus after performing the laboratory studies, 223 workpieces were cut under different machining conditions on the studied stones, of which 112 workpieces belonged to the soft stones, while 111 workpieces were associated with the hard stones.

3. Statistical Analysis and Discussion

For evaluating a dataset and modeling and predicting the relationships between a dependent variable and one or more independent variables in the engineering and academic problems, there is a wide range of regression analysis used by the researchers [82-88]. Since there are so many elements that affect the rock sawability, simple regression models cannot be used to analyze it. As a result, the multiple regression approaches must be used in the study. The twin-logarithmic model, which is one of the non-linear approaches, was employed in this analysis [17]. In this part of the study, the statistical studies on the laboratory results were performed with the help of the SPSS software in order to investigate the relationship between the intensity of the current consumption of the cutting machine and the hardness of the stone samples and the operational parameters. The relationships obtained from the statistical studies are presented as follow in Table 4.

In the equations, IS represents the current of cutting machines in terms of amperes for the soft rock samples, IH is the current of cutting machines in terms of amperes for the hard rock samples, DC is the depth of cutting in mm, Fr represents the feed rate in centimeters per minute, YM is the modulus of elasticity in gigapascals, and E is the energy density stored in the rock sample. In all of the equations above, the device's consumption current was considered the dependent parameter. In contrast, the rock sample's operational or machining specification and modulus of elasticity and energy density were considered the independent parameters. The statistical tests were employed in order to examine and control the obtained equations. The flowchart shown in Figure 6 shows the steps to control and validate the relationships, respectively.

Table 4. Resulting relations using statistical analysis.

Relation No. 1	$I_S = \frac{D_c^{0.542} \times F_r^{0.433} \times YM^{0.253}}{10^{1.119}}$
Relation No. 2	$I_S = \frac{D_c^{0.544} \times F_r^{0.432} \times E^{0.104}}{10^{0.641}}$
Relation No. 3	$I_H = \frac{D_c^{0.69} \times F_r^{0.497}}{10^{1.166} \times E^{0.169}}$
Relation No. 4	$I_H = \frac{D_c^{0.67} \times F_r^{0.508} \times YM^{0.471}}{10^{1.81}}$

One of the important points that should be considered in the statistical analysis, especially in presenting the statistical relations, is the existence of logical coefficients or, in other words, following the relationship of the inherent nature of the process [89]. In the equations presented in this work, only Equations 1, 2, and 4 have consistent values, and are acceptable in terms of logical coefficients. What is certain is that by increasing the modulus of deformation and energy density stored in the rock sample, the cutting ability of the sample is reduced. This can be attributed to the increase in the resistance characteristics of the rock sample (grain boundary resistance and rock matrix), and its consequent decrease in the chip-taking capacity of the diamond grain.

As shown in Figure 6, F-test was used in order to control the significance of the relationship, while t-tests were used to control the significance of each one of the independent variables. The exponential coefficient of each parameter is determined separately for each equation using the SPSS statistical software. The results of the statistical studies (correlation coefficient and F-test and t-tests) are shown in Table 5. Given that the value of the F-test obtained from the distribution table is greater than the value of F obtained from the relation with a confidence level of 99%, the null hypothesis, which states that there is no linear relationship between the dependent variable (intensity of the current consumption of the device) and independent variables (stone specifications and machinery specifications), is thus rejected. Hence, it can be concluded that at least one of the coefficients of the fit is not zero. After examining the overall significance of the relationship with the F-test, the significance of each one of the independent variables was controlled with a t-test. The null hypothesis in that each one of the coefficients of the independent variables being zero can be investigated using this method. In this section, the t-values of each one of the variables were compared with the t-value obtained from the distribution table. The results of these studies indicate that for all the relationships presented, only the t value obtained for the energy density variable stored in the rock is less than the value obtained from the distribution table (with a 90% confidence interval). Therefore, among the remaining relationships (Equations 1, 2, and 4), Equation 2 is disqualified in terms of validity at this stage. Based on the experiments conducted at this stage, the null hypothesis is rejected, stating that the coefficients of the independent variables for Equations 1 and 4 are zero. Thus the two mentioned relations are nominated as the best relations following a proper control and validation.

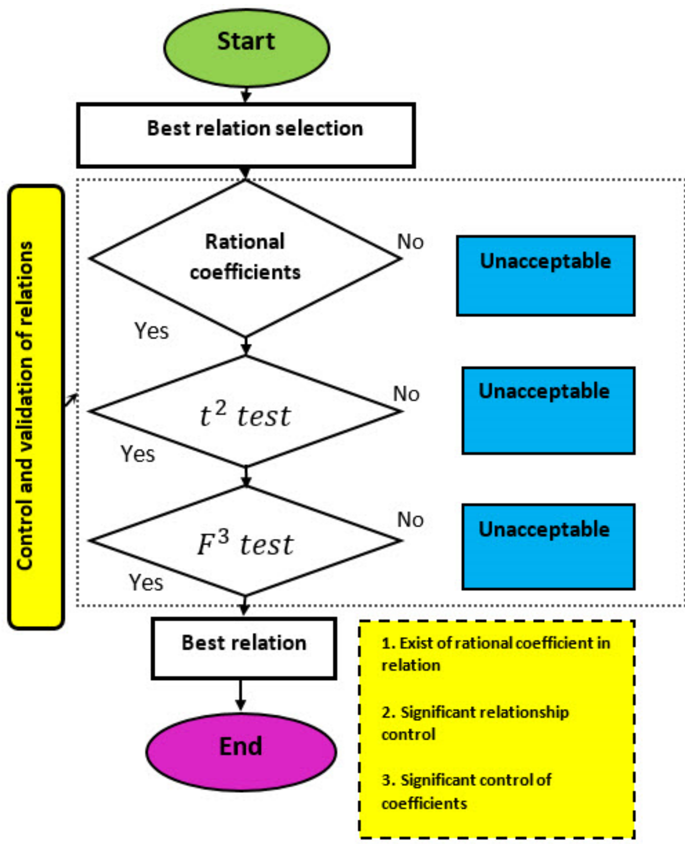

Figure 6. Flowchart of statistical control and validation of obtained relationships.

In order to make a final assessment of the statistical relationship, the distribution of the predicted and real points relative to the 1:1 bisecting line was investigated. The dispersion of the predicted points relative to the actual values of the current consumption for the cutting machine is shown in Figs. 7 to 10 for the two Equations 1 and 4. The higher the density of these points towards the bisecting line, the better the accuracy of the relationship. According to the dispersion of the predicted and real points for the training and testing data, it can be inferred that the presented relationships have a good accuracy in estimating and predicting the consumption current.

Table 5. Results of statistical analysis to predict cutting rate.

Relation	Parameters	Exponential coefficients	Standard error	F	Table F	t	Table t	R
No. 1	Constant	-1.119	0.067	205	5.56	-16.71	1.66	0.97
	Dc	0.542	0.023			23.28		
	Fr	0.433	0.013			32.28		
	YM	0.253	0.033			7.61		
No. 2	Constant	-0.641	0.136	295	5.56	-4.72	1.76	0.95
	Dc	0.544	0.03			18.29		
	Fr	0.432	0.017			25.21		
	E	0.104	0.133			0.92		
No. 3	Constant	-1.166	0.137	121.73	5.56	-8.54	1.66	0.9
	Dc	0.69	0.057			12.19		
	Fr	0.497	0.03			16.45		
	E	-0.0169	0.135			1.25		
No. 4	Constant	-1.81	0.138	203	5.56	-13.07	1.76	0.93
	Dc	0.67	0.046			14.64		
	Fr	0.508	0.024			20.83		
	YM	0.471	0.065			7.19		

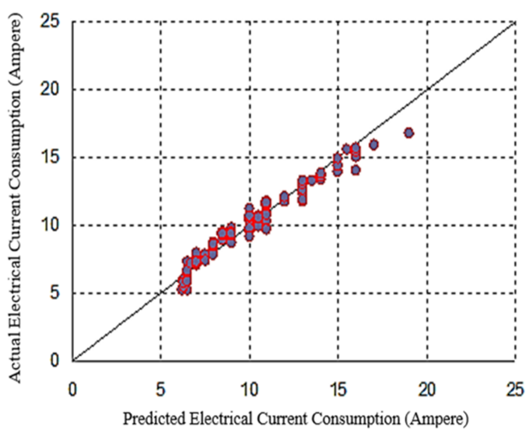

Figure 7. Scatter of predicted and actual data relative to bisector of first coordinate region (Model No. 1).

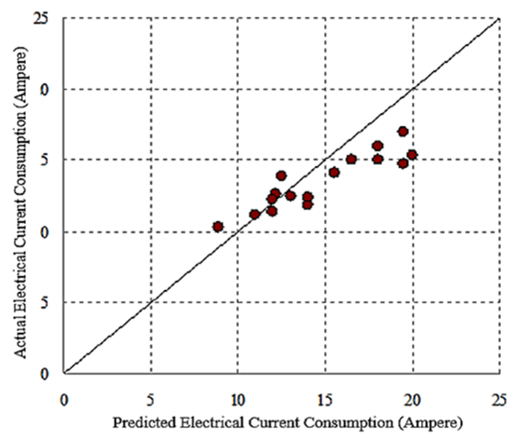

Figure 8. Scatter of predicted and actual data relative to bisector of first coordinate region (Model No. 2).

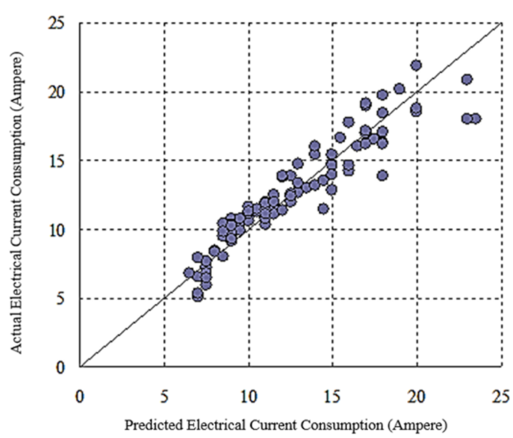

Figure 9. Scatter of predicted and actual data relative to bisector of first coordinate region (Model No. 3).

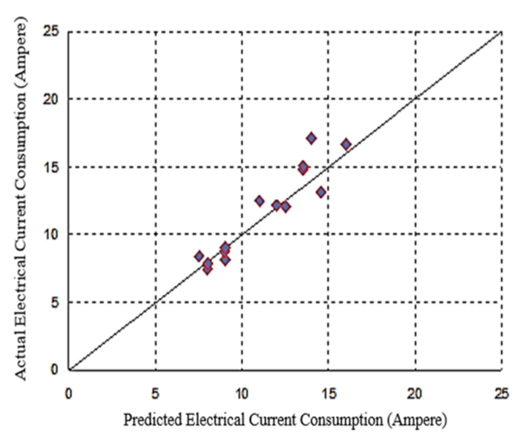

Figure 10. Scatter of predicted and actual data relative to bisector of first coordinate region (Model No. 4).

4. Conclusions

In this work, the relationship between the intensity of the current consumption of the cutting machine and the operational parameters and one of the important mechanical characteristics of stone was studied by conducting detailed experiments and statistical studies. For this purpose, 12 samples of the construction stones from the hard and soft ones were selected. The current consumption of the cutting machine in different machining conditions was recorded in the laboratory. The samples were then transferred to the Stone Mechanics laboratory for rock mechanical testing, and the elasticity modulus of the rock samples was determined. Consequently, the statistical studies were performed on the statistical population. The multivariate adjustments showed that in both groups of stones, as the amount of elasticity modulus and machining characteristics improved, the amount of current flow intensity of the device increased. During this research work, the relationships obtained from the statistical studies were examined using the t-test and the F-test in order to control and measure the significance of the relationship and the coefficients. The results of these studies indicated that using multiple regression made it much easier to find the relationship between the cutting machine consumption and the effective parameters. Also the intensity of the current consumption of the cutting machines could be evaluated and predicted according to the specifications of machining and elastic modulus of the stone sample, with a high level of confidence and a good correlation coefficient.

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مطالعه آماری برای ارزیابی عملکرد دستگاه برش در فرآیند برش سنگ ساختمانی

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چکیده:

پیش‌بینی میزان آمپراژ ماشین‌های برش می‌تواند یکی از گام‌های حیاتی در بهینه‌سازی مصرف انرژی برای صنعت برش سنگ ساختمانی باشد. از این رو، بررسی رابطه بین ویژگی های عملیاتی ماشـین های برش و سـنگ ها با تمرکز بر انرژی مصـرفی دسـتگاه اجتناب ناپذیر اسـت. بدین منظور در مرحله اول، مطالعات آزمایشـگاهی تحت شـرایط عملیاتی مختلف در عمق برش و نرخ پیشـروی متفاوت بر روی ۱۲ نمونه سـنگ نرم و سـخت انجام می شـود. در ادامه مطالعات آزمایشگاهی، نمونه های سنگ به منظور تعیین خواص مکانیکی (مقاومت فشاری تک محوری و مدول الاستیسیته) به آزمایشگاه مکانیک سنگ منتقل می شوند. مطالعات آماری در نرم افزار SPSS به منظور پیش بینی جریان الکتریکی مصرفی دستگاه برش با توجه به مشخصات مکانیکی نمونه سنگ، عمق برش و سرعت تغذیه انجام می شـود. مدل های آماری ارائه شـده در این کار را می توان با قابلیت اطمینان بالا به منظور تخمین جریان الکتریکی مصـرف شـده در فرآیند برش استفاده کرد.

کلمات کلیدی: فرآیند برش سنگ، سنگ های سخت، سنگ های نرم، مصرف جریان الکتریکی، مشخصات ماشین آلات، مطالعات آماری.