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Estimating the sawability of large diameter circular saws based on classification of natural stone types according to the geological origin

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ABSTRACT

Different physico-mechanical parameters (density, uniaxial compressive strength, Brazilian tensile strength, Cerchar abrasivity index, Schmidt hammer hardness, Shore scleroscope hardness, and mean grain size) were used to find out the sawability of large diameter circular saws in the metamorphic and sedimentary natural stones. The simple, multiple linear and non-linear regression models were developed for estimation of the areal slab production rate of the large diameter circular saws. First, simple regression analyses were performed to find out the best relationships between the dependent variable (areal slab production rate) and each independent variable (physico-mechanical properties) in three different groups of natural stones as metamorphic, sedimentary, and metamorphic/sedimentary (combined). Second, multiple linear and non-linear regression analyses were carried out using selected independent variables. Then, the significances of these models were statistically validated. The models developed in this study could be used by planners and natural stone producing companies for cost prognosis and sawing operation schedule in the metamorphic and sedimentary stones.

1. Introduction

Natural stones have been used worldwide as construction and decorative materials. The classification of the natural stones is the first step towards proper selection of the saw tools and equipment. Two different methods might be used to classify the natural stones. The first one is based on the implementation fundamentals such as strength properties, hardness, porosity, color, and durability. The second one is based on the geological origin which are igneous rocks, sedimentary rocks, and metamorphic rocks. In recent years, the demand for natural stones has highly increased due to consistently developing technologies and rapidly spreading innovative design ideas.[1]

The large diameter circular saws (LDCS) are one of the most common types of machines used in the stone processing plants to cut slabs into different sizes. LDCS offer the most effective way to produce slabs with smooth surfaces which do not need any extra work for shaping. In addition, a single person can operate the machinery. All of these features make the LDCS very cost effective compared to other sawing machines commonly used in natural stone processing plants. However, these machines have their limitations and disadvantages in some cases which are generally related to the geotechnical properties of the natural stones. These machines are used for production of large blocks and slabs in nonabrasive to extremely abrasive and soft to hard strength natural stones.[2–5]

Proper selection and accurate performance estimation of LDCS are two main parameters that affect the cost estimation and planning of the plants. These two parameters generally depend on the physico-mechanical properties of the stones, specifications and design of the machine, and the operational conditions. Sawability and areal slab production rate (ASPR) are the most investigated parameters in the literature. Norling[6] stated that the grain size was more relevant to sawability than the quartz content. Burgess[7] suggested some models for sawability estimation based on the hardness, abrasion resistance, mineralogical composition, and grain size of the granites. Clausen et al.[8] used the acoustic emission to classify the stone sawability. Gunaydin et al.[9] applied the brittleness indexes for sawability estimation of carbonate rocks. Kahraman et al.[3] proposed some equations for estimation of the sawability of carbonate rocks based on the multiple curvilinear regression analysis. Based on the investigations performed on the pink Spanish granite, Delgado et al.[4] found a strong correlation between rock

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microhardness and sawability. Ribeiro et al.[10] correlated the sawability of stones with the specifications of machine, the depth of cut, and the features of stone. Kahraman and Gunaydin[11] correlated hourly production rate of circular saws with the indentation hardness value of the carbonate stones. Guney[12] investigated the performance of LDCS based on the surface hardness tests in the five different marbles. Tumac[5] suggested two statistical models based on the Cerchar abrasivity index and the deformation coefficient to estimate the ASPR of carbonate rocks. Sarisik and Sarisik[13] investigated the optimum performance parameters (cutting force, power, and specific energy) of a circular saw. Mikaeil et al.[14] suggested a new classification system for assessing of carbonate rock sawability as carbonate rock sawability index. Mikaeil et al.[15] correlated the ASPR of LDCS with rock brittleness indexes in natural stones. Kahraman et al.[16] used artificial neural networks method to estimate the sawability of carbonate rocks from cohesion, porosity, friction angle parameters. Tutmez et al.[17] investigated the performance of LDCS by using the multifactorial fuzzy approach. Tutmez and Kaymak[18] stated a new method for estimation of ASPR from mechanical properties of natural stones by fuzzy linear programming. Yurdakul et al.[19] used neuro-fuzzy method for estimation of specific cutting energy of carbonate rocks in LDCS. Tumac[20] investigated the sawability of LDCS with artificial neural network application in the sedimentary and metamorphic stones. The common point in the existing literature is the use of statistical analysis to find a meaningful correlation between the obtained data from the field and laboratory studies. Statistical analysis is one of the most important methods that is used to create models and explore the relationship between field and laboratory data. In addition, the previous studies indicated the importance of physico-mechanical properties of natural stones in performance estimation of LDCS. Fener et al.[21] investigated the sawability of carbonate rocks and determined good correlation between ASRP and uniaxial compressive strength of carbonate rocks. Yurdakul and Akdas[22] analyzed the prediction of specific energy of LDCS based on operational variables of block cutters and natural stone properties. Bilim[23] tried to find out the optimum cutting speed of block cutting machines.

However, to the knowledge of the present authors, in the existing literature, there are few models for performance estimation of LDCS that included the metamorphic and sedimentary natural stones together. Generally, the suggested models were obtained for specific types of natural stones such as carbonate rocks or marbles. In addition, only Guney[12] investigated the relationship between ASPR and crystal size in marbles.

Considering these facts, in this study, it was attempted to develop simple linear, multiple linear and nonlinear regression based models to estimate the ASPR of the LDCS in metamorphic, sedimentary, and metamorphic/sedimentary (combined data of metamorphic and sedimentary stones) rocks. The input parameters of these empirical equations are uniaxial compressive strength, Brazilian tensile strength, Schmidt hammer hardness, Shore scleroscope hardness, Cerchar abrasivity index, density, and mean grain size. In the statistical analysis, as a first step, the simple regression analysis was performed to find the best relationship between one physical or mechanical property and ASPR. In the second step, the stepwise regression procedure is applied to the physico-mechanical properties of the natural stones and ASPR of LDCS. The analysis of variance table is investigated for testing the significance of regression in the multiple regressions. Finally, the alternative models were suggested to estimate the areal slab production rate of the large diameter circular saws for the metamorphic, sedimentary, and combined metamorphic/sedimentary natural stones.

2. Details of the previously suggested performance estimation models

As briefly stated in the previous section, there are many performance estimation models used to estimate sawability of the large

Table 1
Summary of the LDCS performance estimation models.

No.	Estimated parameters	Natural stone parameters	Machine parameters	Origin of natural stones	Investigated block samples	Applied method	Reference
1	ASPR (m^2/h)	UCS, BTS	–	Sedimentary	8	Simple regression	Gunaydin et al. [9]
2	ASPR (m^2/h)	c, φ, UCS, BTS, SHH, IS, ISI, LA, Vp	R, d, D, N	Sedimentary	13	Multiple curvilinear regression	Kahraman et al. [3]
3	ASPR classification	UCS, BTS, SHH, I_s, ISI, LA, V_p	–	Sedimentary	8	Multifactorial fuzzy	Tutmez et al. [17]
4	ASPR (m^2/h)	UCS, BTS, SHH, I_s, ISI, LA, V_p		Sedimentary	8	Simple and multiple regression	Fener et al. [21]
5	ASPR (m^2/h)	ρ,*n*, IHI	–	Sedimentary	8	Simple and multiple regression	Kahraman and Gunaydin [11]
6	ASPR (m^2/h)	SSH, SHH, S_{cr}	–	Metamorphic	7	Simple and multiple regression	Guney [12]
7	SE (J/mm^3)	SHH	d, V_f	Metamorphic	6	Multiple linear regression	Yurdakul and Akdas [22]
8	SE (kWh/m^2)	–	S_c	Sedimentary	5	Simple regression	Bilim [23]
9	ASPR (m^2/h)	SHH, UCS, BTS, K, CAI	–	Sedimentary, Metamorphic	7	Simple and multiple regression	Tumac [5]
10	ASPR (m^2/h)	UCS, BTS, CAI,*n*, ρ	–	Sedimentary, Metamorphic	11	Artificial neural network	Tumac [20]

ASPR: areal slab production rate, SE: specific energy, UCS: uniaxial compressive strength, BTS: Brazilian tensile strength, c: cohesion, φ: frictional angle, SHH: Schmidt hammer hardness values, SHH: Shore scleroscope hardness, IHI: indentation hardness test, Is: point load strength, ISI: impact strength, S_{cr}: crystal size, K: deformation coefficient, CAI: Cerchar abrasivity index, LA: Los Angeles abrasion loss, Vp: P-wave velocity, ρ: density,*n*: porosity, Qc: quartz content, R. advance rate of saw, d: depth of cut, D: saw diameter, N: rotational speed of saw, V_f: feed rate, S_c: cutting speed.