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Energy consumption analysis and cutting cost reduction strategies in granite cutting operations

Murat Yurdakul

Fine Arts and Design Faculty, Bilecik Seyh Edebali University, Gulumbe, Bilecik, 11100, Turkey

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The main problem encountered in natural stone cutting has been how to ensure clean and efficient production conditions that minimize saw blade wear and energy consumption, while maximizing production/cutting quantities, involving the finding of a balance between cutting costs and sales price. This study analyzes cutting data from more than 400 cutting cycles in an industrial granite-cutting process, obtained at different feed rates and cutting depths using a two-column block cutter with 23 x 1200 mm saw blades. Of the cutting parameters, feed rate and cutting depth values were varied, and power consumption values were measured using a mobile power analyzer, after which recommendations have been made for efficient cutting. Cutting tests have been conducted under conditions in which the feed rates were 8, 10, 15 and 20 m/min, and the depth of cuts were 3, 4, 6, 8 and 12 mm. The changes in energy consumption values at different depth of cut values and feed rateshave been evaluated under actual production conditions. According to the results of the study, changes in power consumption under shallow and deep cutting conditions were analyzed in detail, and an empirical model is proposed to explain the relationship between power consumption, production speed and saw blade costs.

Keywords: Granite cutting, Cutting costs, Power consumption, Economic model

1 Introduction

Granite has been used throughout the ages, and is the archetype that feeds the perception that stone is durable. Categorized as a hard stone in the natural stone sector, granite has been used both in rough-cut and polished forms, and comes in a wide range of colors, while being highly resistant.

From the quarry to the natural stone processing plant, granite differs from other rock, both in its cutting and processing. Granite is cut sequentially, at shallow depths, using multi-blade block cutters that have a different body design and a different segment structure.

With the advances in cutting technologies that have been seen since the 1980s, natural stone cutting costs have reduced overall, and cutting efficiency has started to increase[1]. The advances and innovations in cutting technologies have made it necessary to obtain optimum conditions if efficiency is to be assured.

Previous studies of natural stone cutting have been mostly laboratory-based, with cutting tests carried out using a single blade and with continuous rim diamond saw blades. These studies have usually focused on segment wear, loads on the saw blade and cutting forces, and the more prominent are detailed below:

Noting that natural stone cutting is a multi-dimensional problem, Konstanty[2] has examined cutting conditions in up and down cutting modes, which are used together in granite cutting, as well as the mechanism of the resulting wear in the segment. The author subsequently has made recommendations for the optimum cutting mode to improving the life of saw blades. In a study conducted with granite, Unver[3] has developed a new approach to the estimation of specific wear and cutting forces, finding saw blade wear to be statistically related to the quartz content of the rock, the average particle size, the NCB cone indenter hardness and the average plagioclase particle size. Webb and Jackson[4] have examined the effects of cutting forces on saw blade wear in granite cutting operations, and identify a significant relationship between wear and the ratio of cutting forces.

In a similar study to the present one, Ertingshausen[5] has conducted tests with cutting depths varying between 10 and 60 mm using a bridge saw machine with a 600 mm diameter saw blade. In practice, it is extremly difficult, if not impossible, to obtain a cutting depth of 60 mm using circular saw blades with large diameters. According the results of study, the more advantageous cutting mode is the up cutting mode when the depth of cutis less than 20–25 mm.

In another study aiming to explain the mechanism in the cutting process, Xu[6] has investigated the relationship between the diamond particles in the segment and the granite plate to be cut in granite cutting operations using circular saw blades. On the basis of these relationships, the author has shown how the power consumed in cutting is affected by this interaction. The author has found that most of the energy expended during cutting is a result of the friction between the diamond particles and the cut surface. The present study also aims to explain the main contributory factors in power consumption.

There have been studies in the literature examining how the segments used in cutting are affected by the cutting process, in other words, examining the wear mechanism, which is one of the most significant costs in the sector. In a study on segment wear, Luo[7] has examined the effects of the condition of the diamond particles on cutting efficiency in granite cutting operations that used circular saw blades at a depth of cut 20–30 mm. Li *et al.*[8] have emphasized that interaction between a diamond segmented saw blade and the material to be cut in granite cutting operations in which wear is an important factor. They conclude that diamond particles coated with titanium-chromium alloys, in particular, provide larger gaps for the removal of fragments from the rock. Sun *et al.*[9] have found that cutting efficiency could be increased in diamond segmented circular saw blades by changing the matrix structure in which diamond particles are embedded, specifically by adding SiC to the matrix. In a study conducted with granite, Zhang *et al.*[10] have examined the relationships between cutting forces on the one hand, and feed rate (V_f) and depth of cut on the other, and they find that lower cutting speeds and higher V_f are associated with lower cutting forces. The authors have developed a model to explain this relationship. In addition to diamond segmented circular saw blades, granite is also cut using multi-wire saws. Based on the relationship between processing time and the total volume of the stone processed, Faria *et al.*[11] have found rock hardness to have a direct effect on energy consumption values. Many of the studies in the literature note that granite is classified as a hard rock, and is difficult to cut[12–16]. Not with standing the difficulty and costs associated with granite cutting, it is sales price that determines the cut ability of granite. In other words, if sales prices exceed cutting costs, then the stone in question is considered suitable for cutting. When identifying the factors that affect cutting costs in natural stone cutting, power consumption and wear have always been taken into account, as are indirect saw blade costs[17–19]. Obviously, saw blade costs cannot be ignored, but whether they become the determining or the main factor in production decisions is another matter. There have been studies looking to optimize the cost of cutting processes in natural stone cutting, regardless of whether diamond wires or saw blades are used[20–22]. In natural stone cutting, costs are directly affected by a large number of parameters. Of the parameters that affect wear or cut ability, the one that has received most emphasis in the literature has been the physical and mechanical properties of rocks, which affect both energy costs and saw blade costs in natural stone cutting[23,24].

Almost all previous studies have been conducted under laboratory conditions, and cutting tests are usually carried out using continuous rim circular saw blades with a diameter of 200–400 mm.

In contrast, the present study has been conducted in an industrial setting, and is therefore, better able to capture actual working conditions than laboratory-scale studies.

All cutting data has been obtained from a multi-blade block cutter used actively in a granite cutting plant for commercial cutting. Both up-cutting and down-cutting data has been obtained from a 23-blade block cutter under shallow and deep cutting conditions, and in order to optimize cutting costs, an empirical model has been developed to explain the relationships between energy consumption, production speed and saw blade costs. By associating saw blade wear and cutting costs, the proposed model aims to help operators or production planning engineers obtain the optimum cutting conditions in production.

2 Materials and Methods

This study is based on cutting data obtained from the cutting of Balmoral red granite turned into plates using a multi-blade block cutter. The blocks to be cut were regularly shaped blocks (1.5 -5 m^3). The blocks were cut sequentially to obtain plates of the desired thickness using circular saw blade block cutters.

2.1 Cutting material

The cutting data in the study was obtained during the cutting of blocks with sizes varying between 160x170x250 cm and 180x180x300 cm, together with blocks of relatively smaller sizes.

The cutting parameters in granite cutting, that is to say, depth of cut and V_f, are set depending on the properties of the rock to be cut. Therefore, the basic properties of the granite should be known. Samples from the blocks to be cut were sent to the Geological Survey of Finland, and number of the basic properties of the rock was identified (Table 1).

The mineralogical make-up of Balmoral red granite, as is the case with all Rapakivi granites, is

Table 1 — General physical and mechanical properties of the Balmoral red granite used in the study.

Standard	Test	Value
EN 13755	Water Absorption (%)	0.12
EN 1936	Apparent Density (kg/m^3)	2640
EN 1936	Open Porosity (%)	0.39
EN 1926	Compressive Strength (MPa)	171
EN 12371	Compressive Strength after Frost (MPa)	179
EN 12372	Flexural Strength (MPa)	13.4

Fig. 1 — An overall view of the blocks cut and the block cutter from which power consumption values were obtained.

mainly large orthoclase crystals surrounded by plagioclase. The mineralogical composition of the Balmoral red granite used in the present study was 39.6% K-feldspar, 30.1% quartz, 22.1% plagioclase, 5.2% biotite, 1.3% muscovite, and 1.8% other minerals.

2.2 Obtaining the cutting data

The data used in the study was obtained in an industrial stone cutting process. To be able to compare data, measurements were made in different shifts. Balmoral red granite blocks were cut using a two-column multi-blade block cutter with 23 saw blades installed (Fig. 1).

In industrial cutting conditions, the usual practice is to line blocks of similar or different sizes next to one another, and complete the vertical cuts first. This is followed by horizontal cuts to obtain the plates. Obtaining plates from blocks is the first stage in the process in creating the final product.

To avoid variation in electricity data due to different cutting lengths, we focused exclusively on cutting conditions in which all of the saw blades cut for the same cutting length. If the cutting lengths are not the same, not all of the blades would be inside the block at a given time, which would change or partially reduce the power consumption values.

Each of the circular saw blades installed on the block cutter used in the study had a diameter of 1200 mm. The saw blade segment thickness was 8 mm, the segment lengths were 24 mm, and the segment height was around 12 mm. The segments were conical sandwich-type segments and with a Rockwell hardness number of B90.

The saw blades used in laboratory-scale studies have a lower body strength, different segment structures and water channels, and relatively smaller diameters than those used in cutting plates to size. Therefore, the forces and consumed power values are different when cutting with large saw blades than with blades with smaller diameters (200–600 mm).

The data used in the study was obtained in real time from the cutting of different blocks, measured with a power analyzer that draws data from current meters and voltage alligator clips installed on the electrical panel of the block cutter.

Power analyzers measure current, voltage and engine multipliers simultaneously, and record power consumption in real time (Fig. 2). The mobile power analyzer used in the study was installed on the main line that sends the electrical current to the vertical saw blades on the block cutter. The power consumption values during the forward and backward movement of the saw blades in each cutting cycle were recorded. When using block cutters to obtain plates from granite blocks, the saw blade is operated differently when compared to other natural stone and marble cutting operations. The saw blades cut as they move both forward and backward and the desired cutting depth is reached after multiple cutting cycles. This is also known as sequential cutting. In industrial cutting operations, unlike in laboratory studies, different depth of cuts and V_f values are selected for the forward and backward movement of the cutting discs. In the present study, the same cutting depths and feed

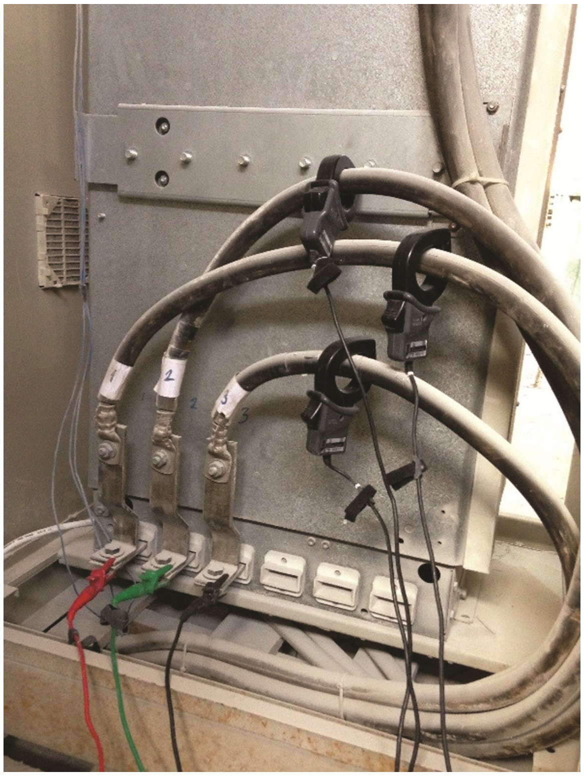

Fig. 2 — Placement of the power analyzer used for the power measurements on the control panel of the machine.

rates were selected for the forward and backward movements of the saw blades in each measurement condition. This was done to measure saw blade behavior – or power consumption values, during the forward and backward cutting using the same parameters.

Feed rates of 8, 10, 15 and 20 m/min were selected, as well as cutting depths of 3, 4, 6, 8 and 12 mm, and the differences between the shallow and deep cuts were recorded. All cutting tests were conducted at a peripheral speed of approximately 35 m/s. When cutting hard stone, such as granite, previous studies recommend, and operators usually prefer, a peripheral speed of around 30-35 m/s[7,8,13]. The operating parameters for cutting tests are reported in Table 2.

For each cut, the power consumed during cutting was recorded with the power analyzer over a minimum of 20 cycles, and the results were averaged. This study presents only general graphs showing the average values in order to avoid overcomplicating the paper with cutting data from over 400 cuts.

3 Results and Discussion

Identifying costs has always been important in natural stone cutting, particularly in granite cutting operations, in terms of production efficiency and sales. There have been many studies in the literature reporting wear to be an important cost item[8,9]. Wear is a natural result of the cutting operation, and is a function of the mismatch between the rock and the cutting segment, the amount of water, and more importantly, the cutting depth and feed rate. In a way, wear is not a cause of increased costs, but a natural result of cutting disc and operating parameters.

Table 2 — Operating parameters for the saw blade from which energy values were obtained

Cutting Depth (mm)		Feed Rate (m/min)	
Forward	Backward	Forward	Backward
3	3	8	8
		10	10
		15	15
		20	20
4	4	8	8
		10	10
		15	15
		20	20
6	6	8	8
		10	10
		15	15
		20	20
8	8	8	8
		10	10
		15	15
		20	20
12	12	8	8
		10	10
		15	15
		20	20

The consumed power values obtained in this research for the up and down-cutting conditions are reported in Table 3. These are the average values for a minimum of 20 cuts under each cutting condition.

According to Table 3, in the up-cutting mode, the average power consumption was 20.84 kW at a depth of cut of 3 mm and V_f of 8 m/min, and 34.24 kW at the same depth of cut and a V_f of 20 m/min (Cuts 1, 4).

Changes in consumed power values depending on depth of cut are reported separately in Figs 3 and 4, for up and down-cutting modes respectively. In general, there is an exponential relationship between depth of cut and consumed power. The coefficient of determination (R^2) values were found to be 0.993, 0.998, 0.989 and 0.997, respectively, for the V_f of 8, 10, 15 and 20 m/min.

Higher feed rate and depth of cut values are associated, in both cutting modes, with higher power

Table 3 — Average power consumption values and cutting conditions under which the data were obtained

Cutting No	Depth of cut (mm)		Feed rate (m/min)		Average consumed power (kW)	
	forward	backward	forward	backward	forward	backward
1	3	3	8	8	20.84	23.50
2	3	3	10	10	22.10	25.41
3	3	3	15	15	28.02	31.24
4	3	3	20	20	34.24	37.85
5	4	4	8	8	23.15	25.24
6	4	4	10	10	25.41	28.15
7	4	4	15	15	33.76	34.31
8	4	4	20	20	38.17	40.95
9	6	6	8	8	31.17	34.41
10	6	6	10	10	33.40	36.10
11	6	6	15	15	41.90	45.84
12	6	6	20	20	47.14	51.88
13	8	8	8	8	37.58	39.94
14	8	8	10	10	40.10	42.11
15	8	8	15	15	45.13	48.40
16	8	8	20	20	51.78	54.24
17	12	12	8	8	43.17	45.19
18	12	12	10	10	46.34	49.70
19	12	12	15	15	51.77	54.88
20	12	12	20	20	57.15	61.40

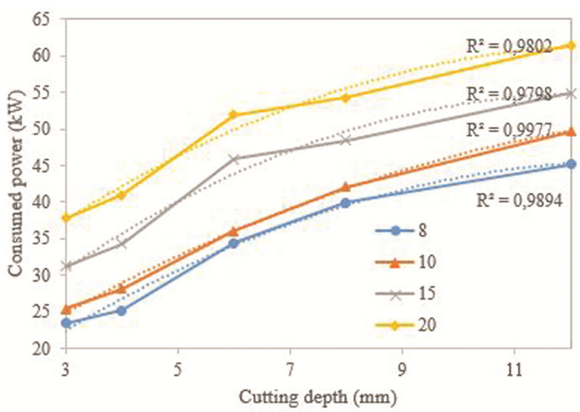

Fig. 4 — The relationship between cutting depth and average power consumption in the down-cutting mode, at different feed rates.

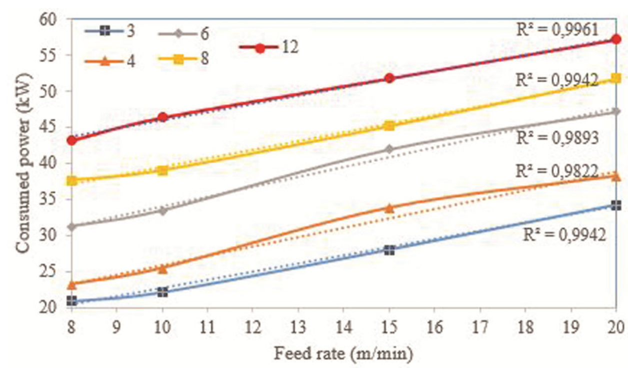

Fig. 5 — The relationship between feed rate and average power consumption in the up-cutting mode, at different cutting depths.

consumption values. Looking at the down- and up-cutting modes separately, at a given feed rate, the difference between the consumed energy values in the all of the cutting modes is 2–4 kW at all cutting depths. Figs 5 and 6 plot the power consumption against feed rate at five different cutting depths.

Under industrial cutting conditions, it is known that deeper cuts result in higher power consumption values. However, the extent of change in power consumption as a result of changes in cutting depth has not previously been studied.

Table 3 shows that in the up-cutting mode, power consumption was 20.84 kW at a depth of cut of 3 mm and a V_f *value* of 8 mm (Cut 1), and increased to 31.17 kW when the depth was doubled (Cut 9).

Therefore, a doubling of the depth did not result in double the power consumption. At all of cutting depth levels, doubling the depth less than doubled power consumption, and this observation applies also to other cutting conditions when the cutting depth is doubled (Cuts 5 and 13; Cuts 9 and 17).

This is also true when the cutting depth is doubled at the V_f values of 10, 15 and 20 m/min. To give an example, power consumption in Cut 7, carried out at a 5 mm depth of cut and a Vf of 15 m/min, was 33.76 kW. In Cut 15, however, carried out at double the depth, power consumption was 45.13 kW. In other words, production was doubled, while power

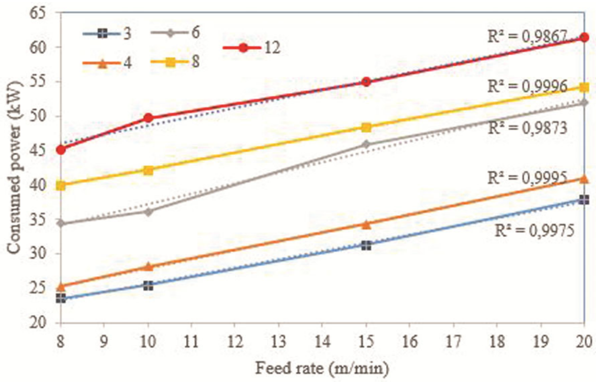

Fig. 6 — The relationship between feed rate and average power consumption in the down-cutting mode, at different cutting depths.

consumption increased by 1.34 times. This shows that increasing the cutting depth can be advantageous in terms of total energy consumption.

Table 3 also shows the change in power consumption when the cutting depth is increased by three times (Cuts 5 and 17). The power consumption values for Cuts 5 and 17 were 23.15 and 43.17 kW. Therefore, when the cutting depth was increased by three times, the energy consumption value increased by 1.86 times. In other words, the operator or the production manager would get three times the cut in return for less than triple the power.

This observation also applies to Cuts 2 and 18, where cutting depth was increased by four times. A quadrupling of the cutting depth increased power consumption by 2.10 times, and this is also true when depth is quadrupled at other feed rates (Cuts 1 and 17; Cuts 2 and 18; Cuts 3 and 19; Cuts 4 and 20). At feed rates of 8, 10, 15 and 20 m/min, quadrupling the depth increased power consumption by 2.07, 2.09, 1.84, and 1.66 times, respectively.

This leads to the conclusion that, in general, the rate of increase in depth of cut does not equal the rate of increase in consumed power. Accordingly, under all conditions, increasing the cutting depth meant reducing total power consumption. When other parameters are kept constant, doubling, tripling or quadrupling the cutting depth means more production from each cut, and consequently, savings in labor costs. Production managers or operators would therefore always want to work with deeper cuts. Increasing the depth would also reduce cutting time, labor costs and the risk of work accidents, providing savings in many cost items.

Given all of these potential benefits, the most important consideration is the extent of additional saw blade wear as a result of making deeper cuts. The equation developed in the present study aims to decide whether shallow cuts or deeper cuts are mode advantageous in terms of saw blade costs.

Another finding of this study concerns the relationship between feed rate and power consumption. Many studies have reported higher feed rates to be associated with higher levels of power consumption. However, we were unable to identify any studies in the literature examining the extent of the increase in power consumption relative to the rate of increase in feed rate. The findings of the present study show that power consumption was 21.16 kW in the 3 mm cutting depth and 8 m/min feed rate (Cut 1) cutting condition, and increased to 22.10, 28.02 and 34.24 kW at the V_f of 10, 15 and 20 m/min, respectively, when the depth of cutwas constant. In other words, doubling the feed rate (Cuts 2 and 4) increased power consumption by 1.55 times (less than twice), and the same is true for all cutting depths (Cuts 6 and 8; Cuts 10 and 12; Cuts 14 and 16; Cuts 18 and 20). For cutting depths of 4, 6, 8 and 12 mm, this ratio was 1.50, 1.41, 1.29 and 1.23, respectively. Another notable finding was that the deeper the cut, the lower the rate of increase in power consumption. In other words, greater feed rates and cutting depths are associated with lower levels of power consumption.

It can therefore be concluded that, as the rate of increase in energy consumption is not equal to the rate of increase in feed rate, at any given cutting depth, performing faster cuts is more efficient in terms of consumed power, andthis also applies to labor costs. Everything else being equal, feed rates up to 12 m/min faster (the difference between the feed rates of 8 m/min and 20 m/min) would reduce total cutting time and therefore, labor costs. Cutting 12 more meters a minute, assuming a net 6 hours of cutting in an 8-hour shift, would equate to cutting approximately 4,320 more meters a shift. This also applies to the down-cutting mode, with similar figures.

Table 3 also shows that energy consumption values are different for the forward and backward action of the cutting blade (up and down cutting mode). As Table 3 shows, in all cutting conditions, forward movement of cutting blade is more advantageous than backward movement in terms of consumed power. In other words, down-cutting has relatively lower power consumption values.

On the basis of these findings, a new empirical economical model is suggested. It is well known that faster cutting increases the cutting forces acting upon the saw blade or the cutting head, and results in greater blade wear[25-27]. Accordingly, operators should consider whether the labor and energy savings from faster cutting offset the additional saw blade costs and, if so, faster cutting would always be more advantageous.

This study presents a new perspective to cutting costs in industrial granite cutting operations that can aid operators and production managers.

Average cutting cost will henceforth be denoted as *"AVC"*.

"AVC" is affected by numerous factors. In general terms, *"AVC"* can be formulated as shown in Eq. 1, under standard cutting conditions.

In Eq. 1, cutting costs are defined on the basis of labor, energy and saw blade costs. These parameters are the most important and the largest cost items in natural stone cutting operations.

$$AVC_{i,j} = \propto_{i,j} E + \beta_{i,j}L + \gamma_{i,j}B \quad \ldots(1)$$

where, $\propto, \beta, \gamma$ are cost coefficients; αE denotes unit energy cost, βL denotes unit labor cost, and γB denotes unit saw blade cost.

The "*i and j*" indices, on the other hand, denote shallow and deep cuts, respectively.

Regarding shallow and deep cuts, the following perspective is adopted:

If the cost of shallow cutting exceeds the cost of deep cutting, deep cutting should be preferred (Equation 2). In the present study, a cutting depth of 3 mm should be considered shallow when compared to cutting depths of 6 and 12 mm.

$$AVC_i > AVC_j \quad \ldots(2)$$

Combining Eqs 1 and 2, we obtain Equation 3, in which deep cutting would be more advantageous.

$$\propto_i E + \beta_i L + \gamma_i B > \propto_j E + \beta_j L + \gamma_j B \quad \ldots(3)$$

The data collected in this study shows that when the feed rate and other conditions are kept constant, the power consumption with deep cutting (12 mm) is 2.07 times (≈2) the power consumption of shallow cutting (3 mm). Moreover, operating at a 12 mm depth of cut requires four times the labor needed to operate at a 3 mm depth of cut (4x3=12 mm). That is to say, if we were to reorganize Eq. 4 as follows;

$$(\propto_i - \propto_j)E + (\beta_i - \beta_j)L + (\gamma_i - \gamma_j)B > 0$$
(deep cutting is more advantageous) …(4)

$$(1-2)E + (4-1)L + (\gamma_i - \gamma_j)B > 0 \quad \ldots(5)$$

$$-E + 3L + (\gamma_i - \gamma_j)B > 0 \quad \ldots(6)$$

$$3L - E > (\gamma_j - \gamma_i)B \quad \ldots(7)$$

$$3L - E > \gamma_j B - \gamma_i B \quad \ldots(8)$$

In cases where Eq. 8 holds, deep cutting is more advantageous in terms of cutting costs.

In simple terms, Eq. 8 expresses the following: When the difference between the saw blade cost of deep cutting and the saw blade cost of the shallow cut is smaller than the sum of the differences in energy costs and labor costs, deep cutting is always more advantageous.

The cost calculations in Eq. 8 can also be expressed in m^2 terms. In other words, if, using the same amount of labor, deep cutting increases production compared to shallow cutting, and the profits from this additional production are greater than the additional saw blade costs, cutting deeper and faster is always more advantageous.

In terms of business management, the most important issue for producers is the timely delivery of orders, while in engineering, the leading issue is identifying the optimum cutting conditions that can produce faster and deeper cuts. It is well-known that a quadrupling of depth of cut reduces life span of cutting discs life due to the additional wear, further increasing cutting costs.

In natural stone cutting processes, each cut is a custom order, and the profit to be made from the cut is weighed against the cutting costs. There are many factors that play a role in this comparison, including the timely completion of the cut, the time-cost relationship, and labor.

The equation proposed in this study can guide decisions related to cost savings in cutting. In every natural stone cutting operation, the main factor in the optimization of cutting parameters is gaining a true understanding of the entire cutting process. The present study presents a detailed examination of the granite cutting process that uses multi-blade block cutter sunder industrial conditions and proposes a model for the optimization of the cutting conditions of granite.

4 Conclusion

In a laboratory-scale study, Ertingshausen[5] has conducted cutting tests at cutting depths of 10-60 mm using a cutting machine with a blade of 600 mm diameter. The author argues that the up-cutting mode is more advantageous for shallow cutting depths, while the down-cutting mode was more advantageous for deeper cuts. Buyuksagis[25] has examined the effects of cutting mode on cutting performance at a cutting depth of 20 mm. Using a laboratory-scale cutting machine, the author finds the up-cutting method to be more advantageous than the down-cutting method in terms of specific cutting energy and specific wear values. Both of these laboratory-scale studies report findings similar to those in the present study, which was conducted under industrial conditions. Almost all of the relevant studies in literature use saw blades with diameters of up to 600 mm, and usually use continuous rim circular saw blades. In contrast, previous studies had worked with cutting depths of 10–60 mm, while the present study works with cutting depths of 3-12 mm. This is because, at the industrial scale, granite is cut sequentially using multi-blade block cutters.

In industrial cutting operations, block cutters with high-power motors are used at shallow depths, which mean power consumption values are different from those obtained in laboratory-scale studies.

When the feed rate is increased in granite cutting operations, the rate of increase in energy consumption is not equal to the rate of increase in feed rate, and as a result, at any given cutting depth, performing faster cuts is more advantageous in terms of consumed power and in other respects, including labor costs. Here, the most important consideration is how the saw blade will be affected by the increase in feed rate. Based on all these considerations, this study has developed a model that explains the relationship between cutting costs and cutting depth. In practice, the most important issue to be considered when increasing the feed rate is the potential effects on the product. If the operator is not careful, higher feed rates may result in saw blade traces on cut surfaces, which may be difficult to remove later, as well as axial deviations from the desired size.

The findings of this study show that quadrupling the cutting depth approximately doubles power consumption. Therefore, according to the developed model, if deep cutting increases production when compared to shallow cutting over the same period of time, and the profits from this additional production are larger than the additional saw blade costs, cutting deeper and faster is always more advantageous.

Quadrupling cutting depth would quarter both cutting time and labor costs, and so the most important consideration is the extent of additional saw blade wear as a result of the quadrupling of cutting depth. In other words, what would be more advantageous in terms of saw blade costs? Would it be quadrupling the cutting depth, or working with shallow depths? Under real production conditions, the answer to this question depends on the sale price of the stone. For almost all stone sold on the natural stone market, increasing the cutting depth to the optimum point would provide cost benefits.

Wear and power consumption are the two most important cost factors in natural stone processing. In the event of wear, the worn segments of the saw blade should be renewed, which increases saw blade costs. In other words, saw blade costs feature prominently in the sales price of 1 m^2 of natural stone. In the plant examined in the present study, and in the sector in general, 2,000 to 5,000 m^2 of stone can be cut after re-tipping a saw blade, assuming optimum conditions. In the natural stone processing plant from which the data for the present study has been obtained, this figure is approximately 4,500 m^2, which translates to an extremly low cost per m^2.

Therefore, the focus in natural stone processing operations should be on power consumption, labor costs, the accuracy of the desired product sizes and producing the desired cutting surfaces.

This study reflects real cutting conditions, as the data for the study has been obtained from a plant that produces a minimum of 8,000 m^2 of cut stone a month, using five different cutting machines. Operators reach optimum conditions through trial and error, taking costs into account, and this requires both the cutting depth and the feed rate to be as high as possible, without exceeding the optimum level.

A better understanding of real production conditions would also improve the quality also of laboratory studies, while a fuller understanding of real conditions would help both researchers and practitioners obtain better results.

It should be kept in mind that the data reported in this study has been obtained from more than 400 cutting cycles, and that findings should be generalized only after conducting similar tests on other types of natural stone.

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