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Predicting the performance of large diameter circular saws based on Schmidt hammer and other properties for some Turkish carbonate rocks

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ABSTRACT

Schmidt hammer hardness values (SHH_1, SHH_2, and deformation coefficient) are used to determine the performance of large diameter circular saws. The measured Schmidt hammer hardness values are correlated with the physical and mechanical properties of natural stones and areal slab production rates of large diameter circular saws. Two statistical models for prediction of the areal slab production rates for these machines are developed, which is very important in decision making for engineers. A simple statistical model is suggested taking into account the deformation coefficient and a multiple regression model is also suggested by using the deformation coefficient and Cerchar abrasivity index. The reliability of these models is tested against actual performance of large diameter saws. Verifications and comparisons showed that the models suggested in this study may be a very useful and reliable tool for prediction of areal slab production rates for large diameter circular saws.

1. Introduction

Large diameter circular saws (LDCS) have been widely used in the natural stone processing plants in order to produce slabs in different sizes. LDCS, among other machines used in the natural stone processing plants, achieve excellent production performance with minimum cost, with only operator. The surface of the slabs cut by a LDCS is neat and shaping is not required. However, they also have some limitations, which generally arise from geotechnical features of the stone. Selection of a suitable machine and its performance generally depends on the physical and mechanical properties of the stone, machines characteristics, saw properties, penetration rate, and tool consumption. Machine performance directly affects the planning of the plants and the cost estimation of the producing companies. Burgess [1], Hausberger [2], Ceylanoglu and Gorgulu [3], Brook [4], Wie et al. [5], Gunaydin et al. [6], and Kahraman et al. [7] are among the researchers who have published relationships between sawability capacity and stone properties. Norling [8] correlated sawability of stones with petrographic properties and concluded that grain size was more relevant to sawability than the quartz content. Clausen et al. [9] performed acoustic emission tests and suggested that acoustic emission might classify the sawability of stones. Konstanty [10] proposed a theoretical model for chip creation and removal process in optimizing the tool composition and sawing process parameters. Zhang and Lu [11] studied the optimal designing and rotational use of diamond saw blades. Kahraman et al. [12] established artificial neural network (ANN) models to estimate the sawability capacity of carbonate rocks and they concluded that ANN models were more reliable than the statistical models for this purpose. Delgado et al. [13] investigated the relationships between rock microhardness and sawing rates of pink Spanish granite and they found a strong correlation between sawing rate and rock microhardness. The performance of LDCS and stone properties were evaluated by Tutmez et al. [14] by using the multifactorial fuzzy approach which is a special case of multiple objective multifactorial decision making for the sawability classification of building stones. They classified the sawing performances of diamond saws into three main categories. Ribeiro et al. [15] related the sawability of stones with machine characteristics, type and diameter of saw, depth of cut, and stone properties. Kahraman and Gunaydin [16] investigated the performance of LDCS on eight different carbonate rocks and found strong linear correlation between indentation hardness index values and the hourly production of circular saws. Guney [17] studied five different marbles quarried in the Mugla Province of Turkey. He developed several statistical models based on the relations between hourly slab production, rock surface hardness, and mineral grain size.

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Schmidt hammers (SH) have been used throughout the world as a nondestructive compressive strength estimating machine. The SH is a portable, cost effective instrument capable of estimating the rock properties with several advantages over traditional rock testing methods. SHs are available from their original manufacturers in several different energy ranges. These include: Type L with 0.735 N m impact energy, Type N with 2.207 N m impact energy, and Type M with 29.43 N m impact energy. A method was suggested by ISRM [18] for conducting the SH test. Schmidt rebound value can be calculated by averaging the highest 10 values out of 20 rebound values from single impacts separated by at least a plunger diameter.

Many research studies using the SH have been carried out by rock engineers in order to estimate the intact rock mass properties and the performance of mechanical excavators (roadheaders and impact hammers). Hucka [19], Deer and Miller [20] performed some experiments on rocks and concluded that compressive strength might be predicted from rebound values with a statistical reliability. Kidybinski [21] analyzed the SH rebound values and the quantitative description of roof conditions; and found a good correlation between the rebound values and roof quality. Fowell and McFeat-Smith [22] stated that the most suitable instrument for the determination of the in-situ hardness of rocks was SH. They determined the deformation coefficient (K) of rocks according to SH values. A series of 20 tests is made with the hammer held at a position proved to be competent. A plot of the hardness against test number shows that the readings increase initially and then maintain a constant level after 20 tests, with only a small variation. Deformation coefficient can be calculated as follows:

$$K = \frac{SHH_2 - SHH_1}{SHH_2} \times 100 \quad (1)$$

where K is the deformation coefficient expressed as a percentage, SHH_2 is the constant value obtained after approximately 20 tests at the same point, SHH_1 is the first rebound value. The results obtained from this approach were correlated with the performance of roadheaders. Young and Fowell [23] monitored the performance of a roadheader during the extension of a heading in the Four Fathom Mudstone, in the UK. They pointed out that in fractured rock the primary influence on the performance of the machines were rock discontinuities rather than the intact rock properties, and SH rebound value were a good indicator of rock discontinuity. Poole and Farmer [24] tried to determine the influence of rock discontinuities and they stated that SH rebound values were a good indicator of rock discontinuities. Sachpazis [25] found out that there was a possibility of estimating the compressive strength and tangent Young's Modulus of rocks from rebound numbers. Goktan and Ayday [26] pointed out that SH had a possible use in the prediction of the performance of mechanical excavators considering the mechanical properties of rock if proper testing, recording, and data processing methods are used. Kahraman [27] analyzed the relationships between SH rebound values and uniaxial compressive strength values on 48 different rocks. He determined that significant non-linear correlation exists between the compressive strength of rocks, SH values, and density. Bilgin et al. [28] pointed out that SH rebound values were a good indicator of rock characteristics and they stated that these values had a significant correlation with the net breaking rates of impact hammers when the rock formation is grouped based on RQD values. Goktan and Gunes [29] carried out SH tests on 36 different rocks and compared the SH values with roadheader performance. Statistical test results suggested that incorporation of all recorded rebound values at a point, rather than selecting only the peak values, gives a better representation of overall rock hardness and hence a better performance prediction. Ozkan and Bilim [30] suggested a new procedure in order to determine the optimum test number and to find the optimum grid section area for coal-face testing in underground and open-pit coal mines. They also aimed to analyze the cutting performance of a drum shearer used at the coal face.

Researchers are interested in finding a method to predict the performance of excavation or sawing machines by using rock properties obtained by simple tests. Schmidt hammer hardness is one of the simplest methods giving the surface hardness of the tested material. Although it has been previously demonstrated that Schmidt hammer hardness is related, to some extent, to rock/stone cuttability [22], the number of the researches in this respect is rather limited. In the light of this fact, this study aimed to develop statistical relationships between Schmidt hammer hardness values (SHH_1, SHH_2, and deformation coefficient), physical and mechanical property values, and areal slab production rates (*ASPR*s) of large diameter circular saws (LDCS). The results of laboratory and field studies are used to develop simple and multiple regression models in order to predict *ASPR*s of LDCS. Therefore, two models are suggested and statistically verified. One of the models is based on the deformation coefficient, and the other model is based on the Cerchar abrasivity index and deformation coefficient. Finally, the relationships between actual and predicted *ASPR*s are analyzed.

2. Experimental studies and discussions

Block samples with a minimum size of around $25 \times 25 \times 30$ cm^3 were obtained from natural stone factories where large diameter circular saws (LDCS) were employed to produce slabs. Physical and mechanical property tests according to ISRM [18] were carried out on seven different natural stone samples: Afyon tigerskin marble, Afyon white marble, Karacabey black limestone, Manyas white marble, Marmara white marble, Milas white marble, and Eskisehir supreme limestone. Cerchar abrasivity tests (*CAI*) were performed based on the procedures described by ASTM [31]. Schmidt hammer (SH) hardness tests, SHH_1, SHH_2, and deformation coefficient (K), were carried out by using an L type SH, as determined by Fowell and McFeat-Smith [22]. SH tests were performed on stone blocks (dimensions can be seen in Section 3) prepared for sawing process of LDCS. Measurement points are at a distance of at least a plunger diameter from each other, only one test at the same spot is carried out to obtain SHH_1 values, and the minimum number of tests for each sample is taken as 20. SHH_1 is calculated as the average of readings at 20 points. To obtain SHH_2, 20 rebound tests are made constantly at one point on the stone surface. After the first rebound, the SH hardness values steadily increase and stay constant after a certain rebound. SHH_2 is the constant value of SH hardness. SHH_2 is calculated as the average of 20 SHH_2 values. Deformation coefficient (K) is taken as the difference in percentage between the values of SHH_2 and SHH_1, as given in Eq. (1). Some of the physical and mechanical properties of natural stone samples are given in Table 1.

Table 1
Summary of the physical and mechanical properties of natural stone samples.

Natural stone name	Density (g/cm^3)	Porosity (%)	*UCS* (MPa)	*BTS* (MPa)	CAI
Afyon tigerskin marble	2.81	0.27	81.3	5.1	3.05
Afyon white marble	2.68	0.16	88.6	6.0	3.50
Karacabey black limestone	2.70	0.50	70.8	5.4	1.86
Manyas white marble	2.71	0.40	65.3	3.9	2.00
Marmara white marble	2.71	0.20	70.4	4.1	2.15
Milas white marble	2.72	0.20	97.3	7.1	2.99
Eskisehir supreme limestone	2.74	0.30	89.0	5.3	2.44

UCS uniaxial compressive strength, *BTS* Brazilian tensile strength, *CAI* Cerchar abrasivity index.