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ASPECT REGARDING THE GRINDING PROCESS OF GRANITE USED IN PAPER INDUSTRY

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Abstract: *The paper presents same information regarding the grinding process of granite rollers mantle used in paper industry and a research that is focused on the quality and economical aspects of the plane grinding process of some samples of granite material (identical to the granite mantle of the analyzed roller). The main purpose was to determine a correlation between the cutting parameters: cutting speed, longitudinal cutting feed and cutting depth and the machined surface roughness, cutting temperature and machine –tool power consumption for rough and finish granite grinding process. Polynomial regression equations that reflect the correlation between the dependent parameter considered and the independent parameters are also given. The paper also gives recommendations regarding the rough and finish granite grinding process with diamond discs and without any cutting coolant.*

Key words: *external cylindrical grinding, granite rollers mantle, process parameters, diamond discs, temperature, power, roughness.*

1. INTRODUCTION

Granite has been used as material for paper industry press rollers since 19th century because of its excellent sheet release properties when the paper passes through the press section of a paper machine [1]. Grinding of granite paper press rollers is a very difficult grinding operation in industry. This is because of the close tolerances and surface finish required, because of the workpiece gauge and slenderness (they are very long relative to diameter).

The net mass of the rollers used in the paper industry is usually 9630 kg; its granite mantle weighs 5690 kg. Additional safety measures are required to be respected when handling the rollers on the grinding machine- tool. The grinding process of the press rollers granite mantle must be executed with abrasive diamond tools. The prescribed technological crowning is recommended to be 0.307 mm, the length of the granite mantle is usually: *L* granite mantle = 4850 mm and the roll diameter *D* roll = 850 mm (see Fig. 1).

In order to obtain the qualitative characteristics prescribed for the rollers is important that special conditions to be assured. Amount these conditions; special cylindrical grinding machines with high rigidity and high installation power (over 100 kW) must be used.

Roller grinding processes are currently carried out based on the manufacturer's previous experience, without any research concerning the optimal machining conditions, thus eliminating the chances of increasing productivity and assuring high quality for the rolls.

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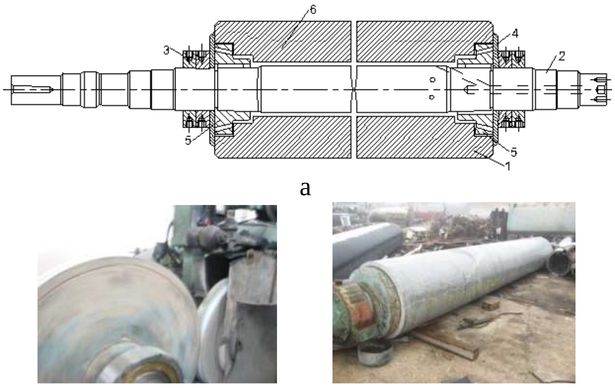
The roller is fixed to the machine-tool between peaks, placed on two semi bearings supporting, and rotated by a driving group with a high installed power ($P_{disc\ drive}$ = 32 kW) with the possibility of varying the speed from 5 rpm to 1500 rpm. The specific roller grinding machine-tools have a abrasive tool training head which can be tilted to obtain the prescribed roller crowning and the possibility of continuous grinding wheel velocity variation (5–1500 rpm) that has large diameters: *D* = 500–900 mm (see Fig. 1).



b c

Fig. 1. Granite roller: *a* – cross section (1 – granite cylinder; 2 – shaf; 3 and 4 – tightening washers; 5 – nut; 6 – cement filling; *b* – granite mantle grinding; *c* – granite mantle roller.

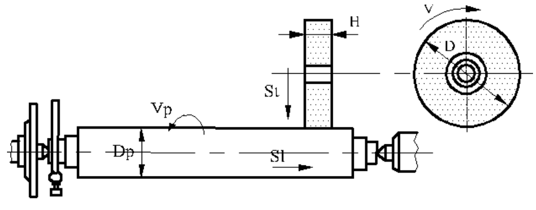


Fig. 2. Scheme of external cylindrical grinding process of rollers on special grinding machines tools [2, 3].

2. PROBLEM STATEMENT

The identification of the granite machinability characteristics is a problematic subject due to the following aspects of the grinding process:

- granite is being considered a difficult to cut material;
- the material has the tendency of cracking during machining (formation of lateral and conical cracks with the possibility that the chip size becoming larger than the cutting depth);
- high energy consumption due to high friction forces;
- high consumption of cutting tools due to intensive tool wear - the extremely low thermal conductivity of the granite compared to the steel gives a rapid wear of the cutting tool;
- compared with the metal grinding where there are shear splints [5, 6, 7] at the ceramic and mineral materials, the plastic deformation step is replacing by a crack formation after the dislocation planes and the chips are generally removed by micro-fragile breaks, the process continuing behind the granules due to the return and to the closure of the lateral and conical cracks. The nature of plastic deformation and / or cracking depends on the composition and properties of the mineral material.

Manufactures nowadays have to deal with increasing energy costs and continued pressure to reduce cycle times and costs. Therefore, energy consumption issues are considered an important aspect of every machining process. Grinding is one of the most used machining processes for finish machining and due to its specific material removal technique is also one of the most energy consumption machining process. Energy consumption in cutting process is directly related with power consumption. Machine tool power consumption is not new to metal cutting. These measurements have been used to determine and predict tool wear and fracture as an alternative to using force measurement. In this paper machine tool power consumption during granite rough and finish grinding is investigated.

There is poor research literature dealing with mineral material machining processes. Most paper in this field discusses the sawing process. The process of grinding is usually applied for polishing stone parts used as decoration products or as casing materials. Mineral parts are also used in different mechanical engineering practices, for instance as measuring machine's elements. Granite is one of the most popular mineral materials used nowadays for industrial applications. Its specific proprieties, high hardness, abrasion resistance and resistance to thermal deformation and shock resistance recommend this material as mantle for paper industry rollers.

Ribeio et al. [15] studied the influence of tehnological parameters over machined surface roughness when sawing granite. Their study investigated the influence of the material texture and mineralogy, overal the two diffrent types of granite proprieties and the influence of the cutting speed on surface quality. They showed that amoung granite proprieties the heterogeneity of grains and the relation of the components (between quartz and feldspar grains) exert a great influence over the machined surface roughness.

Kenda and Kopač [16] had presented some aspects regarding the surface roughness for each machining process, from sawing, grinding to polishing of granite. They also presented different type of diamanted tool and examinated the diamond tools wear and machining forces during the basic type of machining for mineral materials.

Wang et al. [17] studied the influence of cutting conditions over surface quality for the platen belt grinding machining process of granite. In their research they used two different types of granite and other mineral materials. In this paper, the authors analysed the influence of some process parameters: normal forces, belt speed, coolant type, the movement of machine – tool table, the grit size and the abrasive type used for the cutting tool over the material removal rate and surface roughness.The ground surface aspect and the surface profile were also analysed. For granite samples and the specific machining condition chosen, the grinding effect was not so good.

Zhang et al. [18] studied the ceramics grinding process and the mechanism of grinding force. They mention that the rigidity and precision of machine- tools and process parameters as grinding fluids, tool wear, abrasive particle size of grinding wheels have a great influence on the grinding force magnitude and its variation.

The machining parameters of the external cylindrical grinding process of paper industry rollers: cutting speeds, longitudinal cutting feed and cutting depth are the main factors directly responsible for the machined surface quality. One of the main issues regarding mineral material cutting processes is the energy consumption that affects the process cost. High cutting energy is generated due to high mechanical friction and a high amount of this energy is transported as heat to the grinding wheel leading to intensive tool wear.

It is necessary to optimize the grinding processes of the mineral materials in order obtain quality surfaces at the prescribed roughness and accuracy.

3. EXPERIMENTAL SETUP

For economic reasons, samples of granite material (identical to the granite used for roller's mantle) were subjected to experimental tests on the plane grinding machine tool RPO-200 RKS from the mechanical workshop S.C. Vrancart S.A., Adjud, Romania. The material surface roughness, cutting temperature and cutting power consumed by the machine tool were investigated.

The process of plane grinding was chosen considering the following reasons: less energy and time consumption and less expensive diamond tools. The machining time in the case of plane grinding is shorter than the actual grinding process of the paper industry granite roller mantles and the cutting tool used had a smaller diameter than the ones used in grinding paper industry rollers. Also, plane grinding forces measurements can be performed relatively easily using the Kistler dynamometer on the RPO-200 RKS mounted on the machine magnetic plate (see Fig. 3).

The material used for the samples submitted to plane grinding experimental tests carried on the RPO-200 RKS

a b

Fig. 3. a) Experimental setup with Kistler dynamometer; b) Granite workpiece on RPO 200 - AKS grinding machine.

Table 1

Important physical and mechanical characteristics of "Iacobdeal" granite according to STAS 6770-73 [4, 8, 9]

Nr.crt	Physical and mechanical characteristics	Determinations on specimens
1	Density kg/dm^3	2.66
2	Total porosity %	1.20
3	Dry wear resistance g/cm^2	0.02
4	Mechanical shock resistance daNcm/cm^3	45

machine tool using diamond abrasive discs (for rough and finish operations) manufactured by SC Diasfin SA and SC Diateh SRL from Romania, was "Iacobdeal" granite. Some material characteristics are given in Table 1.

The "Iacobdeal" granite is alkaline granite, an intruding magma rock. Macroscopically, this granite looks compact; the overall color is gray with yellowish or pink tones. The structure is medium grained holocrystalline. The texture is massive and the mineralogical composition includes alkaline feldspars, quartz, alkaline amphibols, alkaline piroxens, zirconium, opaque minerals, and secondary minerals [4, 5].

Taking into account the recommendations from the scientific literature [6–11] as well as the cinematic possibilities of the plan-grinding machine (RPO-200 RKS) used for performing the experiments in order to issue pertinent conclusions regarding the optimal cutting regime for grinding granite, the experiments were conducted by modifying the depth a_p [mm], the longitudinal cutting feed f_l [m/min] and of the cutting speed (rotation speed of the disc) v_d [m/s] at the values given in Table 2.

Table 2

Grinding conditions

Machine tool: RPO 200 - RKS Abrasive discs used: a) For roughing: 1A1-200-10-3 D126 M75 H76,2 Metallic binder 1A1-175-10-4 D126 M75 H76,2 Metallic binder b) For finishing: 1A1-200-10-3 D76 R75 H76,2 Resinoid binder 1A1-175-10-4 D76 R75 H76,2 Resinoid binder [12]		
Input factor	**Values**	**U.M.**
Depth of cut a_p	0.01; 0.03; 0.05	[mm]
The longitudinal cutting feed f_l	0.4; 0.8	[m/min]
Cutting speed v	27; 31	[m/s]
Observation: - transversal cutting feed f_t = 0.4 mm/DH; - the grinding processes (roughing and finishing) were done without cooling liquid.		

Fig. 4. Practical measurement of surface roughness with MITUTOYO roughness tester.

Measurements of surface roughness were done with a MITUTOYO roughness tester located in the laboratories of the Machines and Manufacturing Systems Department, IMST Faculty from University "Politehnica" of Bucharest, as shown in Fig. 4.

The calculation of cutting speed of the diamond discs was made considering the main wheel shaft rotational speed of the grinding machine and the diameters of the discs used, with:

$$v_s = \frac{\pi \times D \times n}{1000 \times 60} \text{ [m/s]} \quad (1)$$

where v_s is the main cutting speed, D – diameter of the disc, and n –diamond disk speed [2].

- For discs with D = 200 mm, the measured speed is n = 2995 rpm (see Fig. 4) results :

$$v_s = \frac{\pi \times 200 \times 2995}{1000 \times 60} = 31.34 \text{ m/s} \quad (2)$$

- For discs with D = 175 mm at a speed n = 2995 rpm it results:

$$v_s = \frac{\pi \times 175 \times 95}{1000 \times 60} = 27.42 \text{ m/s.} \quad (3)$$

For calculating the actual cutting speed, it is necessary to measure the rotational speed of the diamond disk. This was done with a digital tachometer Pocket Laser Tach 200 (PLT200) located in the facilities of laboratories from Machines and Manufacturing Systems Department, IMST Faculty, University "Politehnica" of Bucharest.

Power is a machining output parameter relatively easy to measure and it is usually considered as energy per unit volume of removed material. The specific energy

Fig. 5. Grinding disk rotation speed measurement (n = 2995 rpm).

is a barometer of process efficiency and it is related with other interest process parameters as wheel wear, surface quality, and difficulty of machining, machining cost.

The experimental determination of the electrical power consumed by the machine tool under different machining conditions is done with the QN10 wattmeter (Fig. 6). The wattmeter is connected between the source (network) and the consumer (the electric drive disk). With this device we were able to measure the electrical power absorbed in the grid, the current intensity and the supply voltage.

The cutting temperature during granite grinding was measured using infrared thermography method. The thermal measurement camera used in the experiments was the FLIR TIP E 45 from the Maintenance Department of SC Vrancart SA Adjud (see Fig. 7).

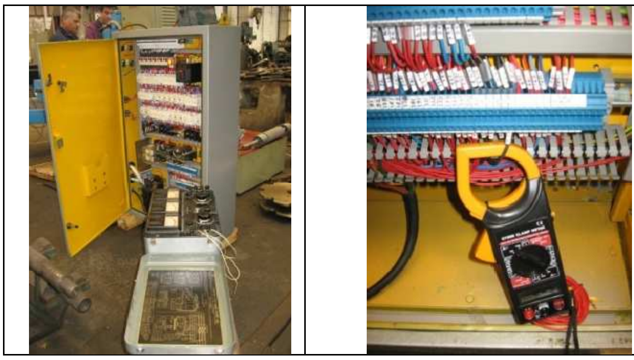


Fig. 6. Measurement of the electrical power consumed by the machine tool.

Fig. 7. Cutting temperature measurement using thermal camera FLIR TIP E 45.

3.1. Design of Experiments – DOE

Designing experiments (DOE) is an important statistical technique for improving the product quality and solving production problems. For the grinding experiments carried out a full factorial design was considered.

In this experimental work, two levels of the input factors (independent variable) for the parameter variation were chosen, minimum (−1) and maximum (+1) [13].

Granite rough grinding. For the granite rough grinding, the following parameters of the cutting regime were chosen: cutting speed v [m/s]; longitudinal cutting feed f_l [m/min] and the cutting depth a_p [mm] are shown in Table 3. Two levels (−1) and (+1) were chosen to carry out the experiments.

Granite finish grinding. For the granite finish grinding the following parameters of the cutting regime were chosen: cutting speed v [m/s]; longitudinal cutting feed f_l [m/min] and the cutting depth ap [mm] are shown in Table 4. Two levels (–1) and (+1) were chosen to carry out the experiments.

The design matrix with the output factors values obtained in the rough and finish grinding tests are presented in Tables 5 and 6.

The diamond tools grain diameters for the rough grinding experiments was 126 μm and for the finish grinding experiments was 76 μm. The diamond concentration of all the diamond wheels used for the granite grinding tests was the same [12]. Therefore, the diamond tool grain diameter influence over the obtained surface roughness can be observed in Figs. 9 and 10.

Table 3

Parameters of the cutting regime at the granite roughing

Factor / Level	v [m/s]	f_l [m/min]	a_p [mm]
−1	27	0.4	0.03
+1	31	0.8	0.05

Table 4

Parameters of the cutting regime at the granite finishing

Factor / Level	v [m/s]	f_l [m/min]	a_p [mm]
−1	27	0.4	0.01
+1	31	0.8	0.03

Table5

Experimental design, 2^3 = 8 experiments for rough grinding

Nr. Crt.	Input factors (independent variables)			Output factors		
	Cutting speed v [m/s]	Long. cutting feed f_l [m/min]	Depth of cut a_p [mm]	Surface roughness Ra [μm]	Power N [kW]	Cutting Temperature T [^{0}]
1.	+ 1	+1	+1	3.8	1.10	34.0
2.	+1	+1	−1	3.9	1.20	35.0
3.	+1	−1	+1	3.7	1.00	32.0
4.	+1	−1	−1	3.5	0.90	31.0
5.	−1	+1	+1	3.7	0.70	32.0
6.	−1	+1	−1	3.6	0.75	32.5
7.	−1	−1	+1	3.8	0.80	33.0
8.	−1	−1	−1	3.4	0.60	30.0

Table 6

Experimental design, 2^3 = 8 experiments for finish grinding

Nr.	Input factors (independent variables)			Output factors		
	Cutting speed v [m/s]	Long. cutting feed f_l [m/min]	Depth of cut a_p [mm]	Surface roughness Ra [μm]	Power N [kW]	Cutting temperature T [^{0}]
1.	+ 1	+1	+1	2.1	1.0	31
2.	+1	+1	−1	2.4	1.1	34
3.	+1	−1	+1	1.9	0.9	30
4.	+1	−1	−1	1.7	0.8	29
5.	−1	+1	+1	1.1	0.6	27
6.	−1	+1	−1	0.9	0.5	26
7.	−1	−1	+1	1.3	0.7	28
8.	−1	−1	−1	0.8	0.4	25

4. EXPERIMENTAL DATA ANALYSIS

In the development of the present experimental research it was necessary to determine the correlation between the three cutting parameters: cutting speed, longitudinal cutting feed and cutting depth and the grinded surface roughness. The polynomial regression function [14] between the input variables chosen and the output factors has the following form:

$$F = C_R v^{\alpha} f_l^{\beta} a_p^{\gamma}. \quad (4)$$

As it can be seen the cutting temperature manifests a slight variation with the cutting parameters variation. The medium cutting temperature for the granite rough grinding experiments was 32°C and for the finish grinding of 29°C. These values will not conduct to thermal deflection and therefore not exert influence over the parts dimensions. The slight smaller values obtained for the finish grinding tests are a result of the resinoid binder of the diamond.

The consumed power of the machine tool is directly influenced by the grinding force. If the force varies strongly depending on the cutting parameters, then the power also varies. The values of the cutting power obtained in the rough and finish grinding experiments show that the diamond cutting tool grain diameter and binder type exert minimal influence over the cutting power and that the cutting parameters variation manifest in considerate machine tool power consumption variation.

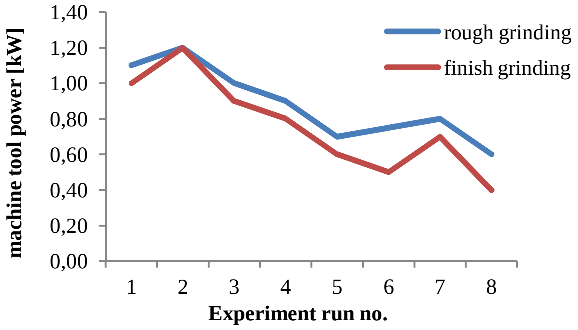


Fig. 8. Machine tool power variation in the rough and finish granite grinding experiments.

The plots and the data from Tables 5 and 6 reflect similar influences of the machining parameters over the machine tool power consumption for the rough and finish grinding process. All of the three process parameters have a positive effect on machine tool power variation. Holding all other cutting parameters constant, an increasing the cutting speed leads to a significant increase of the machine tool power, compared to the effects generated by longitudinal cutting feed and the depth of cut.

In Fig. 9 the surface roughness variation with the cutting parameters for the rough grinding experiments is presented. As it can be seen there is a slight change in the surface roughnes values with the variation of cutting speed, cutting feed and depth of cut chosen for the machining tests. Therefore, there is no need for analyzing or data processing for this parameter.

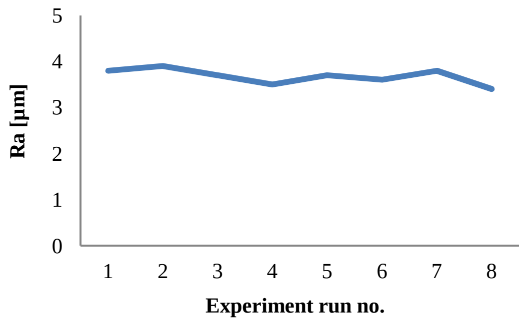


Fig. 9. Surface roughness variation in rough grinding experiments.

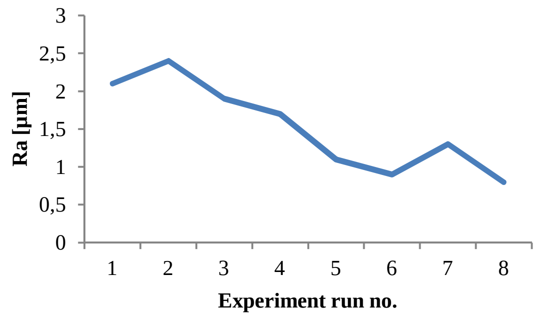


Fig. 10. Surface roughness variation in finish grinding experiments

For the considered regression function $R_a = \mathrm{f}(v, f_t, a_p)$, the experimental data resulted from the finish grinding experiments was process resulting the following variation laws:

$$Ra = 2.164 \cdot 10^{-7}\ v^{4{,}8703}\ ft^{0{,}35904} ap^{0{,}118352}. \quad (5)$$

The predicted values, residuals and relative standard errors of the regression for the data obtained in finish grinding experiments are presented in Table 7. The maximum relative standard error for the regression equation obtained is 25.975%. We can observe that the residuals and relative standard error have higher than expected. Since the *Ra* values are relatively small and the variation in itself is in a restricted domain, the regression predicted values, obtained with the regression equation 5 are processed.

Table 7

Surface roughness Ra processed data for finish grinding

Nr.	Cutting speed v [m/s]	Long. cutting feed f_l [m/min]	Depth of cut a_p [mm]	*Ra* measured [μm]	*Ra* predicted [μm]	Residuals	Relative standard error
1.	31	0.8	0.03	2.1	2.4188	−0.3188	−15.1825
2.	31	0.8	0.01	2.4	2.1239	0.27608	11.50346
3.	31	0.4	0.03	1.9	1.8859	0.01407	0.740888
4.	31	0.4	0.01	1.7	1.6559	0.0440	2.589267
5.	27	0.8	0.03	1.1	1.2342	−0.1342	−12.2032
6.	27	0.8	0.01	0.9	1.0837	−0.1837	−20.4168
7.	27	0.4	0.03	1.3	0.9623	0.3376	25.97597
8.	27	0.4	0.01	0.8	0.8449	−0.0449	−5.62284

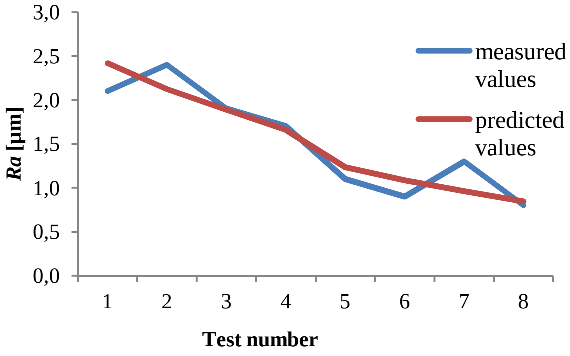


Fig. 11. Measured vs predicted surface roughness values variation in finish grinding experiments.

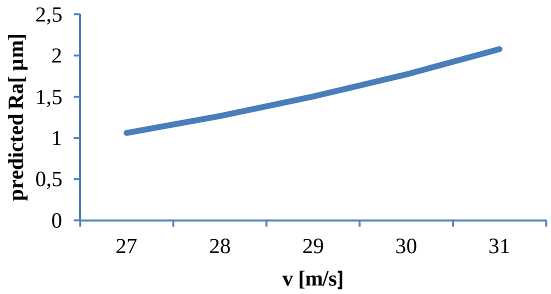


Fig. 12. The cutting speed influence over the predicted *Ra* values.

Figure 12 presents the $Ra = f(v)$ equation plot. By increasing the cutting speed values we will obtain higher surface roughness values. It can be also seen, that for the finish grinding processes, the influence of the cutting speed v [m/s] manifests most on the roughness compared to the longitudinal cutting feed f_l [mm / min] and the depth of cut a_p [mm] (see Figs. 13 and 14).

Figure 13 shows the function $Ra = f(f_l)$ graph. It can be considered the longitudinal cutting feed has a slight negative influence over the predicted surface roughness values.

Figure 14 presents the $Ra = f(a_p)$ function graph. Holding all other cutting parameters constant, an increase of the cutting depth leads to a slight increase of the surface roughness *Ra* parameter predicted values machine tool power, compared to the effect generated cutting speed.

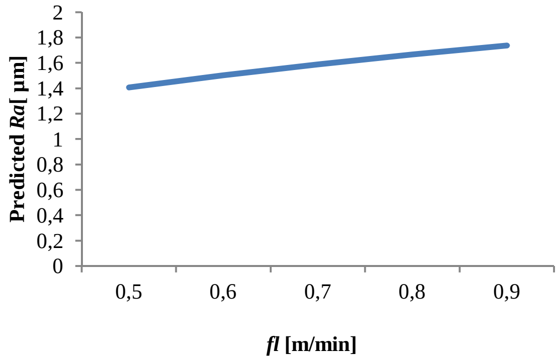


Fig. 13. The longitudinal cutting feed influence over the predicted *Ra* values.

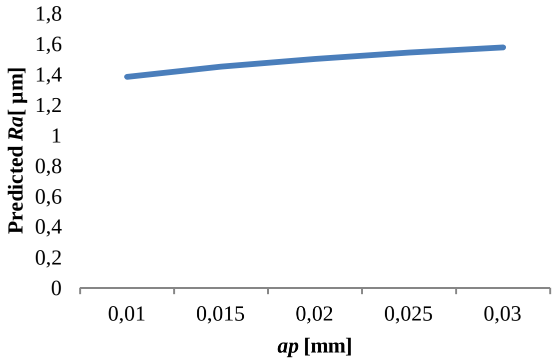


Fig. 14. The cutting depth influence over the predicted Ra values.

5. CONCLUSIONS

Based on this investigation, the following conclusions can be issued:

1. Analyzing the process of plan grinding of granite with diamond discs, there was an increase in the roughness with the increase of the three cutting parameters: cutting depth; the longitudinal cutting feed and the cutting speed. The roughness prescribed for the granite roll mantle is $R_a = 0.8$ μm. This value was obtained in the finishing grinding tests.
2. Close tolerance can be achieved by grinding with the values chosen in the experimental tests for the cutting parameters.

3. Cutting speed, longitudinal cutting feed and cutting depth play an important role for the cutting power variation.
4. The increase in the cutting parameters can cause vibrations and tool wear, therefore an increase of the surface roughness, although this parameter was not taking into consideration in this study.
5. The surface roughness parameter *Ra* manifested a slight variation in the rough grinding tests; therefore the data was not mathematically processed.
6. For the specific values chosen for the cutting parameter, considering the optimization criteria of minimum surface roughness the optimal cutting condition turned on to be the lower levels selected ((−) ; (−); (−)) for both rough and finish grinding.
7. From direct power measurement of the machine tool during grinding tests, the influences of machining parameters on power and therefore energy consumption of the machine tool was examined.
8. The cutting speed manifests the highest influence over the consumed cutting power for the specific cutting conditions considered in the research.
9. The consumed cutting power and surface roughness in the case of granite plane grinding is strongly influenced by the cutting tool diamond grain diameter.
10. The medium values obtained for the cutting temperature measured in both rough and finish granite (32°C and 29°C) cannot conduct to thermal deflection and therefore not exert influence over the parts dimensions.

As a general conclusion, the roughness of the grinded surface increases with the increase of the v, f_l, and a_p Optimizing the grinding and finishing process through full factorial design (2^3 experiments) results in time and cost savings. Thus, the quality of production and machine efficiency can be increased by the correct adjustment of the process parameters.

Future tests must be carried out in order to find optimal machining condition regarding also the productivity aspect of the machining process, and the results correlated with the ones obtained for the qualitative criteria.

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