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Examination of Feedrate Impacts on Different Grain Size Granite Materials from Edge Damage Aspect

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***Abstract* -** Different natural stones as granite, marble and limestone are used in the construction industry and in the last few years, they are also used with a growing amount in manufacturing technology. It can be seen that a minimal damage can be observed on the edge of products of the mentioned industrial segments due to cutting., The primary goal of the presented paper is to examine the changes of the chipping at the edges of damaged granite samples The damage is resulted in cutting with different feedrate speed. The article tries to give recommendations to remedy the explored problems. During the research, there were 3 different granite boards with average particle size. 8 different sample surfaces were produced by 8 feed rates of each. Sample surfaces were made by an NC cutting centre which was especially created for chipping stones. On the sample surfaces, the size of the edge chipping at the output side of the tool was examined. The digitization and evaluation processes were implemented with a DinoLite microscope and its associated software. The examination confirms that the increase in feedrate reduces the average edge chipping rate The increase of federate ends up in a local minimum, whereafter strong loss of edge damage can be observed. The experiments manifest that the feedrate related to the best edge quality is independent from the grain size in all types of stone. It should be noted that in the case of using granite, the same change in can be observed when adjusting feedrate and the same approximation curve can be used for statistical evaluation.

***Keywords*:** Granite, Feedrate, Edge Chipping, Grain, Milling.

1. Introduction

Natural stones are popular in the construction industry as well as industry stones in many other areas like preforms. The commercial application field of the current research is the the interior architecture and manufacturing of commodities. In industrial poin of view, manufacturing technology is the main target in various machine tools and the tables of coordinate measuring machines. In the construction industry, considering kitchen countertops, tables minimized impact of edge damage is important due to ergonomic reasons In the industry, there are various granite tables such as measuring tables where too much edge damage can generate faults while mounting. The author has been doing his research for several years in the field of the machining possibilities of granite products covering the topics of technological parameter estimation for the cutting of granites in the future. The current research, investigates how the changes in feedrate affect the damaged number of edges during the cutting process of granites with different particle size. During the tests, CNC cutting machines and evaluation software specialized for machining stones with a digital microscope have been used. Based on the evaluated measurement data, the dependency between the feedrate and damaged edges has been revealed.

2. Literature Review

In the international literature, there are numerous researches on various that focus on the effect of stresses in the fragile material such as stones. There is a significant documentation of edge analyses with an indenter. Intense experiment with indenter can provide information about the expected lesions of the various brittle materials. Chai [1, 2] analysed with Vickers indenter different curvatures of glass, ignimbrit and basalt edge impact and examined the effect of different curvatures from edge damage point of view. As a result, a new metric has been created which is an estimator that can determine the forces at a given curvature at different distances from the edge.

In the case of stone milling tools, a similar wear mechanism is realized than stone jigging and sawing. Aydin et. al. [3] studied the resulting granite surface when a diamond cutting disc has been applied and concluded that average surface roughness changes with different technological parameters. After machining, the granite surface was analyzed both wear image and surface roughness profile. From the experiments, it was concluded that the increase in cutting speed and depth of cutincreas the surface roughness as well. Goktan et al. [4] performed the Knopp micro-hardness test, that is the only effective way to determine the performance of the specific wear of the saw blades. During the tests, two productivity parameters were modified: dosage speed and depth of cut. Based on the the machining experiments, an estimator system was developed that determines the expected tool wear if cutting depth, feed rate and Knopp mincrohardness values have been known. Franca at. al. [5] examined the topology and scale of segment wear generated by drilling granite products, like crown drills with diamond bit. During the tests, the grains and binder wear rates were examined and different cases of wear and tear of diamond grains observed. Machining experiments led to make statements about wear mechanism of segments. Che et.al. [6] made experiments with "polycrystalline diamond compact" (PDC) cutting tools in order to understand the system of forces generated in the course of linear machnining (in fact, slotting) with machining tools. In the test, they have their own machine tool with which the experiments were performed on limestone boards. Based on the results of experiments, they could prove the validity of their theory that is related to force estimation generated by stone machining with PDC tool. Several interesting research findings can be seen when sawing stone products. Zhanga et al. [7] for sawing granite products investigated the wear cases of diamond particles in the cutting range of the saw. The degree of wear of diamond particles was analyzed by scanning electron microscopy while the diamond particle distribution on the cutting edge was studied with X-ray diffraction apparatus. The effects of titanium in the tool were investigated separately and concluded so that the titanium element can cause fatigue cracking and oxidation due to machining on the cutting surface of the saw. Sun et. al. [8] did tests how the different stone material parameters affect the saw tool segment wear processes. A total of 10 different granite types were sawn in the tests and the segmental topography after sawing was studied. During the tests, it was concluded that the highly worn diamond parts were very rare in the segment rather a diamond binder removal from the binder was the typical wear pattern. Zhang et. al. [9] present an innovative saw machine and analyze in detail the saw after cutting processes with a sawing machine in order for topological image of the segments and the proportion of worn diamond particles. In addition to these tests, sawing with different parameters was analyzed as to efficiency, productivity.

Optimization of technological parameters can be important for a number of purposes for instance creating a finer surface quality, minimizing tool wear, or maximizing productivity. In order for optimization and prediction, technological parameters were researched by Zhang et al. [10, 11]. Optimization primarily targeted the best surface design quality. They carried out various technological parameters, performed cracking processes and investigated for the roughness of the resulting surfaces.

3. Production of Milled Granite Surfaces

In the first phase of the research, 3 different average particle sizes of commercial granite blocks were machined. Granites selected for the tests are completely cover all the groups of the standard and classified by the depth of magmatic rocks based on their average particle size. All granite types in the world can be divided into three different groups according to the standards (Table 1). The fine grain particles average size is less than 1 mm. The granites in the middle-class are between 1 and 5 mm particle sizes. In rough stones, the average is above 5 mm granite grain size.

Table 1: Standard of average grain size of granites.

Average grain sizes	Stone-groups
$d > 5$ mm	large grain-size group
1 mm $\leq d \leq$ 5 mm	middle grain-size group
$d < 1$ mm	small grain-size group

For the production of granite sample surfaces, a rock drilling and milling optimized CNC controlled Italian-made Prussiani Golden Plus type machine-tool drilling and milling of rocks was used (Fig. 1). The maximum power consumption of the machine-tool 15 kW, range of motion 3300 mm in X direction,1600 mm in Y direction and 250 mm in Z direction. The machine can be used with stepless speed and feed rate change that is very advantageous in terms of research, as the different technological parameters can also be changed minimally. In order to fix large mass of granite blocks, vacuum grips have been used to ensure precise, free-cutting machining. NC tools for milling stones are produced with StoneCAM software in the control panel of the tool.

Fig. 1: Clamping of a granite table.

In the milling processes, a 100 mm diameter and 22 segment milling tool was included for application (Fig. 2). The tool used has been specially developed to machine natural stones. During machining, material separation has been observed with grain diamonds having a screen number 40/50, embedded in the cobalt matrix. During the production of sample surfaces with 50 mm cutting width each, 1 mm depth and 1100 m / min cutting speed were used. During the machining, straight milling has been selected because this milling mode is the most commonly used solution for material separation of natural stones. Each sample surface was constructed with a 1 mm step in relation to each other to avoid the so-called overlap phenomenon. It would result transients in different measurable parameters of the sample surfaces that were produced by different technologies. The feedrate is the only parameter that changes according to the sample surfaces. In the experimental progress for all granite types, sample surfaces have been produced at 200 mm/min, 250 mm/min, 300 mm/min, 350 mm/min, 400 mm/min, 450 mm/min, 500 mm/min and 550 mm/min with feedrate values.


Fig. 2: Stone milling tool.

4. Examination of Sample Surfaces

In order for examining the edge damage of the sample surfaces, the “average edge chipping rate” metric has been used by the authors which was determined by Gálos and Gyurika [12]. An average edge chipping rate has been generated by forming a proportionin order for generating a dimensionless quantitative marker: its numerator contains the sum of the volumes of the edge chipping whereas its denominator contains the geometry representing the intact, unharmed body. The equation that yields the quantitative marker is the following:

$$M_{avg} = \left(\frac{\sum_{i=1}^{n} V_i}{V_0} \right) \quad (1)$$

Where:

- $\sum_{i=1}^{n} V_i$ stands for the cumulative volume loss [mm^3] generated by the edge chipping on the tested edge length.
- V_0 stands for the volume [mm^3] of the quarter-cylinder that represents the body free from chipping.

To calculate the volume of the quarter-cylinder used in equation (1), the following formula has been used:

$$V_0 = \frac{r_h^2 \pi}{4} L \quad (2)$$

Where:

- "r_h" stands for the hypothetical radius value of the quarter cylinder [mm]
- "L" stands for the length of the tested edge [mm]

The hypothetical radius value was defined as 1 mm. As a result, after having substituted equation (2) in equation (1), the final, simplified formula of the calculation of the average edge chipping rate has been formed:

$$M_{avg} = 4 \cdot \left(\frac{\sum_{i=1}^{n} V_i}{\pi \cdot L} \right) \quad (3)$$

To determine the average edge chipping rate, a replacement body [13] should be used which can be used with high precision with a complex body to determine the loss of volume generated by the chipping. The complex body consists of two elliptical shapes with a quarter cone joined at them base (Fig. 3). To be able to determine the volume of the solid figure, three parameters of the chipping must be known. The first parameter is as follows: the height of the twin-cone is equal to the distance between the starting and ending points of the chipping. The length of the axis of the ellipsoid used as the base of the cones is equal to the maximum chipping depth measured on each of the surfaces that constitute the edge.

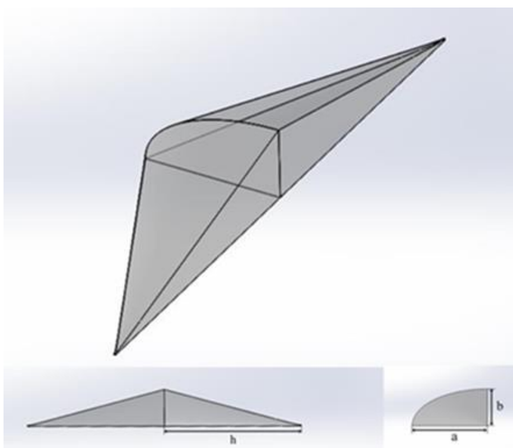

Fig. 3: Replacement body.

To determine the dimensions of the chipping, the Budapest University of Technology and Economics Department of Manufacturing Science and Engineering used the called Dino-Lite high-scanning digital microscope (Fig. 4) and its DinoCapture computer software. The test process used 55x magnification, every 5 mm on each sample surface and the 50 mm test ranges for both surfaces of edges. The results have been digitalized and recorded. After the digitalization, DinoCapture software was used to determine the length and depth values of the particular chipping damages (Fig. 5.).

Fig. 4: Dino-Lite microscope.

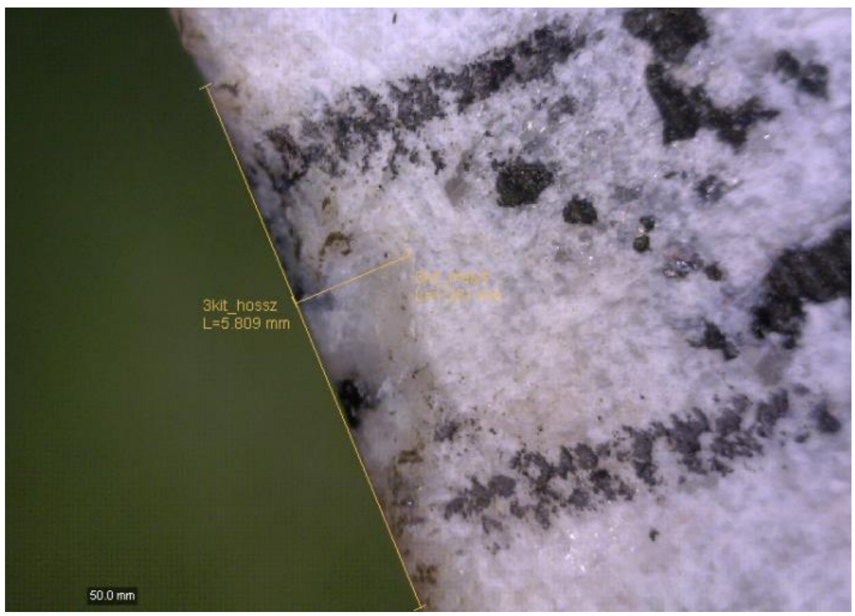

Fig. 5: Determination of an edge chipping.

5. Research Results

The evaluation of measurement data results in 24 sample surfaces were available for the evaluation of a granite types. During the evaluation phase, the degree of change in the feedrate of the individual granite materials to the edge damage was examined. Digitalization and evaluation of marble granite surfaces have been followed by the calculation of volumes in excel spreadsheets and MiniTab 15 statistical evaluation software, Deviations, distributions, expected values of errors, and confidence intervals of each parameters have been statistically analyzed.

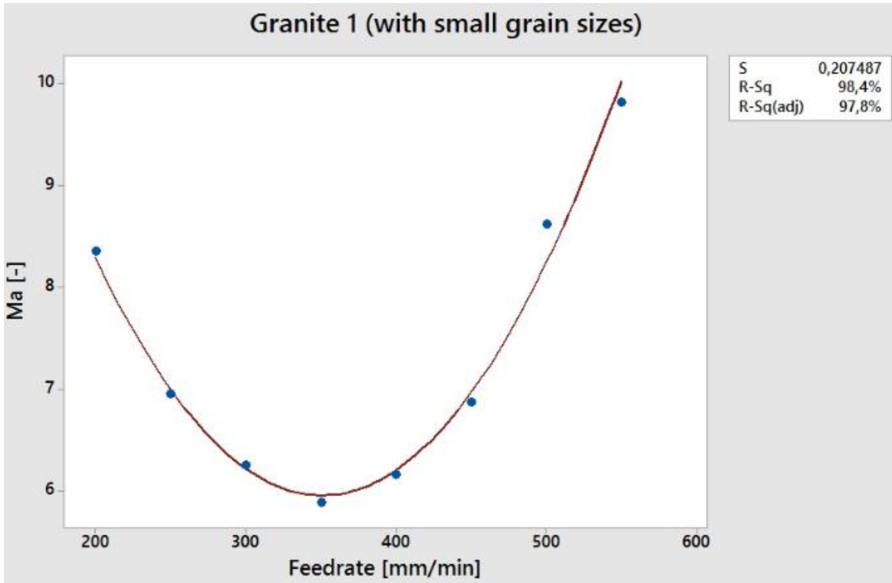

Fig. 6: Changes the average edge chipping rates by the granite 1.

Based on the statistical analysis, it can be stated that the feedrate tend to reduce the average edge chipping rate to a certain limit for each granite type. Thus, the quality of edges continues to improve. However, the increase of federate ends uo in a local minimum , in other words loss- starts to increase again, so there will be a loss of edge quality. The diagrams clearly show (Fig. 6-7-8) that the minimum average edge chipping rate for each granite type were at 350 mm / min feed. This means that regardless the grain size of the granite the best edge quality ever was measured at the same feed rate. The same changes were experienced at all subjected granite types. Consequently it can be stated that the edge damage can be reduced by not only the change in feedrate but also by applying a smaller grain size.

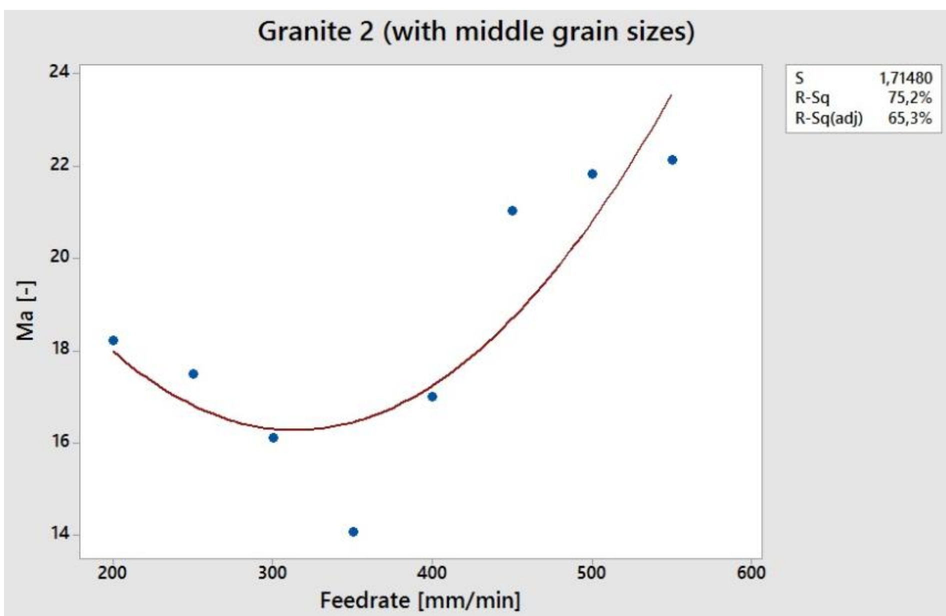

Fig. 7: Changes the average edge chipping rates by the granite 2.

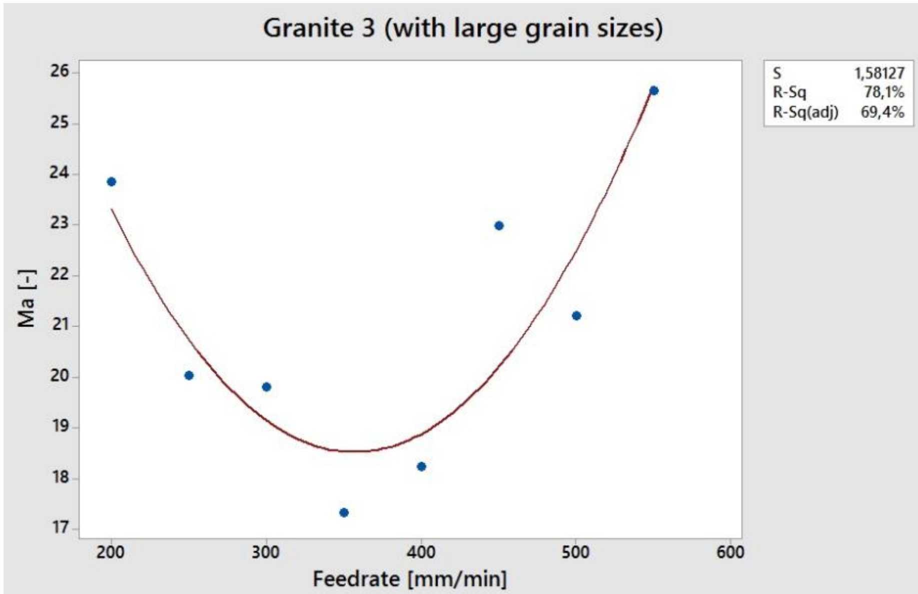

Fig. 8: Changes the average edge chipping rates by the granite 3.

After a closer examination of the diagrams and the ANOVA analysis has been performed, it can be stated that, according to the variance analysis, the significance coefficients in whole stones so low that there is an obvious relationship between the change in the average edge chipping rate and the quadratic regression line assigned to this change. In the case of granite 1, this value is P=0.008, which means that there is only 0.8% likelihood that the regression line applied is not significant with respect to changes in average edge chipping rate. In the case of granite 2, this significance is P=0.031, in the case of granite 3 the referent value is P=0.022. With the help of the ANOVA analysis, it can be concluded that, during the examination of the average chipping rates of the granite edges, effects of the change in feedrate can efficiently be approximated with the help of a quadratic regression line.

6. Summary

In this research we intended to examine how an increase in feedrate, applied during the milling process, affected the edge-qualifier quantitative marker of granite surfaces. The statistical analyses revealed that the average edge chipping rate measured on the edges of the milled granite surfaces shows a continuously decreasing trend, which is caused by a rise of feedrate, until this average rate reaches a borderline rate of around 350 mm/min. Then types this tendency reverses and begins to rise again. Upon drawing the diagrams, we matched a quadratic regression line with the measured results, and then with the help of ANOVA analysis the significance of the regression line to the measured points was examined. On the basis of the analysis, it can be stated that the application of the quadratic regression line provides an effective approximation in the case of all diagrams.

In the future, it is necessary to examine whether similar processes lead to loss of edge and with other tools at the same feedrate we can experience a minimum edge loss rate if we use tools with different diamond grain size for machining.

References

[1] H. Chai, “On edge chipping in cylindrical surfaces,” in *International Journal of Solids and Structures,* Elsevier, vol. 54, pp. 12-19, 2015.

[2] H. Chai, “Modelling edge chipping in flint knapping, cutting tools and sharp teeth using a trapezoidal prism structure,” in *International Journal of Solids and Structures,* Elsevier, vol. 104-105, pp. 1-7, 2017.

[3] G. Aydin, I. Karakurt, K. Aydiner, “Investigation of the surface roughness of rocks sawn by diamond sawblades,” in *International Journal of Rock Mechanics and Mining Sciences,* Elsevier, vol. 3, pp. 171-182, 2013.

[4] R. M. Goktan, N. G. Yilmaz, “Diamond tool specific wear rate assessment in granite machining by means of knoop micro-hardness and process parameters,” in *Rock Mechanics and Rock Engineering,* Springer-verlag Wien, vol. 50, pp. 2327-2343, 2017.

[5] L. F. P. Franca, M. Mostofi, T. Richard, “Interface laws for impregnated diamond tools for a given state of wear,” in *International Journal of Rock Mechanics and Mining Sciences,* Elsevier, vol. 73, pp. 184-193, 2014.
[6] D. Che, W.L. Zhu, K. F. Ehmann, “Chipping and crushing mechanisms in orthogonal rock cutting,” in *International Journal of Mechanical Sciences*, Elsevier, vol. 119, pp. 224-236, 2016.
[7] Z. Y. Zhanga, B. Xiao, D. Z. Duan, B. Wang, S. X. Liu, “Investigation on the brazing mechanism and machining performance of diamond wire saw based on Cu-Sn-Ti alloy,” in *International Journal of Refractory Metals and Hard Materials*, Elsevier, vol. 66, pp. 211-219, 2017.
[8] Q. Sun, J. Zhang, Z. Wang, H. Zhang, J. Fang, “Segment wear characteristics of diamond frame saw when cutting ifferent granite types,” in *Diamond and Related Materials*, Elsevier, vol. 68, pp. 143-151, 2016.
[9] H. Zhang, J. Zhang, Z. Wang, Q. Sun, J. Fang, “A new frame saw machine by diamond segmented blade for cutting granite,” in *Diamond and Related Materials,* Elsevier, vol. 69, pp. 40-48, 2016.
[10] J. Zhang, Z. Zhang, M. W. Ding, H. C. Wang, Z. Wang, “Experimental study on fractal laws of cutting force for machining irregular surface of granite,” in *Advances in Abrasive Technology*, Elsevier., pp. 214-219, 2013.
[11] Z. Zhang, H. W. Xiao, G. Z. Wang, S. Z. Zhang, S. Q. Zhang, “Modeling and experimental study on cutting force of diamond circular saw in cutting granite using response surface methodology,” in *Advances in Materials and Materials Processing*, pp. 652-654, 2013.
[12] M. Gálos, I. G. Gyurika, “Quality measuring numbers of milled edges of granite surfaces,” in *Periodica Polytechnica Civil Engineering,* Budapest, vol. 58, pp. 121-129, 2015.
[13] I. G. Gyurika, T. Szalay, “Examination of the average chipping rate on the edges of milled granite surfaces,” in *Measuerement Science Review,* Bratislava, vol. 15, pp. 1-8, 2015.