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Examination of the Relationship between the Average Surface Roughness and the Average Edge Chipping Rate of Milled Granite Products

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Abstract- Products made of granite have an important role in the fields of manufacturing technology and construction industry. Granite tables and beds can be found as parts of CNC coordinate measuring machines; in addition these stones are often the materials of different counters, tabletops and surface plates. The ergonomical conformance of finished products is especially important in the last mentioned field - e.g. if a tabletop has chipped edges, the customer may not pay for the product. For many years there was no measuring number which could objectively qualify the average edge chipping rates of the edges of milled granite products. This article is based on a study that represents a new stage of a range of experiments which has been in progress for already three years. During the first experiments the mentioned measuring number was established, which was followed by the determination of a body that could accurately represent the decrease of volume caused by the chippings. During this research our main aim was to find out if there is a relationship between the average edge chipping rate and the average surface roughness of milled granite products. If this relationship exists, the change of the average edge chipping rate of granite surfaces (machined with different manufacturing technologies) could be estimated on an indirect way by following the change of the average surface roughness. The research introduced in this article examines the effects of the change of cutting speed, and our future aim is to find all the relationships caused by the changes of any parameters during manufacturing.

***Keywords*:** Granite, Milling, Edge chipping, Surface roughness, Cutting speed.

1. Introduction

Engineers specialised in manufacturing technology has two main aims during the planning of the automated manufacturing of different stones. One is to satisfy customer needs, the other one is the minimization of manifacturing costs and in some cases the manufacturing time. In the last two decades researchers have executed important experiments and developments in the field of optimization of granite, marble and limestone manufacturing. There is a significant amount of international sources related to the development of drilling, cutting and grinding processes, to the wear of tools and the manufacturing costs. However there are almost no implemented examinations related to stone milling with NC machines. The aim of the experiments mentioned in this article is to examine if there is a relationship between the edges' average edge chipping rates and average surface roughnesses in the case of milled granite products while applying different cutting speeds.

During the experiments the relationships were researched in the case of five different granite types. These stones completely cover the different classes of granites which were established on the basis of grain sizes. If the mentioned relationship can be found in the cases of all granite types, we can declare that this correspondence is valid in the case of all granite types those are known at the moment. The milling was performed on a CNC stone machining center. We worked with five different cutting speeds. We determined the average surface roughness with an Alicona InfiniteFocus confocal microscope. We used a Scantech type laser and a Reverse Engineering software to determine the average edge chipping rate.

2. Literary Overview

In the international literature there are a lot of researches related to the qualification of different stone surfaces and to the examination of edge chipping.

Riberio et al (2007, 2011) examined the effects of the granites' average surface roughnesses on the machineability and applicable technological parameters during cutting processes implemented with a diamond cutting disk. The main aim of the researches was to declare the relationship between the surface quality of the stones and the dynamic friction coefficient. Researchers implemented cutting processes on five different granite types, then they qualified the newly fomed surfaces with a portable surface roughness measuring machine. As a result of the experiments the researchers made the conclusion that the mineral structure and the micro-structural surfaces have a great effect on the surface roughnesses of the stone blocks.

Huang et al (2002) examined the relationship between the sizes of the the tool's diamond grains and the surface roughness which is obtainable with the tool in the case of grinding processes. The researchers implemented grinding processes with a vertical tool axis on three different natural granites. During the measuring examinations the researchers applied a scanning electron microscope which determines the morphology of the surface, a digital luminosity measuring machine and a mobil surface roughness measuring machine. With the help of the microscope the group noticed that plastic deformation was the primary reaction in the case of the workpieces, but brittle fracture was also observable on a lower extent. During the experiments it was proven that luminosity is in direct relationship with surface roughness.

Polini et al (2004) examined the change of the manufacturing force as a function of the depth of cut and the manufacturing speed. They examined the case of the cutting and milling of granite products. During the cutting and milling processes they measured the constantly changing force effects with a dynamometer. The experiments which were executed with the diamond milling tool showed that the feedrate speed and the depth of cut have significant effects on the machining force. The empirical model which was established during the research became suitable for predicting the energy and force conditions of manufacturing in different manufacturing environments.

There is only one source in international databases that is related to the examination of edge chippings of granite products. Only a few researchers have been dealig with the examination the edge chippings of natural stones so far. A direct research result was publicized only by Bao et al (2011). During the researches the group established a new model to estimate the force needed for edge chippings near the usage of a tool with concentrated load. The researchers' aim was to prove that the chipped pieces had similar geometries those were independent from the materials. Their further aim was to determine the relationship between the maximum loading force at the moment before the appearance of the chipping and the distance of the load from the edge. They implemented their researches on four different granite types. The examination showed that the previous sources related to the topic estimated false force relations, and this is why the former equations lead to the the wrong determination of the loading force. The model of Bao's group is based on the analysis of the loading force and the energy distribution, using the knowledge on fracture mechanics, on the geometric similarity of the chipped pieces and on the results of cutting tests impelemented on different stones. Based on their examinations the researchers made the conclusion that there is an obvious relationship between the distance of the load from the edge and the maximum force, and they established an estimating system based on the measurements.

3. Antecedent Research

Gyurika (2013) established the measuring number which can objectively qualify the edge chippings of milled granite surfaces between 2011 and 2013. The basis of the examinations related to this number was a concrete industrial problem. In the case of a finished granite product it is common that the customer and the manufacturer do not agree in connection with the rate of edge chipping of the milled surface. As previously there were no objective qualifying systems, if the customer thought the edge of the product was too chipped, he did not pay the costs. With the established measuring number there is already a qualifying method which can determine the average edge chipping rate of milled granite surfaces independentely from the customer and the manufacturer.

3. 1. Determination of the Average Edge Chipping Rate

The first main task of the antecedent researches was to determine a qualification system which can determine the average edge chipping rate of the edges of milled granite products independently from the customer and the manufacturer. While establishing this number the main aims were to find an identical calculation method to determine the general angled edges, to have the best possible structure of the equation and the measuring number to be completely independent from other parameters. The researcher finally created an equation whose dimensionless result provides an effective solution for the determination of the average edge chipping rate.

The dimensionless measuring number – which determines the average edge chipping rate (M_{avg})- can be calculated as the quotient of the loss of volume ($\sum_{i=1}^{n} V_i$) found on the examined 'L' length of the edge which is generated by the edge chippings and the body which represents the whole volume (which is a quarter of a cylinder according to the equation):

$$M_{avg} = \left(\frac{\sum_{i=1}^{n} V_i}{V_0}\right) = 4 \cdot \left(\frac{\sum_{i=1}^{n} V_i}{\pi \cdot L}\right) \qquad (1)$$

The equation above determines the average edge chipping rate for the most general environment. In this case the planes of the milled granite surface those determine the edges are perpendicular (the edge angle is 90°). However it can be easily seen that this equation can also be used for generally angled edges.

3. 2. Construction of the Replacement Body

The aim of the research following the determination of the measuring number was to find a replacement body which could be effectively used for the qualifying equations of the edge chippings those are formed at the edges of milled granite surfaces. In the case of the replacement body it was a requirement that the volume of the body should approximate the volume loss of the product caused by the particular edge chipping as well as possible. It was a further demand that when determining the geometry of the body the number of used geometric datas of edge chippings should be as little as possible. During the examination process the researcher formed ten sample surfaces altogether on two different granite types using five different cutting speeds. The process was observed with the help of an NC stone machining center. After the machining he digitized the surfaces with the help of a laser scanner, then he separated the chippings with the help of a rapid prototyping software in order to determine the volume of each one. In the evaluating phase the researcher examined the total of three bodies to find the one which is the most appropriate to determine the volume loss caused by the chippings. It was an important demand in the case of all the three bodies to have a volume which can be easily calculated, as this is the condition with which they can be effectively used for determining the typical chipping characteristics. As a result of the examinations the researcher made the conclusion that the smallest relative error is received when a compound body is applied, which consists of two quarter cones with ellipse bases having equal volumes, touching each other by their sides (Fig.1). Three parameters had to be used during the determination of the body. Namely, the heights of the cones are equal to the distances of the starting and ending points of the chippings. The lengths of the two axises of the ellipsoid which functions as the base of the cone are equal to the maximum depths which are measured on the two surfaces those determine the edges.

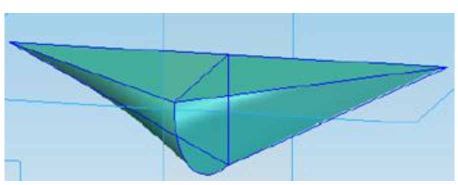

Fig.1. The sketch of the replacement body.

4. Applied Granite Types

Natural stones are separated into five groups by the standard according to their grain sizes (Fig. 2). Among the groups there is the one with average grain sizes smaller than 1 millimeter as well as the one with specifically big (larger than 10 millimeters) average grain sizes. During our examinations we chose a reference stone from each group, so the results can be generalized in the cases of all the granites those are included in one of the groups of the standard.

Average grain sizes of the rock	Appelation
d > 10 mm	large grained group
5 mm ≤ d ≤ 10 mm	coarse grained group
1 mm ≤ d ≤ 5 mm	middle sized group
d < 1mm (The grains are separable with a unaided eye)	small-sized group
d < 1mm (The grains aren't separable with a unaided eye)	fine grained group

Fig. 2. The groups of the natural stones according to their grain sizes.

The granite number ‘1’ is from Italy and it represented the middle sized group during our examinations. This grey (with a hint of pink) coloured, medium grain sized magmatic deep stone has a packed, crystallic structure. Its typical stone building minerals are quartz and potash feldspar. Along with the main stone components we can also find plagioclases and so called colored minerals (amphibole, biotite) in the stone structure. The gnarled, off-white, isometric quartzes have grain sizes with a value of 1-4 millimeters, while orthoclases – these appear in a great number – have the sizes of 5-7 millimeters. The Brazilian granite (number ‘2’) belongs to the large grained group. Its typical components are the gnarled off-white quartz and the potash feldspar. The sizes of the quartzes are between 1 and 10 millimeters. Other important components are the pink orthoclases, those are twin structured and boardly developed, and their sizes can reach the value of 15 millimeters. Granite number ‘3’ – coming from China – belongs to the small-sized group. Its commercial name is gabbro. Its typical compontent minerals are the strewly positioned, boardly appearing, 1-3-millimeter-sized plaghioclase and piroxen, which is a small-sized, boardly developed, 1-3 millimeter-sized mineral. Oliven and chlorite also appear sometimes, these are colored components with the sizes of less than 1 millimeter. The porosity of the stone is intergranular, its rate does not exceed the volume percentage value of 2%. Granite number ‘4’ can be found in the coarse grained group. This stone is light grey with a hint of pink; it has a mineral grain structure, and is a magmatic deep one. The structure of the stone is packed. Typical stone components are quartz and potash feldspar. The gnarled, off-white, isometric quartzes have the sizes of 1-5 millimeters. Orthoclases appearing as the main components tend to split, and have the sizes of 6-8 millimeters. Plagioclases appearing along with potash feldspars are fine grained, boardly developed and gnarled. Stone number ‘5’ is packed and homogeneously structured. Its typical components are plagioclase and piroxen. The strewly positioned, dark colored, board, columnly developed plagioclases has 1-2- millimeter-sized grains. Piroxens those appear along with plagioclases are fine grained and boardly developed; their grains have the sizes of 1-3 millimeters. There are a few more colored components in the structure of the stone (olivine, chlorite). The grain sizes of these are under 0,1 millimeter. Number ‘5’ granite standed for fine grained stones during the research.

5. The Process of Examination

The examination method that was established in order to determine the relationship between the average surface roughness and the average edge chipping rate could be separated into three phases. In the first phase we made 5-5 sample surfaces on each granite type. Each sample surface was machined with a different cutting speed. The second task was to examine the average edge chipping rates of the surfaces. The third step was the determination of the average surface roughness.

5. 1. Machining

For the machining of the granites I used a Prussiani NC stone machining center (Fig.3). The NC system allowed the technological parameters to be accurately set, and the manufacturing process could be automated with the help of it. We made five sample surfaces on each stone. The surfaces have the widths of 45 millimeters. We applied five different cutting speeds in the case of each stone. These speeds had the values of 188 m/min, 283 m/min, 377 m/min, 1225 m/min and 1634 m/min.The depth of cut was 1 millimeter during the whole process. We executed the machining with down cutting. The applied tool was a face milling one with 22 segments and a diameter of 100 millimeters.

Fig.3. The fixing of granite number 1 on the stone milling center.

In order to avoid the path of milling to be missed we made a stair structure of the sample surfaces on the granite blocks according to the different cutting speeds. The stairs helped to avoid the effect of the milling paths - which were working with the different cutting speeds - on the values of average surface roughness and average edge chipping rate.

5. 2. Measurement of the Average Edge Chipping Rate

After the milling processes the next step was to examine the average edge chipping rates at the exit edges of each sample surface. To determine this number we hadto implement a process that consisted of a number of steps.

As the first step I digitized the exit edges of the granites with a Scantech laser scanner fixed on a Kondia CNC manufacturing center (Fig.4). The scanning head measures the beams coming from the reflection of the emitted laser beams through two optics with a linear CCD.The data registering computer, which is connected with the scanner, stores the synchronized and also digitized x, y and z coordinates of the scanned points according to the rate of reflection distance. With the help of the semiconductor laser (with 1 mW capacity) the spatial datas of around 1000 points can be collected per second. The scanner provides an accuracy of ±0,05 mm in regard of the z coordinate of a particular point, in the distance of 400 millimeters maximum.

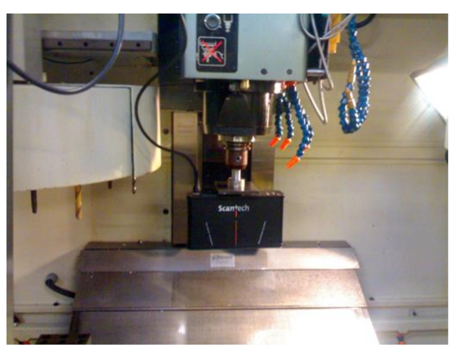

Fig.4. The Scantech scanner in the spindle of the Kondia machine.

After the scanning I fitted a triangle web on each edge with the Rapid Form program (which can be used on personal computer), then I separated the chippings which were visually defined (Fig. 5). After this I measured the distance between the first and the last points of the each chipping (Fig. 6), and the maximum depth of each one on the edge-determining surface (these datas are necessary to apply the replacement body).

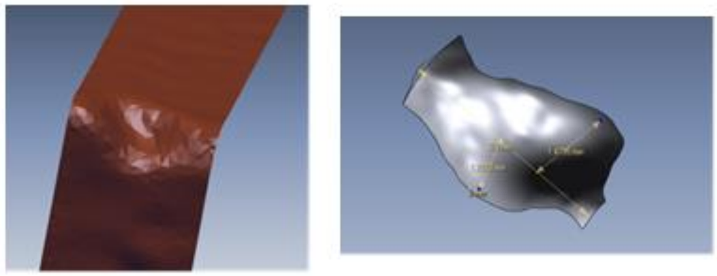

Fig.5-6. The triangle web and the typical sizes of a separated edge chipping.

5. 3. Measurement of the Average Surface Roughness

The determination of the average surface roughnesses of the five granite blocks was performed at the Department of Materials Science and Technology of the Széchenyi István University (Győr). To determine these values I used an Alicona InfiniteFocus confocal microscope. During the examinations I experienced that the line-defined, traditionally explained 'R_a' average surface roughness had a high dispersion because of the homogeneous grain structure, that is why I used the average surface roughness values (S_a) those are projected to surfaces instead of the ones defined on lines (Fig. 7.). In the case of the confocal microscope a work interval can be set in which the tool determines the average surface roughness which is projected to surface. This size always has to be the same as the interval determined in the standard.

During the measurement process I examined three intervals in the case of each sample surface (I measured 50-50 millimeters far from the two edges of the sample surfaces and in the middle of it) and I calculated an average of the three results to determine the average surface roughness.

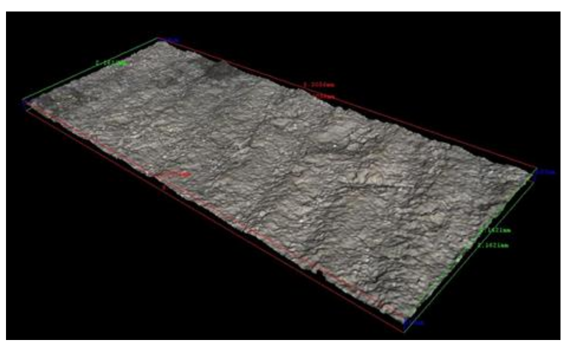

Fig.7. The surface scanned by the confocal microscope.

6. Results

On Fig. 8 we can easily see the changes of the average surface roughnesses and the average edge chipping rates of the five granite types as a function of the cutting speed. It is visible that I experienced the same changes of both parameters in the case of all granites with average sized grains. In the case of number '2' and '4' granites both the average edge chipping rate and the average surface roughness decrease monotonously as the effect of the increase of the cutting speed. In the case of number '1', '3' and '5' stones this tendency can also be noticed, but in all of the three ones we can find intervals where this decreases stop. However the two parameters change on the same way in these cases as well.

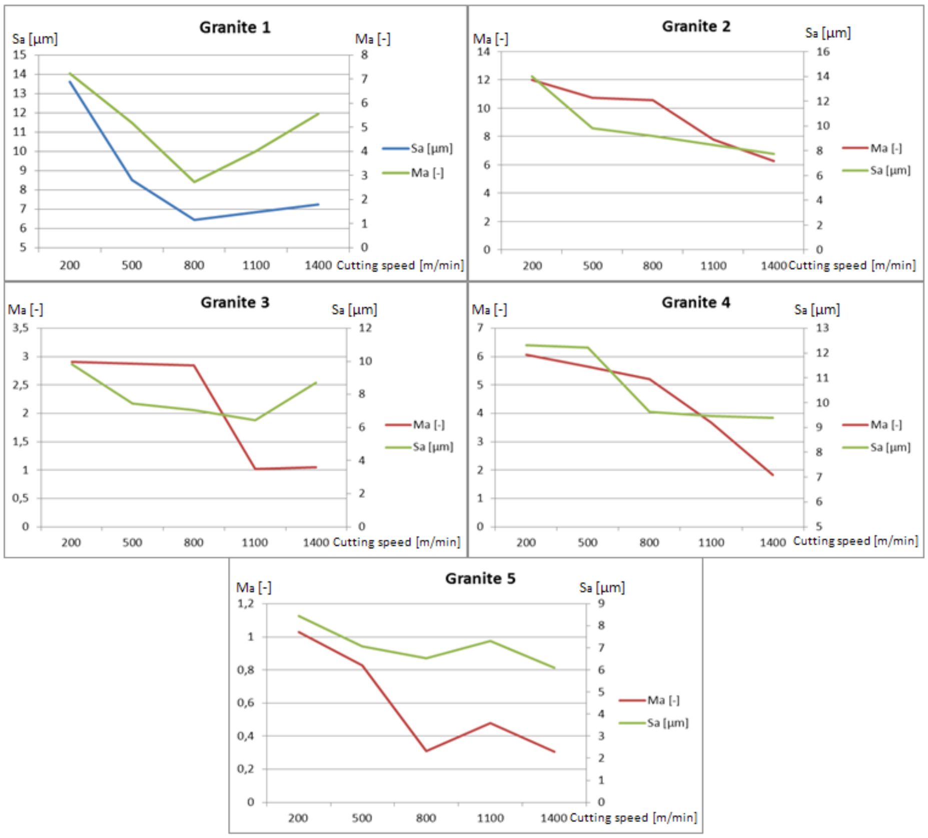

Fig. 8. Measurement results.

Comparing the measurement results we can draw the conclusion that in spite of the obvious parralellism in the changes of both parameters as the function of cutting speed, we cannot establish an obviously effective equation with which we could directly estimate one of the parameter while already knowing the other one. The primary reason for this is the high level of inhomogenity of natural stones (and so granites). This reason can be determined also in the case of the break of the monotonous parameter decreases those can be experienced during the increase of the cutting speed.

Based on the results we can draw the conclusion that although we could not establish a mathematical equation because of the inhomogenity of the granites, it is obvious that in the case of milled granite surfaces the changes of the average edge chipping rates and the average surface roughnesses can be paralleled near different cutting speeds. As a function of this we can state that if we can measure the change of the average surface roughness as a function of cutting speed, we can effectively estimate the change of the average edge chipping rate of the particular product's edge.

7. Summary

The research introduced in this article examined a problem related to milled granite surfaces. The experiments had the aim to reveal if there was a relationship –as a function of cutting speed- between the changes of the average surface roughness values of concrete surfaces and the average edge chipping rates of the exit edges of the corresponding surface. During the researches we machined sample surfaces with 5-5 different cutting speeds on five different types of granite (with different grain sizes), then we measured the values of average surface roughnesses and average edge chipping rates in the case of each surface.

As a result of the examinations we can say the following: there is an obvious parralellism in the changes of the two parameters, and this is valid for each type. However this obvious tendency cannot be determined effectively with mathematical tools, mainly because of the significant inhomogenity of granite materials. As a result of the experiments we can make a conclusion that with the knowledge of the change of the average surface roughness it is possible to make estimations on the average edge chipping rate of the edges of milled granite surfaces.

In the near future I am going to repeat this examination process several times with the aim to find a mathemathic relationship on this field on an empiric way. In addition I am going to examine the effects of other technological parameters.

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