STUDY ON THE ROUGHNESS PARAMETERS DESCRIBING SURFACE FUNCTIONALITY IN BORE HONING

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Absztrakt
A befejező megmunkálások vizsgálatánál a felületi érdesség számszerű értékei mellett a funkcionalitást jellemző paraméterek vizsgálata is szükséges. Ezáltal összetettebb képet kaphatunk a megmunkált felület működés közbeni viselkedéséről. Ebben a cikkben hosszú löketű dörzsköszörüléssel megmunkált furatoknál vizsgálom az átlagos érdesség, a felületi ferdeség és a felületi csúcsosság paramétereit. A vizsgálatok során a teljes faktoriális kísérlettervezés kerül alkalmazásra. Így három kiválasztott paraméter (átlagos szemcsenagyság, nyomás, előtoló sebesség) 2 értékénél összesen 8 beállítással kerültek végrehajtásra a forgácsolási kísérletek. Az elemzés során meg lettek adva a vizsgált technológiai paraméterek hatásai az elemzett érdességi paraméterekre.

Kulcsszavak: *felületi ferdeség, felületi csúcsosság, hónolás*

Abstract
In the examination of the finishing procedures, it is also necessary to examine the parameters characterizing the functionality in addition to the numerical values of the surface roughness. This allows to get a more complex picture of the behaviour of the machined surface during the working conditions. In this paper, the parameters of average roughness, surface Skewness, and surface Kurtosis are examined for holes machined with honing. During the experiments, the full factorial experimental design is used. Thus, the cutting experiments were performed with a total of 8 settings for 2 values of three selected parameters (average grain size, pressure, feed rate). The effect of the investigated technological parameters on the analysed roughness parameters was given in the study.

Keywords: *honing, Kurtosis, Skewness*

1. Introduction

The functional behaviour of the produced parts greatly depends on the applied machining procedures especially in the finishing processes. This is caused by the fact that machine-induced anomalies on the surface greatly influences fatigue, corrosion, stress-corrosion, wear resistance et cetera [1]. There are ongoing researches to improve the functionality of machined surfaces by different methods, such as the use of special environmentally friendly additives in the lubricant between the contacting surfaces [2]. Though specific functionality-related properties can be effectively characterized and correlated with the surface texture parameters in practical production [3]. For example a cause of failure can be the inadequate and insufficient lubrication of contact surfaces [4].

A widely used machining procedure in creating tribologically good inner cylindrical surfaces is honing. Due to the applied abrasive cutting tool and the relative movements between the tool and the workpiece, surfaces with good contacts properties can be made. The grain sizes plays an important role in the cutting process. It significantly affects the material removal rate [5] and the surface roughness as well [6]. The concentration of the abrasive particles also affects the machined surface, such as the stress distribution [7]. Abrasive processes also have a “self-sharpening” effect, as the worn particles breaks out from the tool due to the increasing cutting forces, revealing new, sharper grains to the cutting zone [8]. The choose of the grain size is a complex task, because the improper size of abrasive particles can cause unexpected results, such as the deep-grooved surfaces show larger wear volumes than the shallow-grooved ones [9].

The functionality of the surface can be characterised by the study of roughness parameters. There are more commonly analysed, however there are many specific parameters, which is used by some fields. The Skewness and Kurtosis are good parameters in the characterization of machined surfaces, especially to predict the behaviour of contacting surfaces. *Figure 1* shows the meaning of these two parameters and the interpretation of their values. It can be seen, that these parameters show the character of the dominant structures in the roughness profiles.

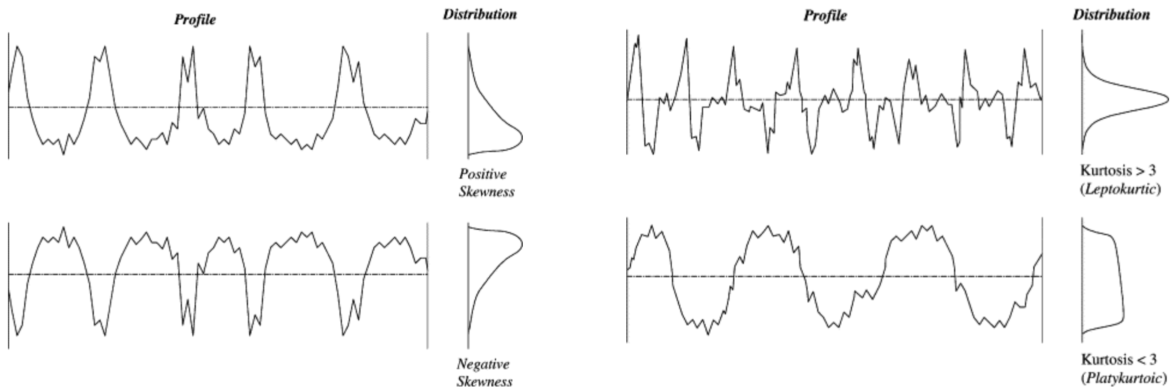

Figure 1. *Explanation of Skewness and Kurtosis of the analysed profile* [10]
(schematic figures, the abscissa is the measured length, and the ordinate is the profile height)

The aim of this paper is to analyse the functional behaviour of bore honed surfaces. To achieve this, cutting experiments are carried out, and roughness measurement are done. Among the gathered data, the Arithmetical Mean Height of the evaluated roughness profile, the Skewness of the evaluated roughness profile and Kurtosis of the evaluated roughness profile are evaluated in this paper. These roughness parameters can characterize a surface well, and show its nature during working conditions (e.g., the outer surface of the workpiece would be worn fast, or it will has a high bearing capability, or how well the surface can hold lubricants, which lowers the friction between the surfaces).

2. Experimental conditions and methods

To study the functionality of the honed surfaces, experiments were carried out with varied values of the selected process parameters (pressure, feed, grain size). The 2^3 full factorial design of experiments are applied during the study and in the selection of the set values.

A WMW 270/700 honing machine was applied for the cutting experiments, which was provided by Belcord Kft. in Eger, Hungary (their help is greatly appreciated). The machining was carried out on sleeves with 192 mm bore length, 88 mm inner diameter. The material was chosen to be EN-GJL-250 lamellar cast iron alloy, since it is frequently in the honing process by the industry. Two kinds of honing tools were used, which had Al_2O_3 grains in a synthetic resin binder with a dense structure. One tool had coarse grains with size code: 80 and average grain size *(d_k)*: 190 µm; while the other tool had finer grains with size code 240 and average grain size *(d_k)*: 45 µm. During the experiments the cutting speed (v_c) was fixed to 200 m/min. The applied pressure on the honing stone (p) was adjusted to 7 bar and 13 bar, the feed per revolutions *(v_f)* was set to 25 mm/rev and 75 mm/rev. These parameters were chosen according to the recommendations given by the company, where the experiments were carried out. The resulted setups, the set parameters and the design matrix for the factorial design can be seen in *Table 1*.

Table 1
Experimental setups

Setup									
		1	2	3	4	5	6	7	8
Selected factors									
p	[bar]	7	13	7	13	7	13	7	13
v_f	[mm/rev]	25	25	75	75	25	25	75	75
d_k	[µm]	45	45	45	45	190	190	190	190
Design matrix									
p	[–]	–1	1	–1	1	–1	1	–1	1
v_f	[–]	–1	–1	1	1	–1	–1	1	1
d_k	[–]	–1	–1	–1	–1	1	1	1	1

Measurements were carried out on the workpieces after the cutting experiments with a Mitutoyo SJ-301 Surftest roughness measurement device. The roughness profiles were registered on three generatrix of each bore. The measured profiles were evaluated with the AltiMap Premium 6.2.7487 surface analysis software. The analysed parameters of the 2D (linear) profile were the following (ISO 21920:2021):

- R_a – Arithmetical Mean Height of the evaluated roughness profile [µm]
- R_{sk} – Skewness of the evaluated roughness profile [–]
- R_{ku} – Kurtosis of the evaluated roughness profile [–]

Equations were determined for the study in the form of Equation 1 based on the measurement results according to the principles of the 2^3 full factorial experimental design method. The dependent value is y and k_i (i = 1, 2, 3, 12, 13, 23, 123) are the coefficients describing the effect of the different factors on the dependent value. The independent variables are the pressure *(p)*, feed *(v_f)* and average grain size *(d_k)*.

$$y(p, v_f, d_k) = k_0 + k_1 p + k_2 v_f + k_3 d_k + k_{12} p v_f + k_{13} p d_k + k_{23} v_f d_k + k_{123} p v_f d_k \quad (1)$$

3. Experimental results

As described before, the linear profile of the machined surface generatrix is measured three times on each workpiece. The profiles were analysed and evaluated by the roughness measurement software, and the values of R_a, R_{sk} and R_{ku} are gathered. Their average values are calculated for the later use. The results of the measurements and the evaluation can be seen in *Table 2*.

The calculation formulas for each studied roughness parameter are determined by the application of Equation 1 using the methods of numerical analysis. Equation 2 is used for the analysis of the Arithmetical Mean Height of the evaluated roughness profile, Equation 3 is applied to study the change of the Skewness of the evaluated roughness profile, and the Kurtosis of the evaluated roughness profile is evaulated by Equation 4.

$$R_a(p, v_f, d_k) = 1.45 + 0.2385p + 0.02006v_f + 0.009598d_k - 0.003121pv_f - \\ - 0.0008736pd_k - 0.0001144v_fd_k + 0.00001379pv_fd_k \quad (2)$$

$$R_{sk}(p, v_f, d_k) = 0.1736 - 0.1438p + 0.003948v_f - 0.006701d_k + 0.0007673pv_f + \\ + 0.001046pd_k + 0.00004276v_fd_k - 0.000009655pv_fd_k \quad (3)$$

$$R_{ku}(p, v_f, d_k) = 1.106 + 0.4167p + 0.01156v_f + 0.02267d_k - 0.003192pv_f - \\ - 0.003391pd_k - 0.0002694v_fd_k - 0.00003908pv_fd_k \quad (4)$$

Table 2
Experimental results

Setup	1	2	3	4	5	6	7	8
R_a [μm]								
1	0.308	1.867	0.165	0.238	0.793	1.785	0.469	0.724
2	0.287	1.062	0.199	0.236	0.821	1.046	0.468	0.729
3	0.321	0.474	0.163	0.263	0.645	0.512	0.546	0.646
Average	0.31	1.13	0.18	0.25	0.75	1.11	0.49	0.7
R_{sk} [–]								
1	–0.841	–1.032	–0.075	–0.311	–0.496	–0.377	–0.349	–0.361
2	–0.771	–1.206	–0.212	–0.907	–0.986	–0.457	–0.344	–0.880
3	–0.196	–1.161	–0.291	–0.640	–0.316	–0.452	–0.407	–0.331
Average	–0.6	–1.13	–0.19	–0.62	–0.6	–0.43	–0.37	–0.52
R_{ku} [–]								
1	3.953	4.756	3.066	3.899	3.292	2.991	3.019	3.215
2	4.025	5.590	3.142	4.793	3.803	2.771	3.037	4.116
3	3.164	4.903	3.327	3.670	3.617	2.766	3.141	3.492
Average	3.71	5.08	3.18	4.12	3.57	2.84	3.07	3.61

4. Discussion

The experiments and measurements are followed by the evaluation of the gathered data by the application of various analysis methods. Firstly, the so-called Main effect plots were drawn and studied separately according to the following. These visualise the basic effect of the three studied parameter on the analysed roughness parameters. Initially the mean value of the averaged values is calculated, which are represented by a dashed line in the Figures. Then two mean values were calculated separately for the lower (–1) and upper (1) limit of *p*, v_f and d_k. These two averages are connected with a continuous line in each figure. The direction and gradient of the slope of these lines show the main effect of the cutting parameter on the studied roughness parameters. The resulted main effect plots can be seen in *Figure 2*. The main effect of the applied pressure alteration can be seen in the first column. Here we can see that increasing the pressure leads to higher Arithmetical Mean Height of the evaluated roughness profile and Kurtosis, while it decreases the Skewness. These tell us that the roughness profile consists of higher and steeper peaks and lower more shallower valleys. This is caused by the phenomenon that higher pressure on the honing block results higher contact force between the grains and the workpiece, which leads to the deeper penetration of the peaks on the grains into the workpiece material. This allows the formation of higher peaks on the surface.

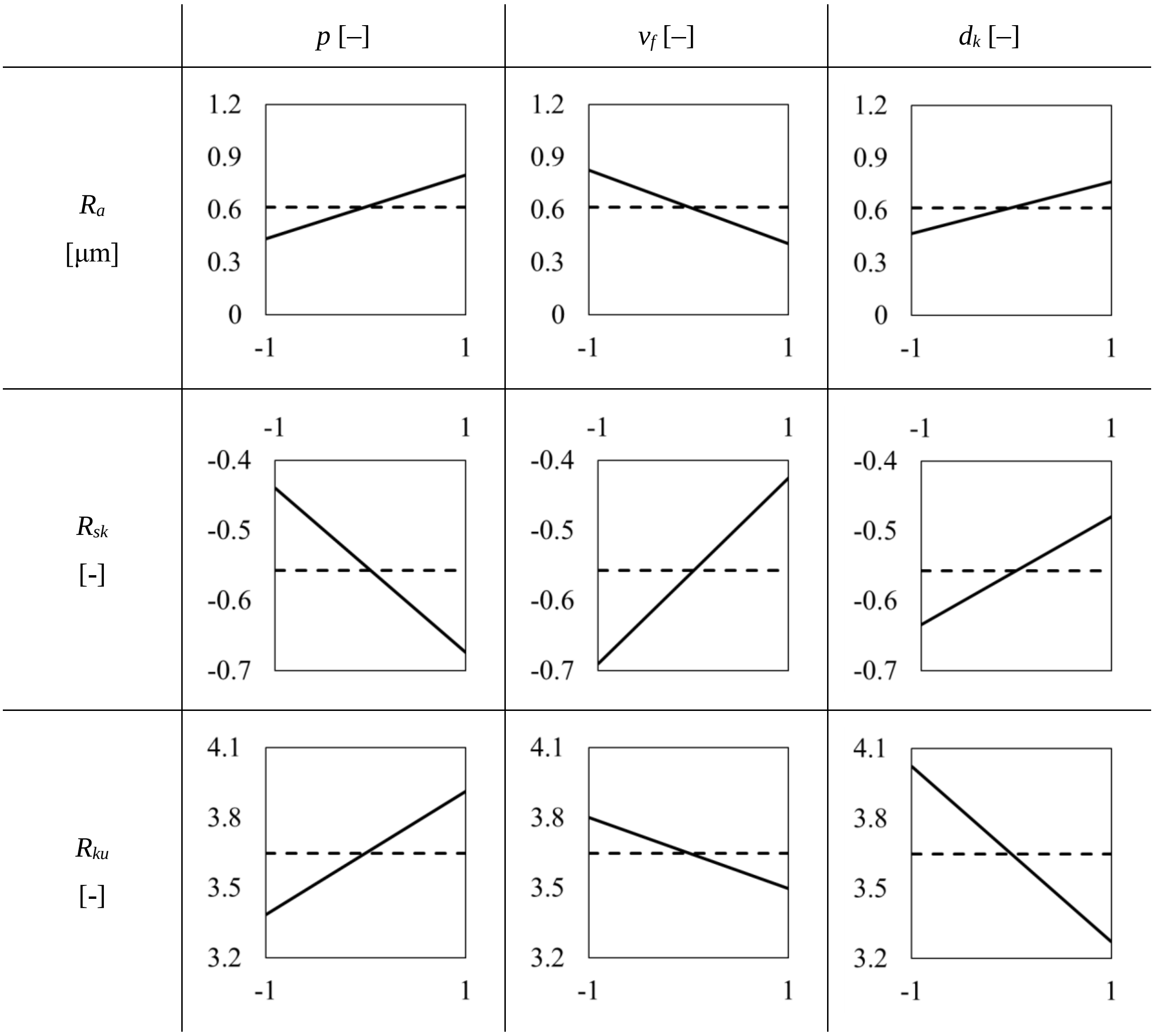

Figure 2. Main effect plots for the selected factors

In the second column of *Figure 2*, the main effect of the feed rate can be seen. It can be seen in *Figure 2*, that increasing the feed rate reduces R_a and R_{ku} to some extent, while is significantly increases the Skewness of the profile. By the increase of the feed rate, the direction of the resultant speed vector changes which leads to differently shaped roughness profiles. The cause-and-effect relationship needs to be studied further in this case in a later study. The last column in *Figure 2* presents the effect of the average grain size alteration. Greater grains resulted higher R_a and R_{sk} values, while the Kurtosis of the profile decreased. If the grain size gets bigger, it results in a wider scratch mark on the machined surface, which produces wider valleys with steeper peaks in the roughness profile, which leads to the previously described alteration in the analysed roughness values.

The study continues with the detailed analysis of the selected roughness parameters by the evaluation of Equation 2–4. The surfaces described by these equations show the correct values of the analysed parameters in the points defined by the experiments and make an approximation between them. This can be used to describe the effect of the studied parameters; however the exact correlation can be determined by the application of other design of experiments methods. *Figure 3* shows the change of the Arithmetical Mean Height of the evaluated profile in the studied range on the different levels of grain sizes. Here it can be seen that the grain size greatly influences the average roughness of the machine surface. A 4-fold increase in d_k results in a nearly 2-fold increase in R_a. Rougher surface can be expected, when the pressure between the honing tool and the workpiece is increased from 7 bar to 13 bar, which results a nearly 1.5-fold increase in the studied roughness parameter. The feed rate has a decreasing effect on R_a, but it is the least significant from the analysed process parameters.

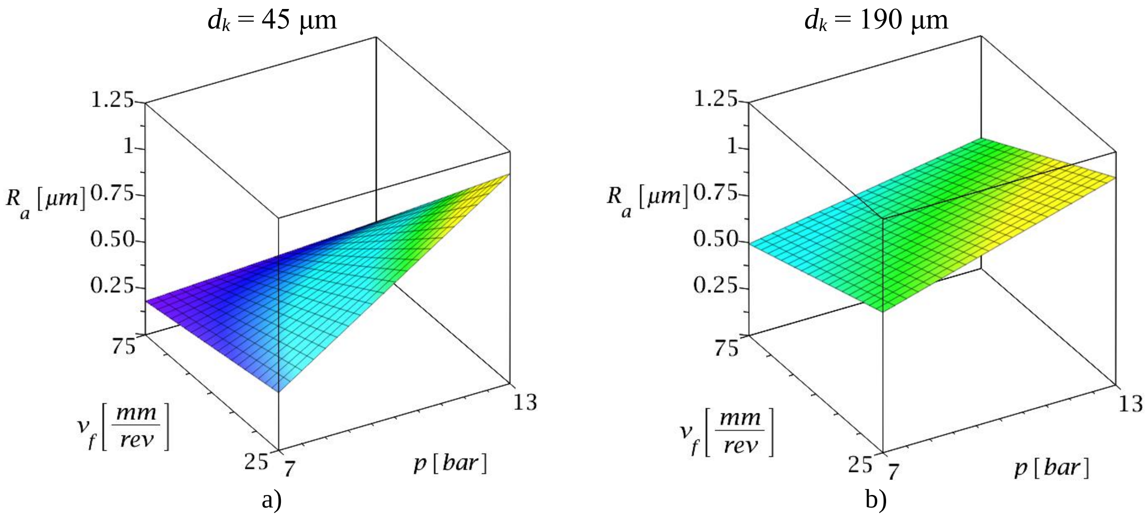

Figure 3. Arithmetical Mean Height of the evaluated roughness profile on different grain sizes

Figure 4 shows the alteration of the Skewness of the evaluated profile. The first conclusion comes from looking at the graphs with different grain sizes. The experiments carried out with greater grain sizes showed lower variance in the value of R_{sk}, while the Skewness changed significantly when the machining is carried out with tools with smaller grains. This suggests that in the point of view of the

Skewness, there is a given grain size for each setup, where the alteration of the process parameters is not affecting the R_{sk}. This phenomenon should be studied thoroughly in later research. However, it can be seen when smaller grain sized tool is applied, that the pressure increase also increases the Skewness, while the feed rate increase decreases it. From the two process parameters, p has the greater effect.

The Kurtosis of the profile is analysed based on *Figure 5*. In the figure we can see that increasing the grain size in the honing tool decreases the Kurtosis. The amount of decrease depends on the other process parameters. The change of the applied pressure has a varying effect on the Kurtosis, however the increased pressure tends to increase R_{ku} as well. The feed rate alteration has an almost negligible effect on the Kurtosis of the profile.

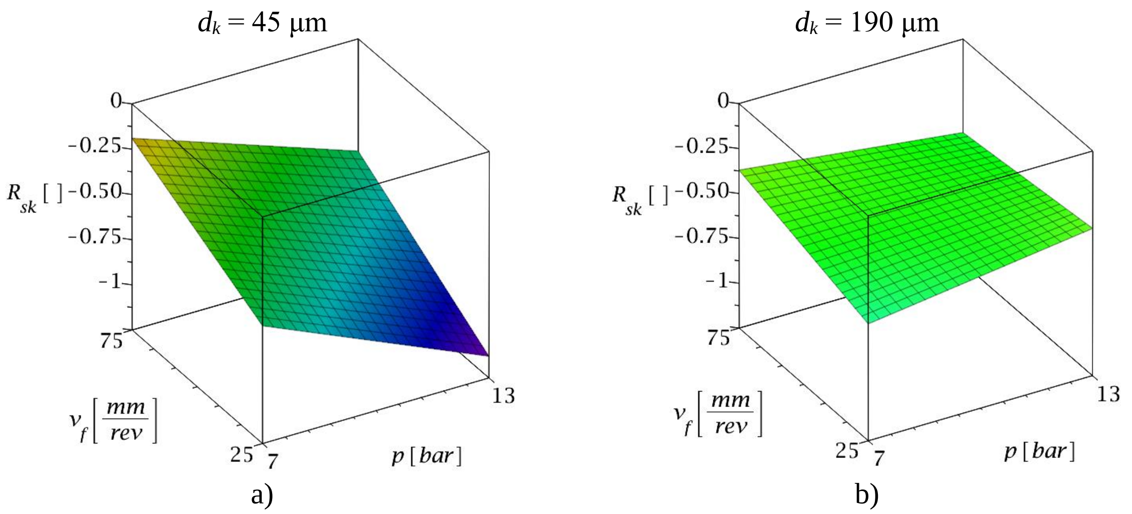

Figure 4. Skewness of the evaluated roughness profile on different grain sizes

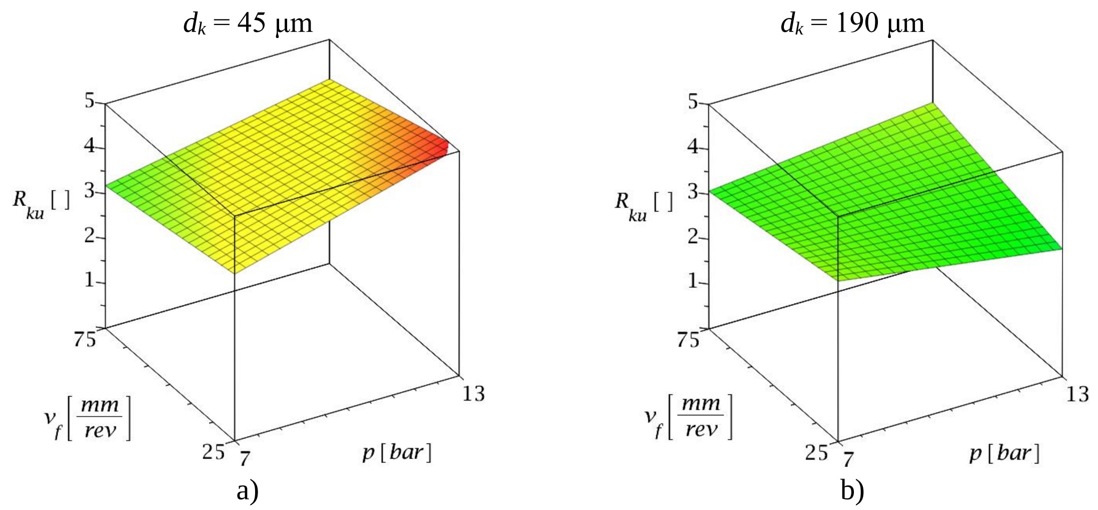

Figure 5. Kurtosis of the evaluated roughness profile on different grain sizes

Lastly the functional properties of the machined surfaces are evaluated. Based on the literature it can be said that those surfaces, which need to be honed, meet the prescribed conditions better, if the average roughness is lower, the Skewness is more negative and the Kurtosis is lower. Looking on the experimental results, the best parameter combination among the analysed setups are the following: d_k = 45 µm, p = 13 bar and v_f = 25 mm/rev.

5. Summary

The effect of the applied pressure, feed rate and grain size on various surface roughness parameters are analysed in honing of inner cylindrical surfaces in this paper. Experiments were carried out using the principles of 2^3 full factorial design of experiments. Among the usually analysed roughness parameters, the Arithmetical Mean Height of the evaluated roughness profile, the Skewness of the evaluated roughness profile and Kurtosis of the evaluated roughness profile are studied thoroughly.

Based on the study the following finding can be highlighted:

- The grain size affects the surface roughness profile. The application of larger grains resulted in higher R_a values.
- Skewness and Kurtosis can be influenced effectively by the alteration of the applied pressure and feed rate.
- In the studied parameter range functionally the most appropriate result is achieved, when small grain size, small feed rate and high pressure are applied.

The study will be continued in more directions. The analyses of other roughness parameters are needed to better describe the honing process. Other characteristics should be studied as well, e.g., shape error. The experiments will be resumed with different parameters, which will be chosen according to the results of this paper.

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