

AN INVESTIGATION OF GRANITE AND BASALT GRINDING PROCESS

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An investigation was carried out to elucidate the phenomena of wheel-workpiece interactions at the interface in the surface grinding of granite and basalt with diamond abrasive wheels. The surface roughness and texture were analyzed. For the grinding process of mineral materials, diamond wheels are most popularly used. From fundamental or technological issues, it is of important to understand what happens at the interfaces between workpieces and abrasives when grinding processes are applied for machining natural stones. The purpose of this study is the understanding of the particularities of granite and basalt grinding and gives technical information for maximizing the machinability of these materials.

Keywords: grinding, granite, basalt, surface roughness, tool temperature.

1. Introduction

Mineral materials, like granite and basalt, are frequently used as surface decorative materials in constructions and for different industry parts because of their durability, aspect and shine. Their surface quality is one of the most important quality criteria for the stone parts.

The grinding process is one of the most rapid ways to remove a lot of material from stone parts, turning or milling processes for these specific materials being reported as impossible. Grinding is a specific abrasive mechanical process that is based on removing very small material stocks in the form of chips by the action of irregularly shaped abrasive particles. The heat released from grinding process is an important factor that affects the mechanical properties of mineral materials and plays a central role for machine surface quality. The study of the temperature distributions on the machined surfaces and abrasive wheel during granite grinding process is necessary to anticipate ground surface damage and tool wear. Temperature distributions on the grinding wheel were measured using spot thermal camera. The grinding temperatures and surface quality for two types of mineral materials were investigated.

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Machining thermal regimes for the two different types of rocks- granite and basalt were compared to establish the influences of material proprieties over the level of grindability of granite and basalt. Grindability of a specific material represents the propriety of that material of being easily machined by grinding. Therefore, this propriety describes the efficiency of grinding process for the materials and it is an important barometer for estimating tool wear, machine the power requirements, machine specific energy demands and costs. The grindability and resistance against mechanical stress of the materials is manifested by increase heat released and cutting energy consumption. In a scientific paper, Popp [5] has concluded after analyzing the behavior of basalt parts submitted to static stress that basalt demonstrate better behavior than steel or grey iron cast parts, which make it suitable for machine-building industry.

The heat generation sources in grinding are considered to be: material deformation and micro- fracture and friction. The grinding mechanism and grinding process of ceramic materials are different from metal and other materials. The mineral materials are brittle materials and materials stocks are cut during machining processes by ductile chip formation because of large compressive stress in the chip formation zone, which shields the growth of pre-existing flaws in the material by suppressing the stress intensity factor [4]. One of the main problems regarding the grinding process surface quality of brittle materials is the remaining micro-cracks as sub-surface damage due to material cracking. In order to achieve desired surface quality and accuracy during the grinding brittle materials process the key is to minimize sub-surface damage by using proper grinding techniques.

The mineral materials samples were grinded with different spindle speeds, feed velocities and grinding depths to determine the optimal cutting parameters for grinding. There are few researches in the field of mineral materials processing and most of them deal with the sawing process. The grinding processes of natural stones is less investigated even if is the one of the few machining processes that can be applied to these materials. Relatively few studies cover the problem of the thermal regime of diamond tools during grinding. Xipeng Xu [11] had carried out a study that covered the the temperatures and energy partition for grinding of granite with a diamond grinding wheel. He measured the temperature in the grinding zone using a two-color infrared detector. His study concluded that approximately 70% of the generated energy at the wheel-workpiece interface during grinding in dry conditions is transported as heat to the grinding wheel. The author also mentioned that the thermal distribution and energy partition is strongly influenced by factors as machining parameters, wheel properties, and workpiece properties. Even if the grinding zone temperature could not have a damage effect on the properties of the granite, the calculated tip temperature could reach over 1000°C, which can lead to excessive wear of diamond tools.

H. Huang et al. [3] studied the glossy granite surface formation mechanism. They investigated surface textures by scanning electronic microscope on the two different types of granite after grinding performed with six dissimilar resin-bounded diamond tools. They concluded that there is a correlation between surface roughness, surface shines and the size of diamond grains of the abrasive wheel. Improve surface roughness can be obtained by using smaller diamond grains. They revealed that there is a certain grain size under which glossy surfaces can be achieved because of the ductile flowing caused by the grinding process. Ductile flowing has an important role in improving surface roughness but its main cause it is not the temperature. Ductile flowing is the result of machining with small grain sized abrasives.

Shen et. al. [6] had finely ground several kinds of rock minerals with different chemical compositions and studied the characteristics of smooth stone surface formation. They reported that during the grinding process mineral materials surfaces with different chemical compositions generate different surface patterns.

Labuz et al. [7] investigated crack propagation in granite and reported that a large number of micro-cracks occur around the crack tip covering the fracture process zone and affecting surface quality. They also reported that specific energy increases with the depth of cut, indicating the action of sliding friction prevailing in the grinding.

Olejnik [8] studied the kinetics of the grinding process of granite taking into consideration the morphology and mechanical properties of particular size fractions of the feed. He reveled that the required granulometric composition can be attained by proper selection of the size of grinding media.

Gyurika [2] investigated the surface roughness of ground granite parts. The aim of his study was to determine if there is a correlation between cutting speed and the average surface roughness. He tested five different granite type (with different grain sizes) with five cutting speeds. He concluded that there is an obvious parallelism in the changes of the two parameters, and this is valid for each type.

Xiqing Xu et. al. [10] had developed an ultrafine abrasive tool for vertical spindle grinding and had found that by grinding with abrasives of $5\mu\text{m}$ can scratches on silicon wafer can be removed and smooth surface of 15nm (Ra) can be obtained.

2. Experimental setup

Plane surface grinding experiments were conducted on a rigid plant grinder using two types of diamond abrasive wheels- metallic bond diamond

wheels with a granulation of D126 for rough machining tests, resin bond diamond wheels with a granulation of D76 for finish machining tests.

The main mineral compositions for the granite are quartz (5%), feldspar (45%), mica and others (50%) [12]. Basalt is composed mainly of plagioclase and pyroxene minerals. The main properties of these mineral materials are presented in table 1.

Table 1

Granite and basalt properties

Properties	Granite	Basalt
Specific gravity, KN/m ³	2.6 - 2.7	2.8 - 3.0
Hardness	6-7	6
Compressive strength , N/mm ²	175	37.4
Specific Heat Capacity kJ/Kg K	0.84	0.79
Density , g/cm ³	2.65-2.75	2.9-3.1

The abrasive wheel peripheral cutting speed usually applied is in the range of $v = 20-80$ m/s [1, 7, 10, 11]. The spindle speed used in all the grinding tests carried out was of 3000 rpm. In order to obtain two different cutting speeds wheels with an external diameter of $D = 175$ mm and $D = 200$ mm were used. All the abrasive wheels used in the experiments had a 1A1 geometry and a width of $b = 10$ mm. The grinding tests were carried out without cutting fluid, dry grinding being a popular process for finishing of granite materials.

The tests were then conducted, measuring the abrasive wheel temperature during machining using an infrared camera Flir TG 165. To ensure a reliable emissivity of the surface, the diamond abrasive wheel approximative emissivity was determined. Some examples of the IR images obtained during the machining test are shown in fig. 1.

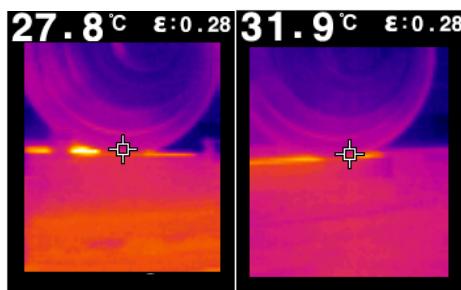


Fig.1 Examples of the IR images taken during the grinding process of granite and basalt samples

The emissivity of the abrasive wheel was calculated considering the resin bond and diamond emissivity and the abrasive wheel concentration (M75 /R75-18,45% diamond concentration). The emissivity was found to be $\epsilon = 0.28$.

Besides the temperature measurement, surface roughness and texture were investigated using MarSurf CWM 100, a precision, computer-controlled optical measuring instrument with sub-nanometer resolution. Because the mineral materials have high porosity the roughness parameters measurements couldn't be realized with tactile roughness measuring devices. For an accurate surface roughness parameter determination, in order to avoid measurement stochasticity, three different areas of the same grinded sample were investigated.

The surface texture measurements were processed with specialized software MarSurf MfM. In figure 2 a report obtained with this software is presented.

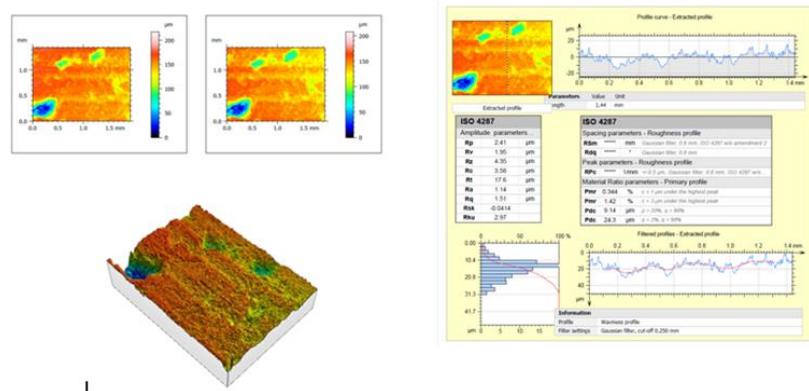


Fig. 2 Surface texture analyze and roughness parameters measurement

A full factorial design with three factors and two levels for every input factor was considered. The input factors and their levels are presented in table 2. Each line in the table represents the tests process parameters that are combinations of the input factors level. The number of passes was equal in the case of the two depth of cut chosen for the experiments.

Table 2

Input factors and their levels

Factor \ Level	v [m/s]	f _i [mm/min]	a _p [mm]
-1	27	2	1
+1	31	5	2

3. Results and discussions

In table 3 the experimental array and the values obtained for the output factors (surface roughness parameter Ra and tool temperature T [$^{\circ}$]) are presented. The small values of the tool temperature obtained in the experiments indicate an error in the emissivity calculation. Even if the values of this parameter are not

correct they reflect the independent variables influence over the interest parameters investigated. As it can be seen the cutting parameters have a negative influence over tool temperature. The increase of the cutting speed, longitudinal cutting feed and depth of cut will result in higher tool temperatures.

Table 3
Experimental array and obtained data

Exp. run	Input factors (independent variables)			Output factors			
	Cutting speed v [m/s]	Long. cutting feed f_l [m/min]	Depth of cut a_p [mm]	Ra granite [μm]	Ra basalt [μm]	T granit [$^{\circ}$]	T basalt [$^{\circ}$]
1.	27	2	1	1,143	1,335	31,90	25,90
2.	27	2	2	0,937	1,130	31,60	24,80
3.	27	5	1	0,829	1,015	28,80	26,40
4.	27	5	2	1,075	1,125	37,80	24,10
5.	31	2	1	0,870	1,147	31,60	24,70
6.	31	2	2	0,927	0,960	37,70	24,20
7.	31	5	1	1,155	0,947	30,90	25,20
8.	31	5	2	1,084	1,620	35,60	27,80

Surface roughness Ra parameters values, on the other hand, seem higher in the case of basalt grinding. The surface roughness measured for the basalt samples varied between 0,947-1,620 μm and for those of granite between 0,829-1,155 μm . The large variation domain for the basalt samples could be a cause of its high porosity. We can say that according to the surface finish criteria granite has a higher grindability than the natural basalt used in this experimental study. Also, for the machining conditions specify in this specific study and according to the tool temperature criteria basalt has a higher grindability level than granite. In figure 3 are presented samples of the surface texture of 1,5x2 mm dimensions observed with the MarSurf CWM 100 optical microscope after grinding basalt (Fig. 3 a.) and granite (Fig. 3 b.) with a cutting speed of 27 m/s, a longitudinal cutting feed of 5 m/min and a depth of cut of 1 mm. As we can see the basalt probes exhibit porous surface aspect. Even if the surface roughness was determined for profiles outside these pores, the surface quality in the case of basalt samples was strongly influenced by the material structure.

Figure 4 show the output factors variation during experiments. The tool temperature measurements taken during the grinding experimental runs of basalt exhibit a slight variation. Therefore, for these values we didn't pursue with a regression or DOE analysis.

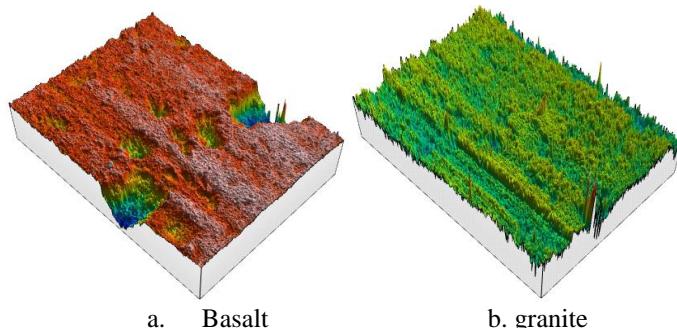


Fig. 3 3D surface texture samples observed with the MarSurf CWM 100 optical microscope

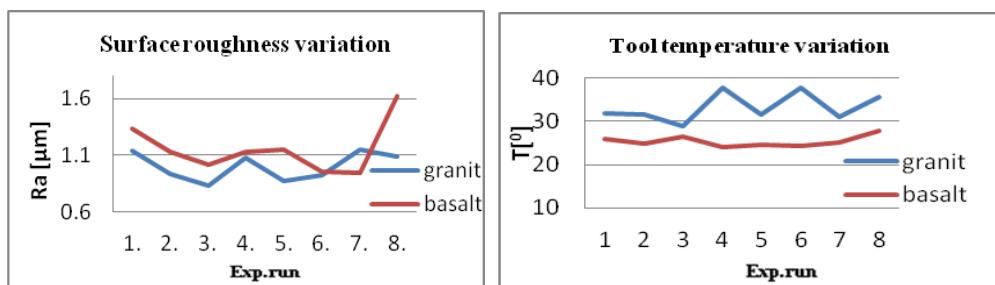


Fig. 4 Output factors variation during experiments runs

The correlation between the input factors (cutting speed, longitudinal cutting feed and depth of cut) and the interest factors, surface roughness and tool temperature were obtained by multiple nonlinear regressions. The regression analysis of the data generated from the grinding tests yielded the exponential functions for surface roughness Ra parameter for granite (1) and basalt (2) materials and for tool temperature for granite (3).

$$Ra = 0,584204 \cdot v^{0,13365} \cdot fl^{0,073954} \cdot ap^{0,0131128} \quad (1)$$

$$Ra = 0,581593 \cdot v^{0,175145} \cdot fl^{0,0466634} \cdot ap^{0,131768} \quad (2)$$

$$T = 10,554 \cdot v^{0,316089} \cdot fl^{0,0599894} \cdot ap^{0,212613} \quad (3)$$

The extremely close values obtained for the exponents in the empirical equations obtained for the Ra – arithmetical mean roughness parameter indicate that the equation (1) and (2) can be considered reliable models for these particular machining process of mineral materials. The standard error of the regression equation, which represents the average distance that the measured experimental values fall from the regression line is for equation (1) $S = 0,160532$, the one of the

equation (2) is $S = 0,285433$ and for the tool temperature regression model is $S = 2,58648$.

The small values of the standard error of the first two regression equations (1) and (2) indicates that the experimental values are closer to the regression equation line. The regression models obtained through full factorial multiple regression analysis for the Ra surface roughness parameter fits well the experimental results, and they show reasonable correlations with minimum errors.

The surface roughness when grinding mineral materials is influenced by a numerous number of variables as: machine part stiffness, machine accuracy, kinematic conditions, material properties as well as the diamond abrasive wheel, work and machine other characteristics. Therefore, the models obtained by the nonlinear regression analyze can be used to calculate the surface roughness under different machining conditions.

The deviation of the surface roughness of values obtained with the regression equations - models from the actual measured values, for the cutting speeds, feeds and depth of cut used in the eight test runs carried out for the two materials investigated is shown in figure 5.

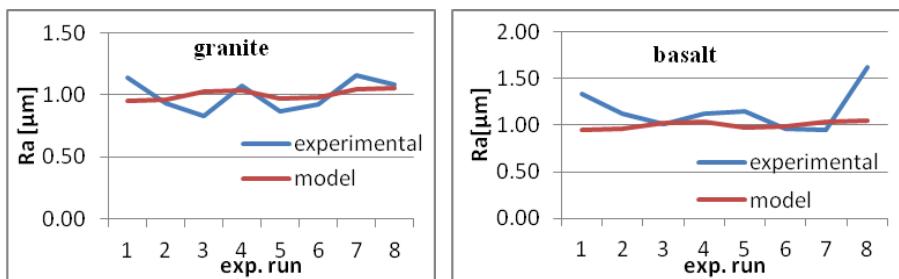


Fig. 5 Comparison between measured and predicted values of the surface roughness parameter Ra

In figure 6 are presented typical results showing the effect of the grinding conditions on the surface roughness. It is seen that with increase in the values of feeds and depth of cut, surface roughness deteriorates.

As we can see, for the independent variables variation ranges selected for this experimental investigation, according to the analytical model graphs, the cutting speed seems to have an almost linear influence over the predicted surface roughness parameter Ra. The longitudinal cutting feed influence graph over the predicted surface roughness parameter Ra exhibits an exponential aspect, indicating a clear power variation law. According to the depth of cut influence graph, we can notice that the surface roughness has a different variation in the case of granite and basalt grinding test. The depth of cut has a stronger influence over the surface roughness parameter Ra when grinding basalt than when grinding

granite. That may be a result of the porous structure of the natural basalt samples used in the experiments.

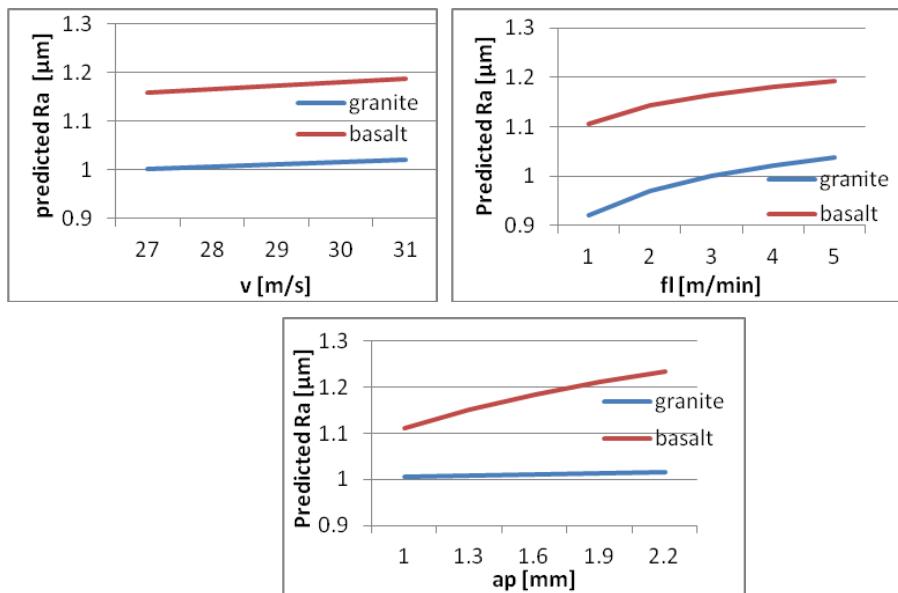


Fig. 6 Surface roughness Ra parameter predicted variation with the independent variable chosen in the study

4. Conclusions

Regression analysis is performed to establish a variation law between factors and surface roughness and tool temperature during grinding of granite and basalt samples. According to the regression analysis the independent variables and the response or output factors are related to each other. A nonlinear regression technique was used to obtain the response function linking the cutting speed, longitudinal cutting feed and depth of cut to the surface roughness parameter Ra. Based on the analytical and experimental results obtained in this study the following conclusions can be drawn:

1. Ra surface roughness parameter empirical models obtained fits well the experimental results, and they show reasonable correlations with minimum errors. According to the surface finish grindability criteria, granite exhibits higher grindability levels than natural basalt.
2. The increase of cutting sped, longitudinal cutting feed and depth of cut during machining show the enhancement of the Ra surface roughness parameter for the two materials investigated.
3. Even if the tool temperature measurement values were incorrect because of the errors in the emissivity determination technique used, we could analyze the

effect of the cutting speed, longitudinal cutting feed and depth of cut influence over this output parameter concluding that the the cutting parameters have a negative influence over tool temperature. The increase of the cutting speed, longitudinal cutting feed and depth of cut will result in higher tool temperatures.

4. For the machining conditions specify in this specific study and according to the tool temperature criteria basalt has a higher grindability level than granite.

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