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Evaluating the cutting rate of travertine stones based on physico-mechanical characteristics through regression models

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Abstract

Evaluating the cutting rate (*CR*) of stones is important in the cost estimation and the planning of the stone processing plants. This research used regression models to estimate the stones' *CR* based on their physico-mechanical characteristics. Stone processing factories in Mahallat City (Markazi province, Iran) were visited, and the *CR* of diamond circular saws was recorded on six different travertine stones. Next, the stone block samples were collected from the quarries for laboratory tests. Stones' porosity (*n*), uniaxial compressive strength (*UCS*), and Schmidt hammer hardness (*SH*) were determined in the laboratory as their physico-mechanical characteristics. Correlation relationships of *CR* with physico-mechanical characteristics were evaluated using simple and multiple regression analyses, and estimator models were developed. Results showed that multiple regression models are more reliable than simple regression for estimating the stones' *CR*. The validity of the developed multiple regression models was verified with the published data of one researcher. The findings indicated that these models are accurate enough for estimating the *CR* of stones. Consequently, the multiple regression models provide practical advantages for estimating the *CR* and save time and cost during the planning and design of the stone processing factories.

Keywords: *Cutting rate; Porosity; Schmidt hammer hardness; Travertine stones; Uniaxial compressive strength*

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Extended Abstract:

1. Introduction

Circular diamond saws have been widely used in stone processing plants. Evaluating the stone sawability is very important in the planning for the plants and their cost estimation. Stone sawability can be measured in terms of the cutting rate (*CR*), also called slab production or production rate. *CR* is the quantity of the area cut per unit of time expressed as m^2/h. In practice, this criterion is calculated using the following equation:

$$CR = \frac{L \times H}{t} \qquad (1)$$

where *CR* is the cutting rate (m^2/h), L (m) and H (m) are the cutting length and height of the stone block work-piece, respectively, and t (h) is the cutting time of the stone block work-piece.

CR depends on non-controlled parameters related to stone characteristics and controlled parameters related to characteristics of cutting tools and equipment. In the same working conditions, the sawing process and its results are strongly affected by the petrographic and physico-mechanical characteristics of the stone. Several studies have reported the relationship between *CR* and physico-mechanical characteristics such as porosity (*n*), uniaxial compressive strength (*UCS*), and Schmidt hammer hardness (*SH*) (Almasi et al., 2017a; Jamshidi 2019).

The *n*, *UCS*, and *SH* are increasingly used worldwide by geotechnical and mining engineers regarding their simplicity, rapidity, low cost in execution, and non-destructiveness. As the index parameters, these characteristics have been used by some researchers in the building stones industry for a quick assessment of the various stones *CR* (Guney, 2011; Tumac, 2015; Almasi et al., 2017a).

The present study aimed to develop new simple and multiple regression models for estimating the *CR* of travertine stones using the *n*, *UCS*, and *SH*. These models provide more insight and add more information to the correlations between *CR* of travertine stones with their *n*, *UCS*, and *SH*.

2. Materials and methods

The present study used simple and multiple regression analyses to estimate the *CR* of the different travertine samples using their *n*, *UCS*, and *SH*. To achieve the objectives of the present study, we made field visits to the travertine quarries in the Mahallat area (Markazi Province, Central Iran). Then, stone processing factories around of Mahallat area were visited, and the *CR* of large-diameter circular saws were measured on six different travertine types. During the cutting operation in the processing factory, the cutting time (*t*) of the travertine stone block was obtained. Based on the recorded time, and cutting length and height (*L* and *H*, respectively) of the stone block work-piece, *CR* (m^2/h) for each travertine type was calculated according to Eq. (1) presented in the “Introduction” section.

In the following this step, the block samples were collected from various travertine quarries for laboratory tests. These samples are marketed in construction industries as ornamental, cladding, and building stones. After transferring the block samples to the Laboratory of Engineering Geology and Rock Mechanics, the specimens with standard shapes and sizes were prepared from them using a coring machine. Finally, some of the physico-mechanical characteristics of the samples such as density (ρ), *n*, *UCS*, and *SH* were determined.

3. Results and Discussion

Simple regression analyses, including linear (y = ax + b), power ($y = ax^b$), exponential ($y = ae^x$), and logarithmic (y = a + ln x) regression, were conducted on the data to investigate the correlations between *CR* with *n*, *UCS*, and *SH* of the samples. These analyses were performed to develop the best correlation between different variables to attain the most reliable empirical equation.The results indicates a moderate linear correlation between *CR* and *n* (R^2 = 0.69).The best-fitted correlation between *CR* and *UCS* was offered by a power regression curve. A moderate power correlation between *CR* and *UCS* was obtained with an R^2 of 0.79. Similarly, a power correlation was observed between *CR* and *SH* with a lower R^2 of 0.65.

Multiple regression analyses were performed to investigate the relationships between *CR* with *n*, *UCS*, and *SH* of the samples. The dependent variable is the *CR*, and the independent variables are *n*, *UCS*, and *SH*. The regression analyses are performed using the SPSS®v.16 code statistical software. Multivariate regression analyses were conducted with a 95% confidence level and the best-fit curves were obtained using the least squares method.

The coefficient of determination (R^2) and standard error of estimate (*SEE*) were used as the numerical measures of the goodness of fitting curves for the regression equations. The degree of fit to a curve can be measured by R^2 and *SEE*. R^2 measures the proportion of variation in the dependent variable. On the other hand, *SEE* indicates how close the measured data points fall to the estimated values on the regression curve. The R^2 of multiple regression equations are higher than 0.80, which is acceptable. The *SEE* values for these equations are 0.36, 0.38, and 0.41, respectively. These measures show that multiple regression equations can be accepted as a highly reliable estimate for the *CR* using *n*, *UCS*, and *SH*.

4. Conclusions

The results of regression analyses revealed that the multiple regression models are more reliable than the simple regression models for estimating the *CR* of samples. The validity of multiple regression models was investigated using the raw data obtained from experimental works published by one researcher. The results revealed that multiple regression models accurately estimate the *CR* from *n* and *UCS*.

Finally, the developed multiple regression model in this study is helpful for stone engineers in processing factories of the building stones such that the performance of large-diameter saw machines can be estimated from *n* and *UCS* of the stone. Overall, the multiple regression models provide practical advantages for estimating *CR* and save much time and cost during the planning and design of the stone processing factories.

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