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Effect of cutting parameters on consumed power in industrial granite cutting processes performed with the multi-disc block cutter

Murat Yurdakul *

Department of Technical Programs, Natural Building Stones Technologies Program, Bilecik Seyh Edebali University, Bilecik, Turkey

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ABSTRACT

The aim of this study was to investigate the effect of the cutting mode, cutting depth, and feed rate on the level of consumed power, during granite cutting using circular saw blades. In this context, two-column multi-blade block cutters were used to evaluate twelve different cutting conditions conducted with more than three hundred cycles. In these tests performed with 1200 mm saws, the feed rates of 10, 13, 15, and 17 m/min and cutting depths of 3, 6, and 9 mm were used, while the peripheral speed was kept constant (≈ 35 m/s). Based on the evaluation of industrial cutting conditions involving the sawing of relatively large rock blocks with a circular saw blade, it was determined that the down-cutting mode was more advantageous in terms of power consumption. In addition, the effects of the cutting mode, cutting depth, and feed rate on the cutting efficiency and power consumption (one of the most important indicators of cutting performance) were also determined.

1. Introduction

Owing to their solidity, their resistance to environmental influences, and the color alternatives they provide, hard stones are extensively used in the natural stone industry. Blocks cut in granite quarries using various methods are transferred to stone processing plants, where they are converted to finished products. In the cutting of relatively small slices from large granite blocks, one of the most significant costs is power consumption. A proper analysis of the cutting processes is of considerable importance for the effective optimization of operational parameters. The cutting operations of hard stones such as granite are different from that of other stones such as marble, limestone, and travertine. Depending on the hardness of the stones, the cutting depth used during the sawing of granite can be relatively small (generally between 1 and 9 mm). In industrial applications, granite and other hard rocks are generally cut in a sequential manner. Compared to the cutting of relatively soft rocks, another important difference in granite cutting is the widespread use of multidiscs rotated by a single motor.

There are numerous laboratory studies in the literature regarding the cutting of granites and natural stones. The study of Ertingshausen [1], for example, used a bridge saw machine with a motor power of 18.5 kW. This saw blade had a diameter of 600 mm, and a peripheral speed of 45 m/s. The cutting depth used during the study was between 10 and 60 mm, and the tests were performed on Colombo red granite. The results of this study demonstrated that the up-cutting mode was more advantageous in terms of power consumption at cutting depths below 20–25 mm, while the down-cutting mode was more advantageous at greater cutting depths. Konstanty [2], on the other hand, investigated the down-cutting and up-cutting modes, and their effects on segment wear. In this context, Konstanty made several recommendations for increasing saw blade life in both cutting models. In another study conducted by Konstanty [3] regarding the cutting of granite, the segment wear of different types of saw blades was investigated. Unver [4] developed an empirical formula for the prediction of specific wear and cutting forces during granite cutting. Based on the results of Unver's study, statistically significant relationships were identified between the saw blade-specific wear and the quartz grain size, NCB cone indenter value, and mean plagioclase grain size. In a study conducted by Luo [5], the segment wear that occurred during the cutting of hard and relatively soft granite with circular saw blades was evaluated. In Luo's study, 300–350 mm diameter circular saw blades were used, while the peripheral speed was 30–35 m/s, and the cutting depth was 20–30 mm. Based on the results of the study, the authors discussed the effects of diamond grits on the cutting efficiency observed during the cutting of hard and relatively soft granite.

In Webb and Jackson's studies [6], the relationship between saw blade wear and cutting forces during granite cutting were evaluated. In these studies, a strong relationship was identified between the normal cutting force and the tangential cutting force.

* Corresponding author at: Department of Technical Programs, Natural Building Stones Technologies Program, Bilecik Seyh Edebali University, 11100 Bozuyuk, Bilecik, Turkey. Tel.: +90 228 214 1569; fax: +90 228 214 1312.
E-mail addresses: murat.yurdakul@bilecik.edu.tr, muyurdakul@gmail.com

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In a study conducted by Xu [7], the interaction that occurs between granite and diamond grits on saw blade segments during the cutting of granite with a diamond saw was evaluated, along with the effect of this interaction on the cutting energy. Based on the study results, Xu concluded that a very large portion of the cutting energy was lost as a result of the friction between the granite and the diamond grit. Sun et al. [8], on the other hand, performed tests regarding a new type of matrix and the cutting performance of the saw blade. Sun et al. used a 105 mm saw blade during their study. In the tests performed within the context of the said study, the effect that adding SiC whiskers to the matrix had on the saw cutting performance was investigated. In this context, it was determined that the addition of SiC whiskers to the saw blades resulted in higher cutting efficiencies.

In a study conducted by Li et al. [9], the authors proposed a new cost-effective machining method for sawing granite materials with diamond impregnated tools. The authors of the study emphasized the importance of the interaction between the diamond tool surface and the workpiece. According to the results of the study, it was determined that high segment performance is dependent on the bonding and wetting that exists between the matrix alloys and diamonds by using a Ti–Cr alloy coating on diamonds. Furthermore, the study illustrated the possibility to improve the level of wetting, and to increase the debris storage capacity. This, in turn, has the effect of decreasing friction during the saw's operation. The study of Xu et al. [10] performed a quantitative evaluation on the forces and loads acting on diamonds grits during the cutting of two varieties of granite with a circular saw consisting of a segmented diamond blade. According to the results of this study, the wear of the diamond grits was associated with the high temperatures generated at the cutting point, and the heat transferred to the segment by diamonds breaking-off/separating from the matrix.

Di Ilio and Togna [11] proposed a theoretical model for describing the saw blade wear process. According to this model, the matrix material should not only support (or hold) the diamond grits on the segment, but it should also wear at a rate that allows the cutting efficiency to remain constant. In the study of Wei et al. [12], the fuzzy ranking method was used to evaluate and categorize the sawability of various types of granite. In the study, the dependence function and the fuzzy relationship of the granite's hardness, compressive strength, abrasiveness, quartz grain size, and quartz content with the sawing force and tool wear were determined by developing a new fuzzy mathematics method. The saw blades used in this study were 600 mm diameter circular saws, while the cutting depth was 10 mm, the peripheral speed was 35 m/s, and the feet rate was 3 m/min. The study concluded that the fuzzy ranking method could effectively determine and select a suitable saw blade by taking into consideration the petrographic and mechanical characteristics of granites. In an experimental study conducted by Xu et al. [13], the forces acting on a saw blade during the cutting of granite with a diamond impregnated saw blade were investigated. According to the results of the study, the cutting depth was the leading factor that affected the tangential and normal force components, and the cutting depth's effect was more significant than that of the workpiece velocity. Despite significant differences in sawing difficulty, the difference between different types of granites with respect to force components and force component ratios was less than expected.

Ersoy et al. [14] conducted an experimental study regarding the wear characteristics of saw blades during the cutting of abrasive and hard types of rocks. Within the context of their study, they developed a statistical predictive model for saw blade wear that took into consideration the specific cutting energy, the total silica content of rock, the bending strength and the Schmidt rebound hardness parameters. Delgado et al. [15], on the other hand, evaluated the relationship between the sawability of Pink Porrino granite and the Vickers microhardness. The results of Delgado et al.'s study demonstrated a strong correlation between the sawing rate and rock hardness. Wright and Cassapi [16] also conducted a study to predict beforehand the sawability of hard rocks such as granite. To this end, they used and evaluated eight different types of rocks in their study. Based on their study results, they concluded that there was no significant relationship between the mineralogic–petrographic characteristics of the rocks and the saw blade wear and consumed power, and that it was necessary to evaluate the physico-mechanical characteristics of the rocks. On the other hand, a strong relationship was identified between the forces acting of the saw and the saw wear and power consumption during cutting.

In a study conducted by Wright [17], the wear characteristics of diamond grits located at five different points selected on two types of segments were evaluated within the context of experiments involving the sawing of Cornish grey granite. The results of the study demonstrated that the wear of the diamond grits was associated with the distribution of these grits on the segment. Hausberger [18] conducted a study investigating the sawability characteristics of hard rocks. Within the context of this study, Hausberger performed mineralogical–petrographical analyses on these rocks and evaluated their physical and mechanical characteristics. He also evaluated the pieces that separated from the rocks during cutting. The mineralogical–petrographical analyses performed within the context of this study revealed that stones consisting of more than 5% quartz were relatively more difficult to cut. In addition to this, Hausberger also determined that the presence of cleavage planes and of minerals such as mica, homeblend, and pyroxene in the rocks favorably affected their sawability.

Jennings and Wright [19] attempted to theoretically describe the factors that affect saw performance during cutting. In this context, they suggested that the saw blade life could be predicted by using the Shore hardness value. Based on their theoretical study, Jennings and Wright described the factors that should be taken into consideration when selecting and using a diamond saw blade for cutting hard rocks. Luo and Liao [20], on the other hand, investigated the wear of diamond grits on saw segments during the cutting of Indian red granite, and evaluated how the diamond grits affected the performance of the saw blade. During the experiments, a saw diameter of 205 mm was used, while the cutting depth was 0.2 mm, and the feed rate was 1.0 m/min. The tests performed during the study demonstrated that in case the diamond concentration within the segments remained the same, segments with smaller diamond grits exhibited higher cutting performance when sawing Indian red granite.

In a laboratory study conducted by Ersoy and Atici [21], very hard and abrasive rocks were cut using 400 mm diameter saws. The results of the study demonstrated that an increase in cutting depth was associated with a decrease in specific cutting energy. In addition to this, an excellent relationship was observed between the cutting performance (in terms of specific cutting energy) and the physical and mechanical properties of rocks (such as their compression resistance, relative abrasion resistance, and abrasion factor). Luo and Liao [22] conducted a study in which three types of one-segmented diamond saw blades with different matrix hardnesses and diamond grit surfaces were used. The study evaluated the effects of the diamond grit surface properties and matrix hardness on the wear performance and the forces acting on the saw blade segment. The results of the study demonstrated that segments with smooth diamond grit surfaces and high matrix hardness exhibited better performance during the cutting of granite. In a laboratory study conducted by Buyuksagis [23], a 400 mm diameter saw blade was used to investigate the effects of the cutting mode on the granite cutting performance. In the