



Research article

Evaluation of the cuttability of Sandstones based on rock texture characteristics and geomechanical parameters

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Keywords

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Regression analysis
Modified Intact Rock cuttability index

English Extended Abstract

Summary

Mechanized drilling methods are considered a suitable alternative to traditional drilling methods. On the other hand, the successful application of these technologies in mining and construction projects requires understanding the cuttability of the rock and matching the ground conditions with the machine design. In

mechanical drilling, the cuttability of the rock refers to the ease or difficulty of breaking (cutting) the rock by the cutting tool, which is expressed by Specific Energy and cutting forces and is a function of the geomechanical properties and texture of the rock. In this study, using laboratory data obtained from the physical, mechanical, and textural properties and cutting force of intact rock samples from various formations (Upper Qormez, Lalun, Gurpi, and Hezardareh) in different parts of the country (Tehran, Qom, and Khuzestan), an attempt has been made to accurately evaluate the cuttability of rocks with the help of these parameters based on statistical methods. In addition to the common mechanical properties, the textural properties of the samples were determined by preparing and studying thin sections of the rock samples and quantifying their parameters. Specific energy is known to be the most important index of rock cuttability, which was determined by a small-scale linear rock shear test. In this study, the correlation of the cuttability index with other geomechanical and textural parameters was evaluated using linear and multivariate regression analysis. The analyses indicate a diverse range of relationships between geomechanical and textural parameters and cuttability in the sandstones and argillaceous rocks studied. These relationships include direct correlations, indirect correlations, and, in some cases, no statistically significant relationship between these parameters. Accordingly, in order to evaluate more quickly and accurately, the cuttability index of intact rock was modified using effective textural and geomechanical parameters.

Introduction

Modern societies must excavate the Earth's crust for mining and construction. This necessity has increased since the 1950s, especially with the advancements in mechanized excavation techniques. In mechanical drilling, understanding the cuttability of rock is essential because this knowledge is used to select, design, and predict the performance of the drilling machine. Technical literature on the subject mentions two terms: "cuttability" and "drillability" of rock. Rock cutting ability refers to data from rock cutting tests (as shown in Figure 1), which allows for comparison of tool and cutting machine performance. Drillability refers to how

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quickly a drilling machine can penetrate rock. Various researchers are studying the relationship between textural properties and the mechanical properties and cutability of rocks. As Bell [1] observed, the strength properties of rock may be associated with grain packing density [2]. The theory of the texture coefficient (TC), developed by Howarth and Rowlands [3], facilitates the determination of the variation in the mechanical properties of rocks in relation to their textural properties. Tuğrul and Zarif [4] investigated the effect of physical and mechanical properties of rocks on their engineering properties. The researchers reported that the type of contact, grain shape, and grain size significantly affect the engineering properties of granite rocks [4-5-6]. The researchers' findings indicate the presence of an inverse relationship between grain size and uniaxial compressive strength of rock. Modeling-based studies demonstrate that the ultimate strength of granite can be inversely affected by geometric heterogeneity [7], mineralogy [8], and grain size distribution [9].

A plethora of additional studies have been conducted by researchers in the field of predicting the drillability of rocks and determining their index indicators, including specific energy (SE) and forces acting on the cutting tool. Ersoy and Waller [10] investigated the relationship between TC and drilling rate on sandstones. The researchers demonstrated that TC and its components exert a direct influence on the drillability, mechanical properties, and abrasion performance of rocks. Furthermore, they proposed that additional rock properties, such as the degree and nature of cementation and structural bonding, should be taken into account when calculating TC. Balci and Bilgin [11] conducted a series of full-scale linear rock shear tests on a variety of rock types and demonstrated that the measured shear force values were in close agreement with the tensile and compressive strengths of the rocks. Furthermore, it was determined that the physical-mechanical properties of the rock were influenced by its mineralogical and textural characteristics [12].

Methodology and Approaches

The objective of this study is to evaluate the cutability and textural properties of rocks and to explore the relationships between these characteristics. A total of 18 rock samples, classified as soft to medium according to the 1981 International Society for Rock Mechanics (ISRM) classification system based on uniaxial compressive strength, were collected from various locations in the provinces of Tehran, Qom, and Khuzestan. In order to ascertain the mechanical properties and cutability of interest in this research, uniaxial compressive strength tests, indirect tensile strength (Brazilian), rock abrasion resistance (Cechar), and small-scale linear rock shear tests were performed on the samples, and the relevant and required parameters were calculated. Additionally, porosity, dry density, and compression wave velocity were calculated as physical properties of the rock samples. To quantify the texture and its morphological characteristics, the texture coefficient (TC), grain size index, and microcrack parameters were used, respectively. A series of statistical analyses were conducted to ascertain the relationships between the various intact rock samples under consideration and to predict their cuttability.

Results and Conclusions

Statistical analyses conducted on the parameters of rock texture and mechanical properties of the samples demonstrate that the relationship between Brazilian tensile strength and the number of microcracks is an inverse relationship with a correlation coefficient of $R^2=0.60$, indicating a substantial relationship between them. The presence of microcracks in the rock texture is indicative of structural weakness, with these cracks reducing the tensile strength of the rock. Consequently, the tensile force is more influenced by the presence of microcracks than by other mechanical properties of the rocks. The texture coefficient demonstrated a low correlation coefficient ($R^2= 0.22$) with the mechanical properties. In summary, the effect of the texture coefficient on mechanical properties is negligible. The texture coefficient is a measure of the geometric characteristics of rock texture. It does not include other textural parameters, such as the number and volume of pores, or structural characteristics, including microcracks and grain orientation.

However, it should be noted that the study does not encompass additional textural parameters, such as the quantity and size of pores, or structural characteristics including microcracks and grain orientation. Among



the mechanical properties of the rock, the Cerchar index with $R^2=0.92$ and the Brazilian tensile strength with $R^2=0.62$ have the greatest impact on the cutability properties. The Cerchar index is a quantitative metric that assesses the resistance of a rock surface to abrasion by a foreign object. It directly influences the cutability of the rock and contributes to an increase in specific energy. The index demonstrates a strong correlation with the cutability of the rock. The tensile mechanism of rock failure under the cutting tool is a critical factor in determining the rock's cutability and its subsequent control. Among the physical and machinability characteristics of rock, the porosity percentage of the rock is of particular significance. This percentage represents the volume of pores in the rock texture and has a considerable impact on the most important parameters of strength and machinability.

The enhancement of microcracks within rock formations has been demonstrated to diminish the strength of the intercrystalline bonds that bind the constituent grains. Consequently, these grains are more susceptible to fracture when subjected to the forces exerted by a cutting tool. The increase in microcracks concomitantly leads to an enhancement in the processability of the material. The observed weak relationship between specific energy and the number of microcracks can be attributed to the dispersion of the data results. Given that the samples examined in this research are sandstone and argillite rocks, their behavior under applied force differs. Specifically, argillite rocks exhibit ductile behavior, while sandstones demonstrate increased brittleness. Therefore, argillite rocks exhibit a reduced propensity for microcrack formation in comparison to sandstones. Multivariate regression analysis was conducted to ascertain the factors that significantly influence rock cutability. The analysis revealed that porosity percentage (n), content index (CAI), and Brazilian tensile strength (BTS) are the most critical physical properties; content index (CAI) and Brazilian tensile strength (BTS) are the most critical mechanical properties, and grain size (d) and microcracks (mic) are the most critical textural properties. These factors were found to have the greatest impact on predicting rock cutability.

The results of the multivariate regression analysis suggest the development of a correction equation for the virgin rock cutability index. This proposition was advanced in the present study. A notable strength of this study is the basis of the proposed index on data from a small-scale linear cutting experiment employing a fixed-section disk cutting tool, which aligns closely with the actual conditions of mechanized drilling. The proposed equation below utilizes less complex texture parameters that can be readily and expeditiously extracted from thin-section images of rocks. Utilizing these parameters in lieu of the texture coefficient not only reduces the computational time but also minimizes human error in micrometric analysis.

$$IRCI' = \text{Log} \left[\frac{10(CAI \times mic \times d \times BTS)}{n} \right] \quad (1)$$

Figures and Tables



Fig. 1. Small-scale linear cutting test with a cutting depth of 2 mm on a rock sample.



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