

Cutting Process Analysis by the Multiblade Gangsaw

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Abstract

The ornamental stone processing industry is an important sector in the national exports scenario as being a reference worldwide. However, it has reached a period of stabilization, whereby it is necessary to focus attention in production optimization in order to reduce costs.

This work was developed in collaboration with *Frazão Rochas, S.A.* and with the support of *Geoinveste, S.A.* and *ETMA, S.A.*. Operational parameters, involved in the production of slabs, were collected in the field, with the main objective of carrying out, a deep revision of stone sawability by the multiblade gangsaw, correlating the interaction between diamond tools, machine characteristics and stone parameters.

The correlation between indentation depth and stone parameters, showed good results, for the uniaxial compressive strength. In order to predict the production of slabs per hour, a multiple linear regression model showed a correlation approximately of 100% between variables and has passed several significance tests. As final result, the model indicated an explanatory equation with the most important parameters of the cutting process: block length, block width, vertical sawing speed and uniaxial compressive strength.

Key Words: Multiblade Gangsaw; Production; Indentation depth; Sawability; Diamond tools; Sawing speed.

1. Introduction

The aim of this work is to define a methodology to estimate the hourly production, of a multiblade gangsaw, for the organization of a stone processing factory. It is necessary to look deep to the relation between the variables of production and geomechanical characteristics of the ornamental rock sawed, using models to predict the sawability, including the analysis of linear regression models.

There are numerous processes involved in the production of stone products, from the moment the block reaches the factory, till the transformation into a marketable product. The block cutting process, into slabs, is one of the first steps and the equipment most commonly used for this purpose today, is the multiblade gangsaw. This equipment is a large machine whose cutting is provided by a set of diamond blades, aligned parallel, to perform an alternative horizontal motion. The contact with the block occurs by ascension of the platform, including the block or a downward movement of the grid.

The application of forces during rock sawing are dependent on the machine characteristics. The cut is performed by an indentation stress of the cutting tools, followed by dragging through the rock surface, leading to the rupture. The efficiency corresponds to the optimization of the operation with regard to the total energy used in the process and the minimization of tool wear.

According to Konstanty, (2002) the parameters that most affect sawability are: the manufacturing process of the diamond segments and their characteristics; the properties and conditions of the equipment; rock properties; cooling efficiency; blade tensioning and the experience of the operator.

Using mathematical models of multiple linear regression, is probably the best solution to correlate different data. Thus, the use of the Matlab software, is the best way to get an expression that characterizes the process of sawing and the production expectation of a specific equipment.

2. Ornamental Stone Industry

The stone processing starts with the extraction of the block from the quarry and reaches a marketable product after spending several stages:

- 1) Block Preparation: the block is received in the stone factory and is inspected;
- 2) Pre-cut: The block is prepared for sawing, it is made a regularization of its shape to fit in the slab sawing equipment;
- 3) Primary Cut: The block is sawed into slabs;
- 4) Secondary Cut: The slabs are sawed into tiles or other final dimensions;
- 5) Surface Treatment and Finishes: The final products surface are treated according to the order specifications and its finished with the last requirements;
- 6) Packing;
- 7) Expedition.

3. The process of Sawing

During the blade sawing process, the axial forces are provided by the pressure exerted against the blocks to which the blades are subjected. The longitudinal efforts derive from the alternative horizontal movements of the grid. In any of these cases, there is a basic reaction of the individual cutting tools, a diamond emerging from a segment. This is caused by the result of a simultaneous action of a normal force, f_1 , and a longitudinal force f_2 with respect to the cut surface, causing the removal of a fragment of rock, p (Figure 1) (Oyanguren, P. et al., 1987).

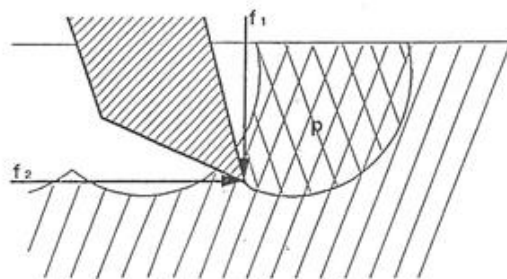


Figure 1 - Elementary action of a single cutting tool. (Oyanguren, P. et al., 1987)

A cutting operation is the result from a range of sequences of elementary actions (Figure 2):

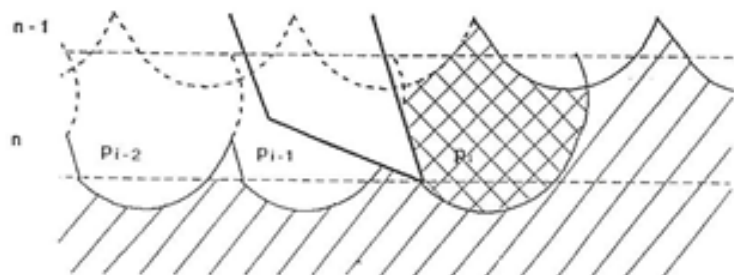


Figure 2 – Elementary cutting sequences. (Oyanguren, P. et al., 1987)

The sawability, phenomena concerning the ability of cutting performance, by a diamond tool, on a rock surface, depends on the properties of the rocks, such as abrasion, hardness, compressive strength, tensile strength, anisotropy and mineralogy. However, as all these properties manifest themselves simultaneously in all rocks and may be combined in different ways, it is practically impossible to use the isolated characteristic values to set the resistance that rocks provide to sawing. (Neves, P. F., 1993)

During the cutting process by a diamond tool, Konstanty, (2002) and Tönshoff, H. K. *et al.* (2002), describe the sawing process with models based on simple geometry of cutting surfaces, providing a division into two mechanisms: primary and secondary chipping. In this model, the process is influenced by several factors such as the properties of the rock, stresses between the diamond tool and the rock, the rock stresses distribution and contact temperature between rock and tool. Tönshoff, H. K. *et al.* (2002) also consider that the mechanical interaction between the rock and the cutting tool is the result of forces caused by: plastic and elastic deformation of the stone, the cutting materials and the result of friction (between the rock and the diamond, rock and the matrix and the chip and the matrix) (Figure 3).

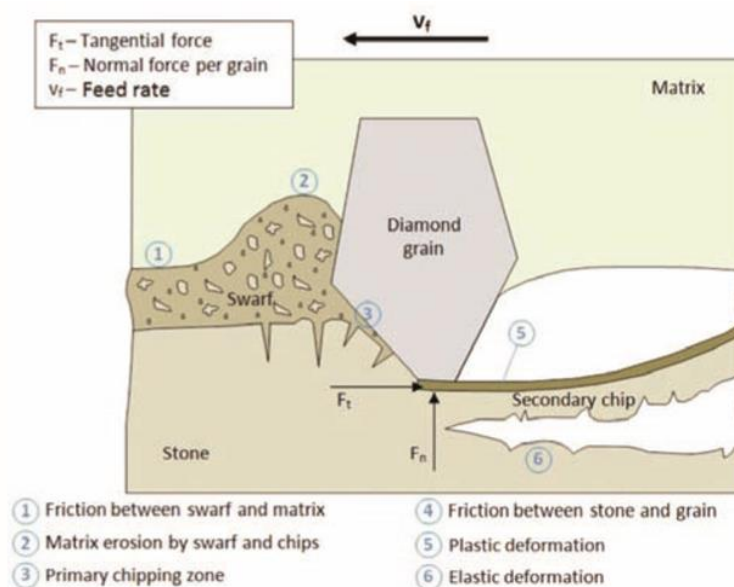


Figure 3– Mechanical interaction between diamond saw and stone piece during the cutting process. (Tönshoff, H. K. *et al.*, 2002)

Figure 4 shows a diamond blade, which is an elongated steel plate, with welded diamond segments (b), separated from each other by a variable distance (L3) (Robleda, A. S. and Castro, J. T., 2009). The basic constitution of diamond segments is a combination of cobalt, cobaltite, diamond and bronze in different ratios to achieve the better abrasion of the rock, depending on its characteristics (Anjinho, C.A., *et al.*, 2013).

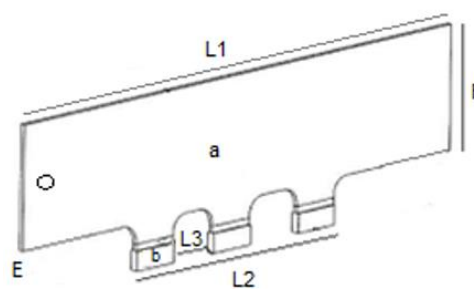


Figure 4– Diamond blade. (Adapted from Robleda, A. S. and Castro, J. T., 2009)

Konstanty, (2002) by analogy to circular sawing, defined the equivalent chip thickness of a single blade passing on the stone block (Figure 5):

$$h_{eq} = \frac{10^2 v_{df}}{36 v_h} l_b \quad \text{Equation 1}$$

Where v_{df} is the sawing speed (cm/h), v_h is the mean horizontal speed (mm/s) and l_b is the length of block (mm).

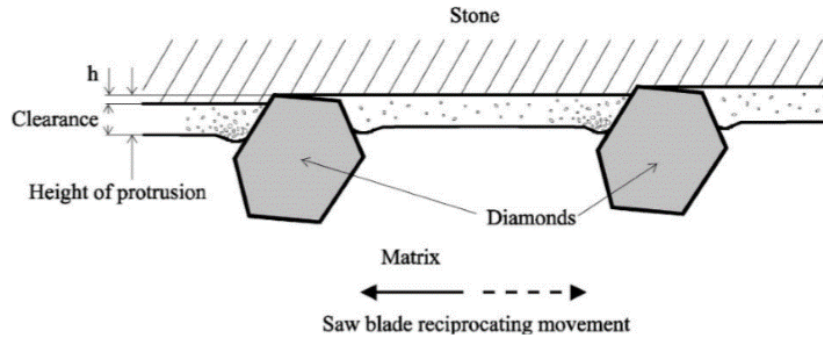


Figure 5 – Schematic representation of the cutting zone in frame sawing. (Konstanty,J., 2002)

4. Methodology

In *Frazão Rochas, S.A.*, stone processing factory, data were collected as the basis of a sawability study. The focused equipment was a multiblade gangsaw (A. J. Figueiredo, SB 80L) with a back and forth horizontal movement at a rate of 90 strokes per minute. The blades have a content of the segment of 30% cobalt, 30% cobaltite, 25% diamond and 15% bronze.

It was tested the sawability of eight different kind of carbonated stones, seven limestones: Moca Creme, Azul Valverde, Relvinha, Branco Alcanede, Rosal, Ataija Creme and Creme do Mar and one marble: Branco Estremoz.

Block measures, the sawing speed and the sawing time were recorded. Also laboratorial studies, were provided by the company, such as: uniaxial compressive strength (UCS), flexural strength (FS), wear resistance (WR), open porosity (OP) and bulk density (BD).

After processing data, hourly production (P_h) and indentation depth per stroke (I_d) were calculated:

$$P_h = \frac{\text{Sawn Area}}{\text{Sawing Time}} \quad \text{Equation 2}$$

$$I_d = \frac{\text{Sawing Velocity}}{\text{Back and Forth Velocity}} \quad \text{Equation 3}$$

To predict the hourly production of the multiblade gangsaw, it was defined a prediction model consisting of quantitative factors (block length, block width, sawing speed, indentation depth and uniaxial compressive strength) and a dependent variable (hourly production). Defined after the removal of the collinear variables by colinearities analysis.

The quantitative parameters and the dependent variable can be mathematically defined by the following expression:

$$P_h = f(L_b, W_b, S_s, I_d, UCS) \quad \text{Equation 4}$$

5. Results and Discussions

For data analysis, the correlation between indentation depth (I_d) and the rock parameters was tested. A single block from each kind of stone was selected, similar in their dimensions to simulate an approximate contact area (Table 1).

Table 1 – Operational and geomechanical parameters of eight blocks, one of each kind of stone, were studied.

Stone	I_d (mm)	P_h (m ² /h)	FS (MPa)	UCS (Mpa)	WR (mm)	OP (%)	BD (Kg/m ³)
Ataíja Creme 4	0,022	8,4	13	161,8	21,6	1,65	2390
Azul Valverde 2	0,019	7,6	19,1	145	21,5	2,8	2370
Branco do Mar 13	0,046	16,9	12,3	86	28	10,1	2390
Creme Alcanede 42	0,033	9,4	11,7	108	24,5	9,2	2390
Branco Estremoz 1	0,027	9,8	27	94	20,9	0,18	2370
Moca Creme 28	0,043	10,7	14	90	24	7,9	2390
Relvinha 6	0,043	14,9	12,4	89	29	9,7	2390
Rosal 15	0,043	13,9	7,2	81	29	13,8	2390

The best correlation was obtained for the uniaxial compressive strength. The result analysis was separated by a distinct value, the Branco Estremoz block (left chart in Figure 6), which is separated from the trend showed by the limestones. A subsequent analysis was performed only to verify the behavior of the limestones (right chart in Figure 6).

In Figure 6, the correlation, of both experiences, shows a decrease of the indentation depth as the uniaxial compressive strength increases. It also can be seen that the exclusion of the Branco Estremoz block, showed a better correlation (91%) when compared to its inclusion (73%).

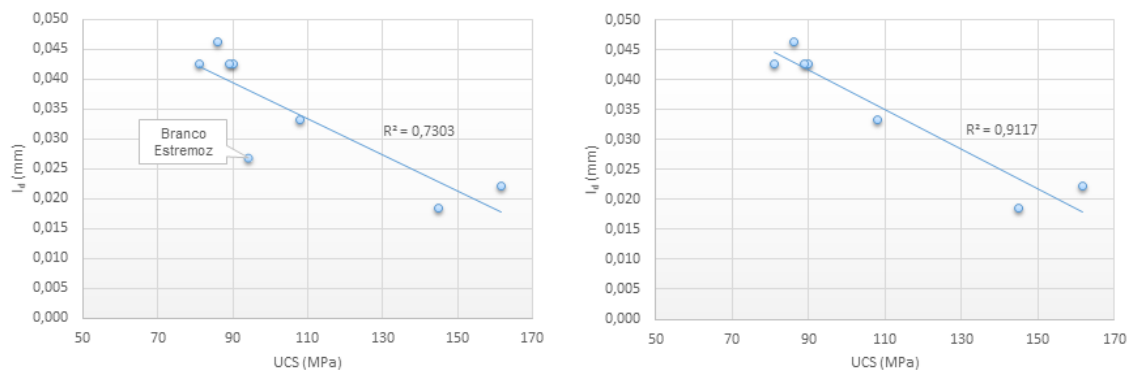


Figure 6 - Relation between indentation depth and uniaxial compressive strength, for all blocks (left) and excluding Branco Estremoz (right).

The relation between the indentation depth with the wear resistance and the open porosity, showed the increase of this parameter, as both geomechanical characteristics increases. The correlation with wear resistance shows a value of 74% and 71% for the open porosity (Figure 7).

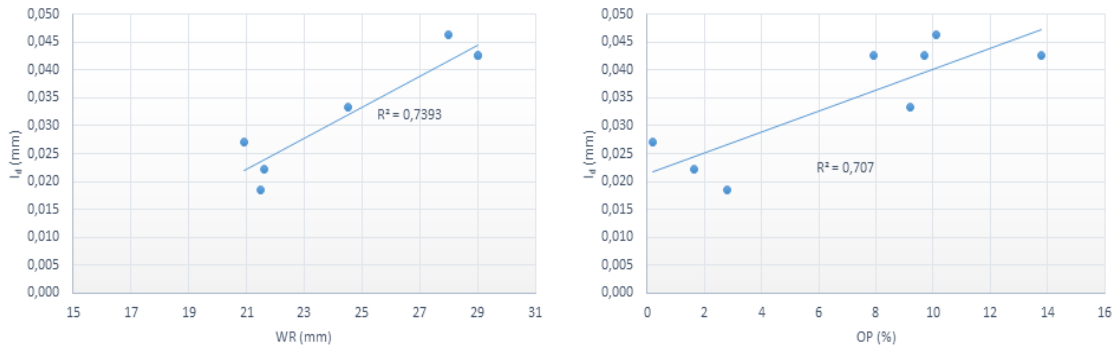


Figure 7 - Relation between indentation depth with wear resistance (left) and open porosity (right)

The bulk density has not been compared because of the similarity of this feature for all blocks involved. The flexural strength revealed no correlation between these variables, reason why, probably, has no influence in the indentation process.

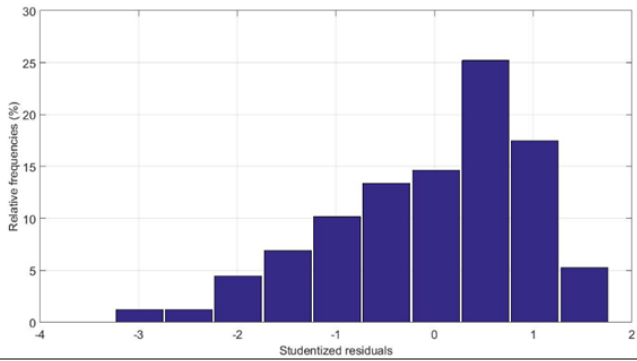
A set of seven multiple linear regression candidate models (Table 2), according to Equation 4, were submitted for analysis.

Table 2 - Multiple linear regression models considered in the study.

Model	General Expression
1	$y = \beta_0 + \beta_1 X_1 + \dots + \beta_5 X_5$
2	$y = \beta_1 X_1 + \dots + \beta_5 X_5$
3	$\log y = \beta_0 + \beta_1 X_1 + \dots + \beta_5 X_5$
4	$\log y = \beta_1 X_1 + \dots + \beta_5 X_5$
5	$y = \beta_0 + \beta_1 \log X_1 + \dots + \beta_5 \log X_5$
6	$y = \beta_1 \log X_1 + \dots + \beta_5 \log X_5$
7	$\text{Boxcox}(y) = \beta_1 X_1 + \dots + \beta_5 X_5$

In regression analysis, there are several criteria for the model suitability evaluation, concerning the field data. These criteria also have the ability to evaluate the generalization ability of those models, when they are used for prediction purposes (Hutner, M. H. *et al.*, 2010). In the present approach, model 4 was chosen by its best suitability (Table 3):

Table 3 – Model 4 quality evaluation criteria and results.

Model Quality Evaluation Criteria	Results
The Coefficients of determination (R^2 and R^2 adjusted)	$R^2=0,9988$
	$R^2_{adj}=0,9988$
Studentized residuals analysis ($\approx 95\% \in [-2,2]$)	
F-statistics analysis $P(F>F_0)\approx 0$	Regression: $P(F>F_0)=0,0000$
	Residuals: $P(F>F_0)=0,0106$
P-value significance (p-value) _{coef.} $\leq 0,05$	Block Length = 0,0000
	Block Width = 0,0000
	Sawing Speed = 0,0001
	Indentation Depth = 0,9654
	Uniaxial Compressive Strength = 0,0000
Akaike and Schwarz–Bayesian information criteria (AIC and SBIC)	AIC = -1183,6
	SBIC = -1166,1

To prove the model suitability, the observed data vs predicted data chart was analyzed (Figure 8). It shows a slight limitation to the initial and final answers, but the intermediate values represent very good results, proving the adaptation of the model.

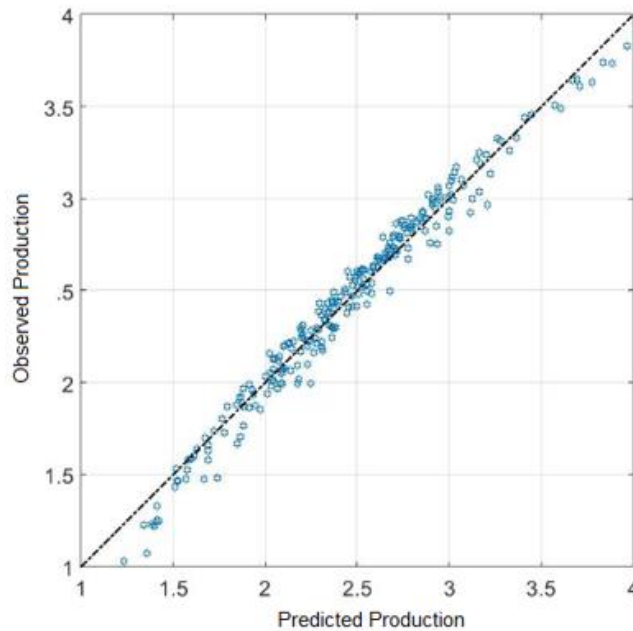


Figure 8 – Observed production vs predicted production

In order to describe the model equation, the statistical analysis of significance, of the model parameters, was focused. Observing the p-value significance in Table 3, the results showed insignificance for the indentation depth. Thus the equation, can be described by the other parameters coefficients:

$$\ln(\text{Production}) = 0,4613L_b + 0,9604W_b + 0,0374S_s - 0,0022UCS \quad \text{Equação 5}$$

Using the single unities for block measures of $L_b=1$ and $W_b=1$, and using the mean uniaxial compressive strength for each kind of stone, a chart can be made correlating hourly production with sawing speed and the stone type (related with its mean uniaxial compressive strength) (Figure 9).

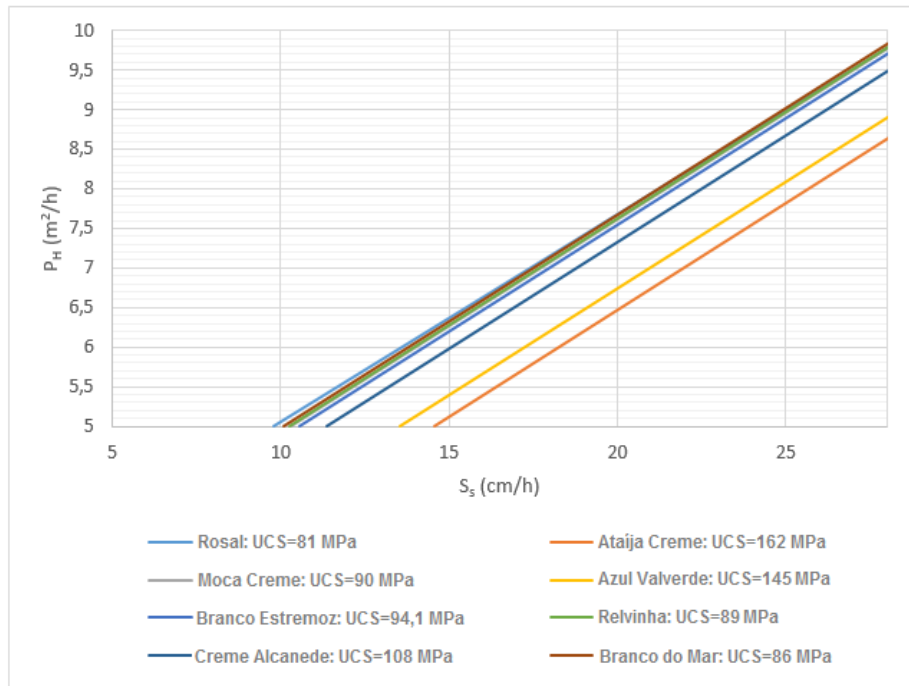


Figure 9 – Relation between hourly production, sawing speed and stone type.

By observing Figure 9, there is a predominance of two families of sawn rocks, differentiated by the average values of the uniaxial compressive strength. The group formed by Ataija Creme and Azul Valverde shows much higher values for the uniaxial compressive strength comparing with the other blocks, which resulted in a lower hourly production tendency, compared for the same sawing speed values.

6. Conclusions

This work made an analysis of the sawability of a multiblade gangsaw, in industrial operations, of 246 blocks, composed by seven limestones and one marble.

The data collection was limited to the time spent in the company, so it was not possible to obtain some data that would have been important. The average consumables wear were registered, however, it was not possible to relate them with the blocks sawed. Energy consumption was kept constant, based on the optimum value set by the equipment manufacturer.

Differences on rock behavior were noticed by correlations of diamond indentation in the rock. It has shown: the indentation depth decreases with the uniaxial compressive strength and increases with the wear resistance and open porosity; the flexural strength and bulk density do not contribute significantly for this parameter.

The multiple linear regression model, represented the best correlation between the geomechanical parameters of rock, cutting tool characteristics and technical parameters of the multiblade gangsaw, in the hourly production of slabs. The equation obtained, allows to generate an estimated value of production using the length and width of the block, sawing speed and the uniaxial compressive strength. This equation, can be used to previously estimate the production (relative to this machine), for any type of rock (preferably in the uniaxial compressive strength range studied), since the cutting tool characteristics are maintained.

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