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ANALYZING THE EFFECT OF THE TOOL PASS NUMBER AND THE DIRECTION OF SLIDING BURNISHING ON SURFACE ROUGHNESS

Abstract. *Nowadays, the concern of environmental protection is becoming more and more important in production as well. They often contribute to this by reducing or eliminating the amount of coolants and lubricants, or by using alternative machining methods. One of them is burnishing, which makes a positive effect on surface integrity, while reduces the environmental load. In this paper we examined the change in surface roughness achieved by burnishing after turning on a corrosion-resistant steel workpiece, where the number of burnishing passes and burnishing direction were changed. The results showed increased smoothness, bearing capacity and dimensional stability by increasing the number of passes from 1 to 2, however, the 3 times repetition did not show any additional favorable improvement on the surfaces. In case of the forward-backward-forward burnishing directions, further chipping occurred, in other cases the effect of the directions was negligible on the amplitude roughness parameters, but considerable on the parameters characterizing the roughness peak. The greatest improvement was achieved with the backward-forward settings.*

Keywords: *turning; burnishing; surface roughness; environmentally friendly machining.*

1 INTRODUCTION

Nowadays, the concern of environmental protection is becoming increasingly important in construction, energy sources and use, waste management, and industries as well, in which this issue is particularly significant in the design and manufacture of products. During machining the workpiece loses a part of its volume which becomes waste, and it must be treated and recycled. The tools, molds do not last forever, and are thrown away as they wear out, deform. During production, the use of auxiliary materials (coolants and/or lubricants) is also a crucial issue in terms of environmental protection, as it can reduce the possibility to recycle the waste (e.g. contaminated chips, sludge, which is produced during grinding), and is also harmful to the health and the environment; some cutting fluids are also responsible for the development of skin diseases and respiratory problems, and are therefore classified as hazardous waste [1].

Increasingly strict national and international environment protection laws are passed, which manufacturers must comply with. Due to restrictions imposed by law, some manufacturing processes involve additional costs; thus, it is necessary to develop new methods to replace the older ones. This is not only a technological challenge for researchers and engineers, but also increases the importance of ecological characteristics in the comparison of different machining processes. One approach to this is environmentally conscious design and manufacturing, which aims to reduce or recycle the by-products of a process. For this, such technologies are developed that are less harmful to the environment, but at the same time the improvement of product quality, cost reduction and productivity increase are facilitated [1,2].

One of the most frequently studied and used methods of environmental protection in production is the reduction of the used amount of cooling-lubricating fluids or its abandonment. The latter, i.e. dry or "green" machining is considered a better approach not only from an ecological point of view, but also in economic respect [1]. Varga et al. investigated the effect of the cutting data and the flow rate of cutting fluid on 3D roughness on turned surfaces with the aim of how this method of reducing the environmental load influences the roughness values [2]. With a full factorial experimental design, empirical formulas for the relationship between technological data and surface roughness were given, based on which optimal cutting data could be selected [3]. In another paper [2], they studied the effect of changing several cutting data on the surface roughness of holes made with environmentally friendly technology in cast burnishing workpieces. They found that the roughness values of the surfaces machined with cooling-lubricating fluid were almost the same or smaller. Furthermore, the consequence of abandonment of cooling-lubrication was investigated on roughness and cylindricity on turned surfaces [4]. The results showed that it had the smallest, negligible effect after feed and cutting speed. Kundrák et al. examined hard turning and combined machining (turning, grinding) as finishing of the bore of case-hardened steel gears. While the same roughness value was achieved on the machined surfaces, hard turning was found to result shorter machining time and lower costs, and the chip did not become contaminated (its composition did not change) with the cutting fluid, so it could be used in metallurgical processes or recycling [1,5]. Application of untraditional turning procedures can also lead to better surface roughness, as showed by Sztankovics et al. [6].

In the production of components, some finishing processes can be replaced by burnishing, which reduces the environmental load by not producing chip, and at the same time improves the integrity of the surface. The turned surface layer has tensile stress. During burnishing, the surface material layer is compressed, resulting in a functionally favorable surface. On the one hand, it creates microstructural compression which generates compressive stress in the surface layer, as well as increases its microhardness, and thereby also improves surface strength, wear resistance and fatigue life [7,8]. Furthermore, the bearing surface characteristics are improved by the indentation of the surface topography, including wear resistance and dimensional stability, without significant changes in the ability to retain the lubricant. Due to the multiple positive effects, it attracts the attention of engineers and researchers both in industry [9] and in research, which is investigated worldwide. We provide a brief overview of them.

Grzesik et al. investigated to what extent the superfinishing and burnishing after hard turning on a hardened Cr-steel workpiece changes the values of 2D and 3D roughness parameters and improves the functional properties of the machined surfaces [10]. Based on their results, smoother surfaces can be achieved with both types of procedures, with lower roughness values and better bearing characteristics.

During burnishing, the burnishing speed, feed, force, and number of passes can be adjusted on the machine tool. By changing these parameters, Ferencsik and Varga analyzed their effect on the surface microhardness and the residual stress of the surface layer [7], as well as on the surface roughness [11,12]. With the application of the full factorial experimental design, formulas were given for the correlations of the adjusted and measured parameters, which can be used to select optimal machining values in the studied ranges. Analyzing the differences in the roughness of the turned and then burnished surfaces for R_a, R_q, R_z and R_t parameters, they found that the increase of the force acting on the low-hardness aluminum alloy from $10N$ to $20N$ has a negative effect and increasing the feed at a pass number of 3 is beneficial, while 1 pass has a negative impact on roughness. By increasing the number of passes from 1 to 3, further significant changes were measured in roughness, in case of feed rates above 0.003 mm/rev. Rami et al. stated in their literature review [13] that the burnishing force and the diamond ball diameter mostly affect the plastic deformation, i.e. the roughness decreases, the hardness and the compressive stress increase. All of these increase the resistance of the part to fatigue, corrosion and wear. In addition, the number of passes also improves the surface quality, but only up to a certain limit. Then, due to the large-scale plastic deformation of the metal surface, it will be overhardened, which causes an increasing demand for compressive force during further deformations and flaking on the surface, without a noticeable change in hardness [14]. On AISI 4140 alloy steel, the average roughness R_a decreased in case of setting a maximum of $100N$ burnishing force, above which material separation was observed and the roughness value increased. When increasing the ball diameter, R_a decreased, which is related to the fact that the depth of the indentations decreases with the same feed. The smallest roughness was achieved with a small feed, low burnishing force, and a large ball diameter, which R_a value was similar to that typical for grinding. However, with the minimum diameter and maximum force, they were able to achieve the highest residual compressive stress in the surface layer [13].

When burnishing, the Workpiece-Fixture-Machine-Tool system can vibrate with a large-diameter tool (in the case of a large contact surface). This was studied for a straight-edged wiper insert tool (which burnished the surface as well) [15]. The regenerative chatter in case of the studied cutting parameters was investigated.

Alshareef et al. analyzed the integrity of turned and subsequently burnished surfaces, including residual stress, surface microstructure and roughness on acid-resistant steel [16]. It was found that the residual stress is mainly determined by surface pressure (burnishing force and ball diameter) and feed, and burnishing speed has negligible effect on it. The large amount of tensile stress in the turned surface layer was significantly reduced during burnishing and compressive stress was generated. The thickness of the changed microstructural layer was about 15 μm. The values of R_a and R_z parameters decreased by more than 60%. Surface integrity characteristics were investigated [17] on austenitic corrosion-resistant steel during ultrasonic burnishing with a ball and a roller, varying the burnishing speed, force, and number of passes. The optimal parameter values for roughness, microhardness and residual stress were determined in the studied ranges. It was observed that with rolling, the parameters showed better results due to the greater overlapping ratio. The most favorable roughness results were experienced for 3 times burnishing, after that the roughness of the surface topography deteriorated with repetition.

Based on the literature review, it can be concluded that burnishing can be recommended to be used as a finishing, primarily because of its effect on improving surface integrity characteristics, but also as an environmentally friendly alternative. It was found that burnishing influences the microhardness, residual stress, and roughness of the surface. The aim of this supplementary paper is to determine how and to what extent burnishing affects the roughness of turned surfaces on corrosion-resistant steel, if the number of passes and the burnishing direction are changed.

2 EXPERIMENTAL CONDITIONS

For the investigation, experiments were performed on an E400 universal lathe. During these, the cylindrical X5CrNi18-10 (1.4301) grade corrosion-resistant steel workpiece was clamped in a three-jaw chuck, on which the surface was segmented to 5 smaller parts. On each segment two different burnishing settings were applied, marked with A and B letters (Table 1 and Fig. 1). The turned diameter was Ø49.5 mm, and the length of the five sections was 26 mm each (Fig. 1). We first carried out turning with the same cutting parameters (n = 375 1/min, f = 0.0812 mm/rev, a_p = 0.5 mm) with a new CNMG 120408-MP cutting insert. During this a 4% emulsion of Rhenus FU71 T (oil viscosity: 160 mm^2/s) cutting fluid was used, which was dripped onto the workpiece in a small amount (flow rate: V_p = 150 ml/min). After that, we performed the burnishing on the prepared surfaces with f = 0.05 mm/rev feed, n = 375 1/min spindle speed and F_b = 10 N burnishing force. The diameter of the diamond ball was Ø3 mm. Burnishing was carried out in different ways on the surfaces by changing the number and direction of the burnishing passes, where “forward” direction is identical to the feed direction in turning, and “backward” is the opposite of that (Table 1). The choice of the variations are based on our preliminary practical experience.

Table 1 – Tool pass number and direction of burnishing on the sections

No.	1st pass	2nd pass	3rd pass	No.	1st pass	2nd pass	3rd pass
1A	forward	-	-	**3B**	forward	forward	backward
1B	forward	forward	-	**4A**	forward	backward	forward
2A	forward	backward	-	**4B**	forward	backward	backward
2B	backward	forward	-	**5A**	backward	forward	forward
3A	forward	forward	forward	**5B**	backward	forward	backward

After the experiments, the roughness of the surfaces was measured on the AltiSurf 520 three-dimensional topography measuring device with a CL2 confocal chromatic sensor, which has a vertical resolution of 0.012 μm. The 2D profile (red line) and 3D areal (red square) roughness measurements on the surfaces were performed at 3 rotated locations on the surfaces, the reported results are their arithmetic mean (Fig. 1). During the evaluation, at first the nominal (cylindrical) surface shape was extracted, then the evaluation (1.25 mm) and cut-off (0.25 mm) lengths specified in ISO 21920:2021 and ISO 25178-3:2012 standards were set according to the turned topographies. In case of the 3D measurements, the topographies had an area of 1.25 × 1.25 mm^2 (Fig. 1). For R_{mr} and S_{mr} material ratio parameters, a cut-off depth of c = 1 μm from the highest peak point was set.

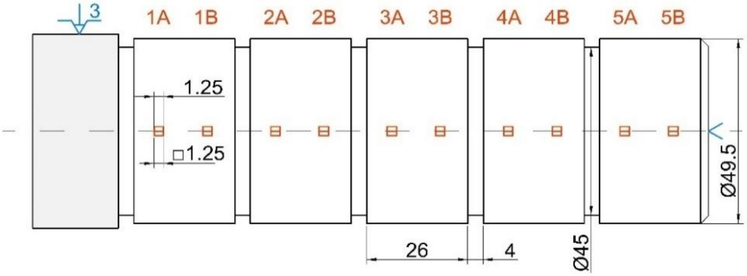


Figure 1 – Measurement locations for surface roughness analysis

3 RESULTS AND DISCUSSION

The roughness measurement results for the following parameters are given for the turned surfaces in Table 2 and for the burnished surfaces in Table 3:

Table 2 – Roughness values measured on the turned surfaces

No.	R_a	R_z	R_{pk}	R_{mr}	R_{sk}	R_{ku}	S_a	S_z	S_{pk}	S_{mr}	S_{sk}	S_{ku}
	[μm]	[μm]	[μm]	[%]	[-]	[-]	[μm]	[μm]	[μm]	[%]	[-]	[-]
1A	1.81	8.36	1.15	2.92	0.04	2.04	1.85	11.20	1.15	0.11	0.05	2.07
1B	1.81	8.33	1.14	2.91	0.02	2.03	1.85	11.16	1.14	0.11	0.05	2.06
2A	1.83	8.46	1.16	2.95	0.03	2.06	1.88	11.33	1.16	0.11	0.05	2.09
2B	1.80	8.29	1.14	2.89	-0.01	2.02	1.84	11.11	1.14	0.11	0.05	2.05
3A	1.81	8.34	1.15	2.91	-0.03	2.03	1.85	11.17	1.14	0.11	0.05	2.06
3B	1.84	8.47	1.16	2.95	0.02	2.06	1.88	11.34	1.16	0.11	0.05	2.09
4A	1.84	8.50	1.17	2.97	-0.01	2.07	1.89	11.39	1.17	0.11	0.05	2.10
4B	1.81	8.33	1.14	2.91	0.04	2.03	1.85	11.17	1.14	0.11	0.05	2.06
5A	1.80	8.28	1.14	2.89	0.00	2.02	1.84	11.09	1.13	0.11	0.05	2.05

5B	1.85	8.53	1.17	2.98	0.02	2.08	1.89	11.42	1.17	0.11	0.05	2.11

- Arithmetic mean height of profile (R_a) or surface (S_a)
- Maximum height of profile (R_z) or surface (S_z)
- Material ratio of profile (R_{mr}), Surface bearing area ratio (S_{mr})
- Reduced peak height of profile (R_{pk}) or surface (S_{pk})
- Skewness of profile (R_{sk}) or surface (S_{sk})
- Kurtosis of profile (R_{ku}) or surface (S_{ku})

Table 3 – Roughness values measured on the burnished surfaces

No.	R_a	R_z	R_{pk}	R_{mr}	R_{sk}	R_{ku}	S_a	S_z	S_{pk}	S_{mr}	S_{sk}	S_{ku}
	[μm]	[μm]	[μm]	[%]	[-]	[-]	[μm]	[μm]	[μm]	[%]	[-]	[-]
1A	1.69	7.36	0.57	10.82	-1.01	2.74	1.76	10.18	0.47	0.51	-0.97	2.60
1B	1.15	6.09	0.67	12.96	-1.30	3.85	1.15	8.64	0.54	1.51	-1.33	4.04
2A	0.96	5.41	0.78	3.86	-1.00	3.64	0.97	7.65	0.72	2.23	-1.02	3.89
2B	0.87	5.06	0.43	20.70	-1.29	4.12	0.91	7.49	0.42	3.08	-1.32	4.36
3A	0.88	5.24	0.67	12.60	-1.27	4.26	0.93	7.50	0.54	1.91	-1.30	4.27
3B	0.90	5.47	0.50	14.76	-1.36	4.48	0.93	7.51	0.56	2.60	-1.30	4.23
4A	1.62	8.01	2.00	1.65	0.38	2.78	1.70	17.90	3.45	0.27	0.76	4.31
4B	0.89	5.17	0.68	5.23	-1.36	4.25	0.91	7.88	0.60	1.05	-1.44	4.67
5A	0.86	4.91	0.45	20.14	-1.4	4.33	0.85	6.85	0.35	2.9	-1.45	4.6
5B	0.78	5.32	0.78	7.54	-1.22	4.72	0.79	7.19	0.69	3.15	-1.42	5.36

In Table 4 the degree of decrease of the roughness values (ΔR_i and ΔS_i) on the surfaces are summarized based on Equations 1 and 2, where *i* denotes the index of the given roughness parameter. Therefore, a negative value in the table expresses a deterioration of roughness. In the case of R_{mr} and S_{mr} parameters, the value increase is displayed as a multiplication factor.

$$\Delta R_i = \frac{R_i^{turned} - R_i^{burnished}}{R_i^{turned}} \cdot 100\ [\%] \tag{1}$$

$$\Delta S_i = \frac{S_i^{turned} - S_i^{burnished}}{S_i^{turned}} \cdot 100\ [\%] \tag{2}$$

During burnishing with setting 4A, material separation occurred, so the beneficial effects from a functional point of view – reduction of roughness values, increase of bearing capability, compressive residual stress – were absent. Regarding the roughness values in Table 4, the experimental results confirm the opposite effects; although the decrease in the values of parameters R_a and S_a is negligible (approx. 7-10%), we experienced the lowest, mostly negative rates for the other examined parameters. Due to the different characters of roughness changes, we analyze the results and the degree of changes without section 4A.

In Table 4, results show that a favorable effect can be achieved with burnishing on the surfaces for all studied combinations of number of passes and direction. In case of the average roughness parameters, this means minimum 6.65% and maximum 57.9% value decrease for R_a, and 5.23-58% improvement for S_a. The decrease in the value of the maximum height parameters is between 11.9% and 42.3% for R_z, and between 9.12% and 39.8% for S_z. Since the peaks of the topography is flattened and rounded during burnishing, we expect a decrease in value for the reduced peak parameters; the thickness decreases of the upper material layer, which wears off quickly during the initial usage. This is confirmed by the experimental results with rates between 33.1% and 62% for R_{pk} and between 38.2% and 70.2% for S_{pk}. On the other hand, an increase is expected in the material ratio parameters, measured at the same cut level; the 1.31–7.16 times increase for R_{mr} and 4.51–27.66 times for S_{mr} also confirm the expectation.

Table 4 – Rate of change in roughness values by burnishing

No.	R_a	R_z	R_{pk}	R_{mr}	S_a	S_z	S_{pk}	S_{mr}
1A	6.65%	11.9%	50.2%	3.71×	5.23%	9.12%	59.3%	4.51×
1B	36.4%	26.9%	41.7%	4.46×	38.0%	22.6%	52.9%	13.45×
2A	47.7%	36.0%	33.1%	1.31×	48.3%	32.5%	38.2%	19.60×
2B	51.4%	39.0%	62.0%	7.16×	50.5%	32.6%	63.2%	27.66×
3A	51.4%	37.2%	41.5%	4.33×	49.6%	32.9%	53.0%	17.02×
3B	50.9%	35.4%	57.3%	5.00×	50.7%	33.8%	52.1%	22.88×
4A	10.0%	3.22%	-76.0%	0.57×	7.50%	-61.3%	-204%	2.42×
4B	50.8%	38.0%	40.7%	1.80×	51.0%	29.4%	47.1%	9.36×
5A	53.4%	42.3%	61.3%	6.79×	54.9%	39.8%	70.2%	25.39×
5B	57.9%	37.6%	33.5%	2.54×	58.0%	37.1%	40.5%	27.50×

In the following, we compare the roughness of the cylindrical surfaces machined with the same number of passes. The values of the parameters in Tables 2-3 are illustrated in bar diagrams in Fig. 2, where the burnishing directions are shown below the columns in chronological order. The arrows on the diagrams show the direction, where "→" means forward, "←" means backward.

Fig. 2a shows the average roughness R_a values, while Fig. 2b illustrates the maximum height R_z values. The two diagrams show a very similar nature, so both are characterized simultaneously, together with their 3D counterparts, S_a and S_z. It can be seen that similar turning and burnishing values were measured for each pass numbers, regardless of the burnishing directions. After turning, with negligible differences, approx. R_a = 1.8 µm, S_a = 1.85 µm, R_z = 8.4 µm and S_z = 11.2 µm were measured, while on the burnished surfaces at i = 1 pass number (on surface 1B) the improvement ratio is 6.7% for R_a, 5.2% for S_a, 11.9% for R_z, 9.1% for S_z, at i = 2; the rate is between 36.4–51.4% for R_a, 38–50.5% for S_a, 26.9–39% for R_z, 22.6–32.6% for S_z, in the case of i = 3 number of passes, we experienced a decrease of between 50.8–57.9% for R_a, 49.6–58% for S_a, 35.4–42.3% for R_z, and 29.4–39.8% for S_z. The differences between the improvement rates are small, at i = 2; the rate is 15% for R_a, 12.5% for S_a, 12% for R_z, 10% for S_z, and every value is smaller at i = 3; 7% for R_a, 8.4% for S_a, 7% for R_z, 10.4% for S_z. In the case of i = 2 number of passes, the highest improvement rate was found on section 2B, while in the case of i = 3, the highest rate was on section 5B based on R_a values, and on section 5A based on R_z values, which have a common in the initial backward-forward directions.

Considerable differences were observed between the R_{pk} (Fig. 2c) and S_{pk} parameters. While on the turned surfaces approx. $R_{pk} = S_{pk}$ = 1.15 µm values were obtained, during burnishing the reduction of these values on surface 1B (i = 1) was 50.2% for R_{pk} and 59.3% for S_{pk}, at i = 2 passes the value of R_{pk} between 33.1% and 62%, and S_{pk} between 38.2% and 63.2% during reinforcement with; during reinforcement with i = 3 passes, the value of R_{pk} decreased between 33.5–61.3% and S_{pk} between 40.5–70.2%. The differences between the improvement rates are no longer negligible; for i = 2 number of passes, 29% for R_{pk}, 25% for S_{pk}; For i = 3 number of passes, 27.8% for R_{pk}, 29.7% for S_{pk}. From the functional – load capability and dimensional stability – point of view, the best result was again shown by section 2B in the case of i = 2, while section 5A in the case of i = 3, where the initial directions are in the same; backward-forward.

Similar functional properties (including wear resistance and dimensional stability) can also be expressed with the material ratio parameters, the values of which are shown in Fig. 2d. During turning, the values of R_{mr} are typically 2.95%, and the values of S_{mr} are equally 0.11%. After burnishing, multiples of these values can be measured on the surfaces; at number of passes i = 1, it is 3.7 times for R_{mr} and 4.5 times for S_{mr}, in the case of i = 2, it is 1.3...7.2 times for R_{mr}, 13.5...27.7 times for S_{mr}, at i = 3, there is 1.8–6.8 times increase in R_{mr} and 9.4–27.5 times increase in S_{mr}. The significant differences between the rates indicate the sensitivity of these parameters to a change in the machining conditions, compared to e.g. R_a, S_a and R_z, S_z. Based on the results, the maximum R_{mr} and S_{mr} values were also achieved in the case of i = 2 on section 2B and in the case of i = 3 on section 5A, where the initial burnishing directions are as mentioned before.

Overall, based on the values of the 8 roughness parameters considered, to achieve the best functional properties, we recommend burnishing with backward-forward directions in case of 2 passes, or an additional pass in forward direction in case of 3 passes.

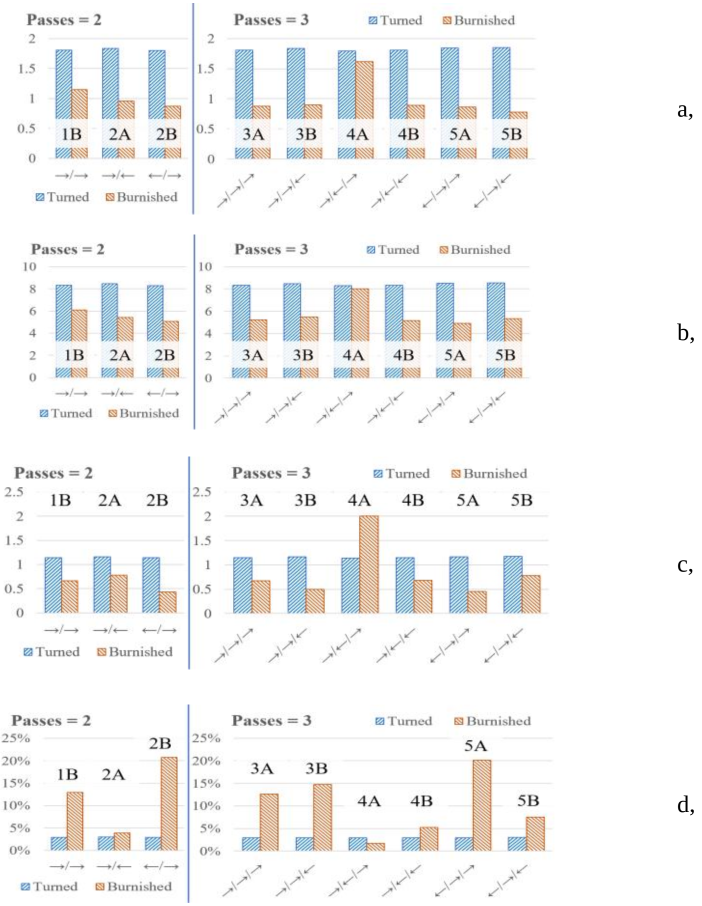


Figure 2 – Comparison of roughness values of R_a (a), R_z (b), R_{pk} (c), R_{mr} (d) by number of passes

After that, we compare the effects of the number of passes with roughness parameters. For this, we consider the most favorable values from a functional point of view for each number of passes, which are also shown in the diagrams in Figure 3, where MR means “material ratio”. The R_a (Fig. 3a) and R_z (Fig. 3b) parameter values show similarly that, compared to the values of the turned surface, a slight improvement can be achieved with 1 pass, there is a significant additional improvement in case of 2 passes, and with 3 passes a further minimal improvement can be achieved. Different characteristics from this show the R_{pk} (Fig. 3c) and R_{mr} (Fig. 3d) parameter values, where a significant improvement is experienced even with 1 pass, then a further large positive change for 2 passes, but a minimal deterioration for an additional repetition. Presumably, with 3 passes we reached the limit where the surface roughness characteristics no longer improve, as described in the literature [14]. Therefore, we recommend the use of i = 2 passes on corrosion-resistant steel, because in the case of i = 3, the overall small improvement no longer compensates for the significant decrease in productivity.

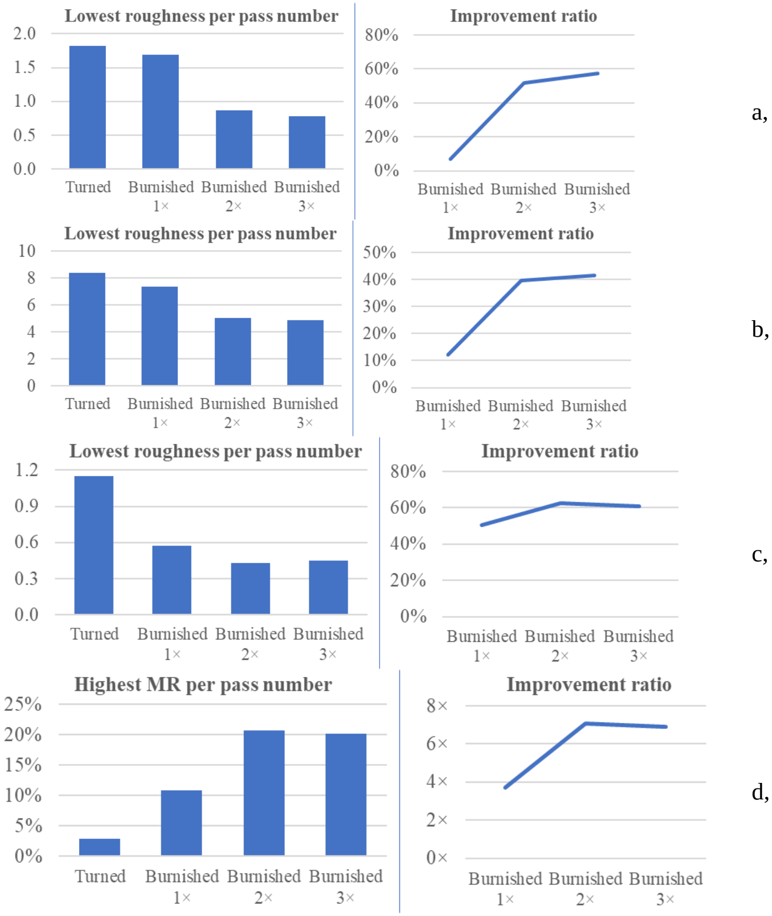
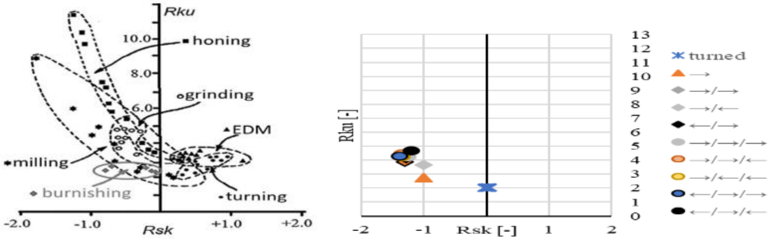


Figure 3 – Roughness values of R_a (a), R_z (b), R_{pk} (c), R_{mr} (d) as a function of number of passes

In the study, the measured values of the R_{sk} skewness and R_{ku} kurtosis indices are analyzed. These can be coupled and placed as points on a topological map, which cover different ranges on the R_{sk}–R_{ku} plane (Fig. 4a). These are typical for each machining method, and thus the characteristic properties of the created surface topographies can be identified [18]. Fig. 4a shows the expected ranges of turning and burnishing. In this plane the measured results are illustrated on a diagram (Fig. 4b). The R_{sk}–R_{ku} value pairs measured on the turned surfaces indicate the nature of the profiles; their peaks and valleys are generally at almost the same distance from the center line, and their sharpness is characteristic of turning. Compared to these, on the burnished surfaces the measured R_{sk} values are smaller (negative values); the profiles have flattened and rounded peaks and narrow, relatively deep valleys, and by increasing the number of passes, these characteristics of the peaks and valleys further increase a little. The R_{ku} values are unexpectedly high and become higher with the increase of number of passes, i.e. the sharpness of the profiles increases. For this, one reason may be the relatively small spaces between turning marks on the profile due to the small feed, another possible reason is the narrowing of the turned roughness valleys during the further deformation of the surface layer during several passes of burnishing.



a, b,

Figure 4 – Topological map of machined surfaces [19] (a) and of the experimental results (b)

4 CONCLUSIONS

In the present paper, we investigated the effect of burnishing on the surface topography of X5CrNi18-10 grade alloyed corrosion-resistant steel after turning, where the number of burnishing passes and directions were changed while the burnishing force, feed and speed were constant. Our findings are as follows.

Based on experimental roughness results, burnishing of turned surfaces resulted in an improvement in a single pass from a functional point of view – smoothness, bearing capability, quickly-wearing upper layer –, and further improvement in the case of 2 number of passes. However, we did not experience any significant changes in roughness in case of 3 passes, besides the reduction of productivity. Based on these, we recommend the use of 2 passes burnishing on the examined material quality and burnishing force.

Within a given number of passes, changing the burnishing directions resulted in almost identical amplitude roughness values, but significant differences in the degree of value changes of R_{pk}, S_{pk} and R_{mr}, S_{mr} parameters characterizing the roughness peak. Compared to the turning feed direction, the greatest improvement was achieved by the backward-forward directions in the case of 2 passes, and by the backward-forward-forward strategy in the case of the 3 times repetition, so we recommend their use. During burnishing with 3 passes in forward-backward-forward directions (on surface 4A), material separation occurred, which deteriorated the surface roughness properties, so it is recommended not to use this setting.

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References: 1. *Kundrák, J., Mamalis, A.G., Gyáni, K., Markopoulos, A.:* Environmentally friendly precision machining, Materials and manufacturing processes vol.21(1) (2006) pp.29-37. **2.** *Varga, Gy., Szigeti, F., Kovács, A.:* Analysis of Surface Roughness of Holes Machined by Environmentally Friendly Way (in Hungarian). Műszaki Tudomány az Észak-kelet Magyarországi Régióban 2012. MTA Debreceni Akadémiai Bizottság, Debrecen, Hungary, 2012, pp. 433-442. **3.** *Varga, G., Sovilj, B., Jakubowicz, M., Babič, M.:* Experimental Examination of Surface Roughness in Low-Environmental-Load Machining of External Cylindrical Workpieces. International Scientific-Technical Conference MANUFACTURING, Springer, Cham, 2019, pp. 307-321. **4.** *Antal, N., Gyula, V.:* Effect of abandonment of cooling and lubrication on surface roughness and cylindricity in turning of steel, Multidiszciplináris Tudományok vol.11(4) (2021) pp.395-407. **5.** *Kundrák, J., Varga, G., Deszpoth, I.:* Analysis of Extent of Environment Load in Alternative Manufacturing Procedures. WSEAS Transactions on Environment and Development vol.14 (2018) pp.313-320. **6.** *Sztankovics, I., Kundrak, J.:* Theoretical Value and Experimental Study of Arithmetic Mean Deviation in Rotational Turning. Rezanie I Instrumenty V Tekhnologicheskih Sistemah vol.96 (2022) pp.73-81. **7.** *Ferencsik, V., Varga, G.:* Examination of surface state-change on diamond burnished aluminium components. Proceedings of the International Symposium for Production Research 2019, Springer, Cham, 2020, pp.535-544. **8.** *Stephenson, D.A., Agapiou, J.S.:* Metal cutting theory and practice. CRC press, 2018. **9.** *Maheshwari, A.S., Gawande, R.R.:* The role of burnishing process in manufacturing industry - A state-of-the-art survey, International Journal of Engineering Research and Development vol.13 (2017) pp.50-60. **10.** *Grzesik, W., Zak, K.:* Modification of surface finish produced by hard turning using superfinishing and burnishing operations, Journal of Materials Processing Technology vol.212(1) (2012) pp.315-322. **11.** *Varga, G., Ferencsik, V.:* Analysis of surface topography of diamond burnished aluminium alloy components. Vehicle and Automotive Engineering, Springer, Cham, 2017, pp.143-154. **12.** *Ferencsik, V., Varga, G.:* The Influence of Diamond Burnishing Process Parameters on Surface Roughness of Low-Alloyed Aluminium Workpieces, Machines vol.10(7) (2022) ArtNo.:564. **13.** *Rami, A., Gharbi, F., Sghaier, S., Hamdi, H.:* Some insights on combined turning-burnishing (CoTuB) process on workpiece surface integrity, International Journal of Precision Engineering and Manufacturing vol.19(1) (2018) pp.67-78. **14.** *Hassan, A.M., Al-Dhifi, S.Z.:* Improvement in the Wear Resistance of Brass Components by the Ball Burnishing Process, Journal of Materials Processing Technology vol. 96(1) (1999) pp.73-80. **15.** *Hirose, M., Hayasaka, T., Shamoto, E.:* Unique regenerative chatter in wiper-turning operation with burnishing process, Part 1: Prediction and analytical investigation of generation mechanism, critical stability, and characteristics, Precision Engineering vol.71 (2021) pp.304-312. **16.** *Alshareef, A.J., Marinescu, I.D., Basudan, I.M., Alqahtani, B.M., Tharwan, M.Y.:* Ball-burnishing factors affecting residual stress of AISI 8620 steel, The International Journal of Advanced Manufacturing Technology vol.107(3) (2020) pp.1387-1397. **17.** *Shi, Y.L., Shen, X.H., Xu, G.F., Xu, C.H., Wang, B.L., Su, G.S.:* Surface integrity enhancement of austenitic stainless steel treated by ultrasonic burnishing with two burnishing tips, Archives of Civil and Mechanical Engineering vol.20(3) (2020) pp.1-17. **18.** *Molnár, V., Sztankovics I.:* Analysis of Roughness Parameters Determining Tribological Properties in Hard Turned Surfaces. Hungarian Journal Of Industry And Chemistry vol.49(2) (2021) pp.77-84. **19.** *Kovács, Z.F., Viharos, Z.J., Kodácsy, J.:* Improvements of surface tribological properties by magnetic assisted ball burnishing, Surface and Coatings Technology vol.437 (2022) ArtNo.:128317.

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АНАЛІЗ ВПЛИВУ КІЛЬКОСТІ ПРОХОДІВ ІНСТРУМЕНТУ ТА ЙОГО НАПРЯМКУ ПРИ ВИГЛАДЖУВАННІ НА ШОРСТКІСТЬ ПОВЕРХНІ

Анотація. *В даний час піклування про охорону навколишнього середовища стає все більш важливим і у виробництві. Цьому часто сприяють, зменшуючи чи усуваючи кількість охолоджуючих рідин та мастильних матеріалів або використовуючи альтернативні методи обробки. Один з них – вигладжування, що позитивно впливає на цілісність поверхні та знижує навантаження на навколишнє середовище. У цій роботі автори розглянули зміну шорсткості поверхні, що досягається при вигладжуванні після токарної обробки заготовки з корозійностійкої сталі, де кількість проходів вигладжування та напрямок вигладжування змінювалися. Для дослідження були проведені досліди на універсальному токарному верстаті. При цьому циліндрична заготовка з корозійностійкої сталі затискалася в трикулачковому патроні, на якому поверхня сегментувалася на 5 дрібніших частин. До кожного сегменту застосовувалися два різні налаштування полірування. При цьому використовувалася емульсія мастильно-охолоджувальної рідини, яку капали на заготівку в невеликій кількості. Після цього проводили вигладжування на підготовлених поверхнях з подачею* $f = 0{,}05$ *мм/об, частотою обертання шпинделя* $n = 375$ *1/хв і зусиллям вигладжування* $F_b = 10$ *Н. Діаметр алмазної кулі становив Ø3 мм. Вигладжування проводилося різними способами на поверхнях шляхом зміни числа і напрямку проходів, що вигладжують, де напрямок «вперед» ідентичний напрямку подачі при точінні, а «назад» протилежно йому. На підставі експериментальних результатів шорсткості автори роблять висновок про те, що вигладжування точених поверхонь призвело до поліпшення за один прохід з функціональної точки зору – гладкість, несуча здатність, верхній шар, що зношується, – і подальше поліпшення у разі 2-х проходів. Однак суттєвих змін шорсткості за 3 проходи, крім зниження продуктивності, вони не помітили. Виходячи з цього, автори рекомендують використовувати 2 проходи полірування в залежності від якості досліджуваного матеріалу та сили полірування. Протягом заданого числа проходів зміна напрямку вигладжування призводить до практично однакових значень амплітуди шорсткості, але суттєвим відмінностям у ступені зміни значень параметрів* R_{pk}*,* S_{pk} *та* R_{mr}*,* S_{mr}*, що характеризують пік шорсткості. У порівнянні з токарним напрямом подачі найбільшого поліпшення було досягнуто при використанні напрямків «назад–вперед» у разі 2 проходів та стратегії «назад–вперед–вперед» у разі 3-кратного повторення, тому автори рекомендують їх використання. При вигладжуванні за 3 проходи в напрямках «вперед–назад–вперед» відбувається розшарування матеріалу, що погіршує шорсткість поверхні, тому це настроювання використовувати не рекомендується.*

Ключові слова: *токарна обробка; вигладжування; шорсткість поверхні; екологічно чисте оброблення.*