Iranian Journal of Engineering Geology
Summer 2022, Vol.15, No.2

Laboratory studies to investigate the relationship between specific energy consumption of diamond wire cutting machine with physical and mechanical properties of carbonate rocks

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Abstract

One of the criterions for evaluating the cutting of building stone using the diamond wire cutting system is the energy consumption of the cutting wire machine. In this study, in order to evaluate the amount of energy consumed in the cutting process, a laboratory diamond cutting wire system was designed and built with the ability to change and stabilize the operational and tooling parameters of cutting, including linear velocity, backward pulling speed and angle of impact of diamond wire. In order to determine the relationship between the physical and mechanical properties of the stone with the energy consumption of the cutting machine, 6 different samples of travertine were prepared from the mines of East and West Azerbaijan, Isfahan, Yazd and Markazi provinces and The values of physical and mechanical properties including density, porosity, water absorption, uniaxial compressive strength, tensile strength and the speed of ultrasonic waves passed through them were measured in the laboratory. Then, by cutting cubic blocks of the samples with the laboratory diamond cutting wire system, the energy consumption of the device in different situations of the angle of the wire with the sample was recorded. Using regression and univariate fitting, the relationship between each of the rock properties and the specific cutting energy with respect to linear, logarithmic, power and exponential functions was investigated. The results showed that the highest relationship between specific cutting energy and uniaxial compressive strength was observed as an exponential function with a correlation coefficient above 0.97 and the weakest relationship between water absorption percentages with specific cutting energy with a correlation coefficient of less than 0.14. The best value for the angle at which the wire hits the specimen, at which the lowest specific energy consumption is recorded, was 15 degrees.

Keywords: *Diamond Cutting Wire, Travertine, Specific Cutting Energy, Linear Wire Speed, Univariate Fitting*

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Extended Abstract:

1. Introduction

Diamond cutting wire machine is used extensively in building stone mines and more than 90% of mines are mined by this method. Iran is one of the richest countries in the field of reserves and resources of building stones in the world, more than ten percent of which is travertine. There are several effective factors in the stone cutting process that are divided into three parts, stone properties, operational and tooling characteristics of cutting and management factors. Among the above three factors, the components related to the characteristics of the stone are uncontrollable or independent and can not be changed and are fixed in all cutting methods. Considering that one of the most important parts in the cost of producing stone blocks from mines is the cost of cutting energy by the diamond wire cutting machine; Specific cutting energy is defined as the amount of energy required to cut a unit area of rock, and its study is of great importance for cost forecasting, mine design, and reduction of rock losses. Investigation of the relationship between cutting specific energy parameter and independent factors of physical and mechanical properties of travertine stones can be used to predict the cutting energy consumption and performance of diamond cutting wire machine. Conducting practical and purposeful research in this field leads to significant savings in energy consumption. In the researches, what has been paid less attention is the study of the type of cutting system with diamond cutting wire in different types of building stones, both in terms of physical and mechanical characteristics of the stone and in terms of different operational components and cutting tools. In this study, in order to determine the relationship between specific shear energy and physical and mechanical properties of rocks, due to the extent of travertine mines, laboratory studies were performed to determine the physical and mechanical properties of this type of rock. Then, by performing cutting experiments in different operating conditions of the wire component, the angle of impact of the wire with the sample, the amount of energy required to cut a unit of rock surface was calculated and determined. Finally, the relationship between the specific energy consumption of a diamond wire cutting machine and its physical and mechanical characteristics was evaluated.

2. Materials and methods

In order to conduct laboratory studies, the studied travertine rocks were first selected from 6 different mines, which were from different regions of Iran as much as possible. In this study, experiments to determine physical properties such as dry density, porosity and water absorption percentage and mechanical properties such as uniaxial compressive strength, Brazilian tensile strength and non-destructive tests such as longitudinal and transverse ultrasonic velocity according to the International Society of Rock Mechanic. According to the design of various experiments to achieve the objectives of this study and in order to minimize the effect of instrumental and operational components of the cut on the relationship between physical and mechanical properties of travertine stones and special energy consumption of cutting, design and manufacture of laboratory diamond cutting wire machine Ability to stabilize and change the tooling and operational parameters of the cut was done in the Rock mechanics laboratory of Shahrood University of Technology. The main components of the laboratory-redesigned diamond cutting wire system consist of four parts: a) the main chassis of the machine, b) the upper part of the chassis and power generating motors, c) the electrical panel and control system, and d) the sample holder. One of the main parts in the electrical panel is the inverter connected to the main motor, which operates to control the motor speed in proportion to the required linear speed by the method of voltage changes in relation to the frequency. Using the inverter used in the construction of this device, the rotation speed of the main motor and consequently the central pulley of the device can be adjusted with an accuracy of 1 rpm from 0 to 1800 rpm. Another inverter has been used to adjust the speed of the wire moving backwards so that the speed of the sub-motor connected to the screw gearbox can be controlled. With the help of this inverter and the screw gearbox system in the path of the gears, the back pulling speed of the wire can be changed from 1 to 100 cm per minute. The samples were cut into cubic blocks to make them easier and safer to place on the sample holder. The dimensions of the cutting surface of the specimens were considered to be one foot by one foot. In this research, a diamond cutting wire with a length of 7 meters, which has 30 diamond beads per unit length of wire and is of Sintered bead type, has been used. The desired speed for performing the experiments of this study was set and stabilized at 2.5 cm per minute for each experiment. To adjust the linear velocity of the wire, the speed of the main motor was set to 1600 rpm with the help of an inverter to set and stabilize the linear velocity of the wire at 50 meters per second. Also, based on the designs made for the experiments of this study, the angle of collision of the wire with the sample for each sample was set to three modes of 5, 15 and 25 degrees and the cutting process was performed. In total, for 18 different test modes, samples were cut and energy data in kilowatt hours were recorded in each section by the energy measuring device and the specific cutting energy consumption for each of the designed test modes was measured in kilowatt hours per square meter.

3. Results and discussion

After performing the designed laboratory tests, the relationship between the physical and mechanical properties of the rock and the specific cutting energy was evaluated using linear, logarithmic, exponential and power functions. In most cases, an acceptable logical relationship was provided with a high coefficient of determination. The best value of the angle of impact of the wire with the sample, in which the angle of the lowest specific energy of cutting is recorded in different states, is the angle of 15 degrees (relative to the horizon surface). The maximum specific cutting energy is related to the 25 degree angle. At an angle of 5 degrees, the reason for the increase in energy consumption can be attributed to the excessive increase in the contact surface of the beads with the sample and high friction and lack of appropriate chip removal. There is a significant relationship between uniaxial compressive strength, Brazilian tensile strength and compressive wave passage velocity, shear wave passage velocity and dry density of samples with specific cutting energy of samples with coefficients of determination above 85%. There is a weak correlation between porosity and water absorption with energy consumption of cutting samples with coefficients of determination less than 25%. In relation to the dry density of the samples with the specific energy of cutting consumption, it is noteworthy that between the minimum and maximum amount of specific energy of cutting consumption at the lowest and highest values of density, about 50% difference has been observed.

4. Conclusion

In this study, studies were conducted with the aim of finding the relationship between the most important physical and mechanical properties of rocks with the specific energy consumption of diamond cutting wire machine in fixed operating conditions with a special attitude towards angular

changes of wire with the sample. In this regard, 6 types of travertine stones were selected and 18 series of experiments were performed using a diamond cutting wire machine and the results were analyzed. The results showed that under constant operating conditions (linear velocity of the wire 50 meters per second and pull back speed of the wire 2.5 cm per minute) with increasing density, compressive and shear ultrasonic wave velocities, uniaxial compressive strength and Brazilian tensile strength, the specific energy of the cutting machine increases exponentially. By increasing the two parameters of effective porosity and water absorption coefficient, the specific energy consumption of the device decreases. There is a significant relationship between the three important characteristics of uniaxial compressive strength, Brazilian tensile strength and compressive wave velocity with specific cutting energy with a coefficient of determination above 93%. For shear wave passage velocity and dry density of samples with a specific cutting energy, a coefficient of determination above 86% was observed. The results showed that the best angle of impact of the wire with the rock surface is an angle of 15 degrees with the lowest specific energy consumption under constant operating conditions. The highest specific energy of cutting in all cases is related to the angle of 25 degrees. The main reason for this position is the lack of proper contact of the beads with the sample and less chipping at the same cutting time due to the open angle of the wire with the sample and excessive tension of the wire in this case. This has caused uneven cuts and sometimes ruptures of the wire.

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