Research results and future orientations for the development of a pre-estimation system for the measure of the quantitative determination of milled granite surfaces

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Abstract. On the manufacturing of different CNC machine-tools, the tables of ultraprecision machine-tools and CNC coordinate measuring machines are made of granite. Despite of the continuous industrial investigations, an accurate estimation system has not been developed so far. Although, an estimation program is necessary to predict the rate of the average edge chipping of different granite types. In this article, a summary of a research work is given connecting to this topic. Furthermore, the tendency of our future research is defined.

1. Introduction
Granite is a favoured raw material used in the construction industry, as it has excellent abrasion resistance. However, due to this feature, it is often applied in other engineering fields as well. For example, in machinery engineering, granite is used as the primary raw material for tables and machine beds of ultra-precision machine tools. Major problem is that pre-estimation system is not developed to the present day in this topic. In this paper the researchers have summarized the achievements of research on the subject and they have determined the future research trends.

2. Literature review
For machining, the shaping of the granite surface is required. The primary forming process is the milling. During this treatment, unexpected surface damage can occur on the milled surface or its edge. The granite surface loses its quality and market reach due to these surface deformations and irregularities. In order to minimize this problem, estimation systems have been developed in the recent years that can efficiently determine the degree of force during the machining process varied according to the applied technological parameters and the properties of the stone materials. Turchetta et al. [1, 2, 3, 4] developed a system to describe the cutting conditions in the immediate vicinity of the stone-manufacturing area, whereby the process elements of the material scaling were defined. Tanovic et al. [5] investigated the properties of diamond segment tools applied in micro-cutting process to define the optimal parameters of the treatment. Jiang et al. [6] measured the effect of the pressure and cooling intensity of mining drill equipment on the breaking and fracture parameters of natural stones. Using finite element simulation, Wang et al. [7] analysed the damage processes of manufactured stone in mining works as well. Furthermore, interesting results have been published by Zhai et al. [8] about
surface damage and breaking in granite materials caused by mechanical vibration with different frequencies.

A further important aspect of the international research is the determination of the technological parameters (cutting speed, feed rate, cutting depth) that minimize specific energy in the milling process of granite [9, 10]. Specific energy is a fundamental parameter for manufacturing of natural stone [10, 11]. The effectiveness and efficiency of a given process can be measured efficiently with the specific energy. Xu et al. [12] studied the specific energy consumption of stone manufacturing processes. In their work, the shape of the segments of the applied tools and the properties of the grains in the segments were taken into account. The influence of technological parameters on the product quality was examined by Aydin et al. [13] as well. Based on their microscopic results, they conclude that the average surface roughness increases under increasing the cutting speed and the cutting depth, but it decreases due to the increase of the intensity of cooling. These models provide effective help in selecting optimal technology parameters and manufacturing tools.

The discrete elements method is a new technology in the impact analysis of grain structures of different stone materials. According to the definition given by Cundall and Hart [14], the fundamental assumption of the method is that the material consists of separate, discrete particles. These particles may have different shapes and properties. Each element has its own freedom and the model is able to follow their shift and turn. The effects of elements on each other may change. Thanks to the method, the relation between the elements as well as their material and geometrical characteristics can be determined. In this way, the manufacturing deformation, surface properties, and surface loads can be simulated. Using this method, Van Wyk et al. [15] studied the change of geometry, forces and force components (such as shear, friction, friction) on the surface of the stone.

3. Experimental processes
Quantitative and qualitative analysis of surface defects has already been monitored by our research team. Our long-term aim in this research is to develop a model system that provides accurate results that is capable of predicting surface defects and thereby optimizing selected materials and tools. After defining the materials and methods, the results of our studies are presented that were obtained so far.

3.1. Used stone materials
Based on the new standard, rocks can be divided into 3 groups according to their particle size. In our measurements, one material was selected from each group and the milling was carried out using tools containing diamond grains of different sizes. 300 x 300 mm granite blocks were used. When selecting arrays (blocks), we took into account the particle size classes defined in the Building Material Standards (BMS) standard and assigned to each class an experimental array (Table 1).

Table 1. Classification of natural stones according to their grain size [16]
4-6 different surfaces were prepared for blocks with different grain sizes so that the currently selected parameter of the surface manufacturing treatment was changed per measurement.

3.2 Evaluation options
During our previous research, we have evaluated the extent of the edge damage by several methods.

One of the excellent solutions is the use of optical microscopes. The edge damage ratio of the shaped surface as well as the degree of the edge chipping are determined by optical microscopy. During the evaluation, the length of the edge chipping is measured manually. Thus, the distance between the starting and end points of the edge chipping is measured and the maximal edge chipping depth is determined as well (Figure 1). Handling these data, the volume of the edge chipping can be determined.

![Figure 1. Determination of the typical dimensions of an edge chipping [16]](image1)

Our other device was the profile scanner (Figure 2). The device uses a scanner mounted on a movable slide that digitizes the surface in small contour sections. The test surface is fitted to the resulting data cloud. Using this 3D scanner, the evaluation is time-consuming but it provides accurate measurement results. The evaluation of these data is done by the MiniTab 15 statistical software. The software gives result for the standard deviation of the measurement sequence, the expected function of normal distribution, the curve prediction band of the set of statistical results, and the confidence interval.

![Figure 2. Measurement with profile scanner [16]](image2)
3.3 Examined parameters

Gyurika et al [17] investigated the effect of cutting speed on the edge damage. In this measurement they have examined granite blocks of 5 different particle sizes. Each set consisted of 5 sample surfaces with 5 different cutting speeds. The other technological parameters that relate to the cutting, such as feed rate, cutting depth, cutting width, tool and track were kept constant. The results were evaluated by means of an optical microscope. In this way the degradation on the surface of the leaving range.

They observed in the range between 200 m/min and 1400 m/min that for some granite types the degree of edge chipping decreases up to a given value (1100 m/min), after that, the alteration trend reverses and starts to increase. We can see the result for one of the stones in Figure 3. A second degree regression curve was fitted to the obtained data. The evaluation was done using the ANOVA statistical method.

During other research Gyurika [18] have investigated the effect of grain sizes of the diamond tool and the effect of feed rate in this theme. Considering the previous experiment, 4 different feed rates (200 mm/min, 300 mm/min, 400 mm/min, 500 mm/min) were adjusted to the 3 different stone materials. The minimum chipping value can be seen even better if the diamond’s grain size is increased at fixed feed rate. Changing the feed rate influenced the degree of edge chipping less than the size of the diamond grains. At the same time, a local minimum is observed for each stone sample depending on the particle size, where the degree of the edge chipping is the smallest. The position of the minimum point is affected by the grain size of the diamond and that of the machined rock as well (Figure 4). The larger the particle size of the rock, the lower the feed rate is where the local minimum appears, while this local minimum is observed at high feed rates if the grain size is smaller.
4. Research conceptions
In case of the milling of granite surfaces, the rupture properties of different types of stone materials have not been analysed yet considering the edge chipping and rupture properties of the grains. Therefore, the next step in our research work is to study the rupture properties of the stone samples, since, these properties have a main influence on the average surface quality and the edge quality as well. In case of a manufacturing process, some grains break apart as a result of various forces, while other stone components dislodge from the surface and from the edge. These deformations can significantly alter surface and edge quality. That is why, the properties of the binding, adhesive components of the stone samples will also be the subject of the further study. Here, the qualitative and quantitative evolution of the forces between the particles will be discussed as well.

In the literature, no publication is found about the impact of the tool paths on the level of surface and edge damage if automated stone processing is used. For that reason, the study of the influence of the applied tool paths and motility on the surface quality of stone material offers an important industrial topic of research.

5. Summary
There is little data available to develop a proper estimating model of the effect of milling on the quality of the stone sample and the existing data is not accurate enough. Therefore, the influence of the technological parameters (cutting speed, feed rate, cutting depth) and the size of the diamond particles in the machining tool is an important field of research. Its results are proposed to be implemented in industrial application as well.

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