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ANALYSIS OF PHYSICAL CAUSES OF MACHINED SURFACES IN SELECTED MACHINING METHODS

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Abstract

In this paper, we will try to theoretically calculate and experimentally determine the roughness of the machined surface in terms of the physical causes. The surface roughness has been experimentally obtained for two turning methods, which are challenging both in terms of setting the cutting conditions and in terms of the economics of the experiments performed. These are the deep turning of hardened steel internal holes and the internal turning of internally shaped surfaces. The article will point out the theoretical calculation of machined surfaces' roughness by the cutting theory and the experimental results obtained.

Keywords: Machining; Surface roughness; Cutting processes; The deep turning of internal holes; Broaching of internal Shaped surfaces.

1. Introduction

The roughness of the machined surface is one of the important parameters for the evaluation of the quality of machined surfaces It is therefore important to know not only the methods for the evaluation of surface roughness [1] but especially to know what are the causes of the roughness of machined surfaces. From the theory of cutting we know the following causes of the roughness of machined surfaces: copying of the shape of the cutting part of the tool into the workpiece, copying of the roughness of the cutting edge into the workpiece, the existence of vibration of the cutting tool or the technological tool-workpiece junction, existence of accretion on the machined surface, accidental causes. These physical causes act simultaneously and thus each of them contributes a certain amount to the resulting roughness of the machined surface. The problem is which of these causes is dominant and contributes most to the overall magnitude of the roughness of the machined surface.

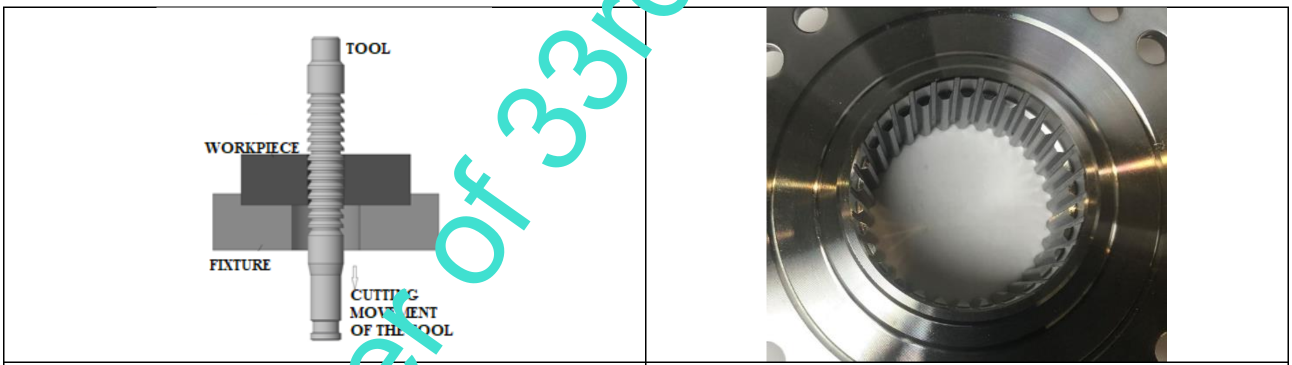
In our article, we will discuss for selected technological methods which of the above physical causes is most involved in the formation of the roughness of the machined surface.

In scientific journals, there are countless articles describing results obtained by experimental research and calculations for example for machining technologies [2] but also for additive technologies [3] and most recently also by prediction and simulation [4]. All articles are focused on the evaluation of the roughness of machined (already additive) surfaces under different changes in technological and process conditions, cutting environment (air, emulsion, oil, ...), machined or additive material, etc. In particular, research is focused on different technological methods. In [5], the authors predicted the roughness of the machined surface in circumferential milling technology. The influence of the cutting edge radius on the resulting roughness in milling was described by the authors in [6]. In [7], the authors analyzed the roughness of the machined surface in HSS tapping technology using different tap coatings. The paper [8] is to evaluate the influence of selected cutting parameters (cutting speed and feed rate) on the surface topography of drilled WPC material and in the [9] study, surface characteristics of the samples of experimentally manufactured wood plastic composites (WPC) were determined. The turning process was used to produce surfaces by removing material from a rotating workpiece.

In our article, we will focus not on the experimental results in terms of the achieved value of the roughness of the machined surface but on the theoretical analysis and experimental proof, which cause (of the mentioned physical causes) has the greatest influence on the given technological method. For this strategy of evaluation of the roughness of the machined surface, those technological methods were selected for which we can clearly say which physical causes cannot contribute to the roughness of the machined surface. For these reasons, we selected the following technological methods: broaching of internally shaped grooves and machining of hardened steel.

1.1 Broaching of internally shaped grooves

The broaching machines perform a straight-line movement. The tools used are broaching tools - so-called broaching mandrels. The shape, design, and material of the broaching tools guarantee high precision and quality of the machining of parts using this metal chip technology. The technology of broaching the internally shaped surfaces of workpieces consists in producing an internal profile that is machined on parts with a continuous circular hole. In practice, this hole 'd' is usually machined by turning or drilling as a previous manufacturing operation. The workpiece is placed, without clamping, in a positioning jig attached to the machine, where it is centered by the broaching tool during the straight-line movement of the machine. The cutting speed in the broaching process is the speed at which the tool passes through the workpiece. By moving the broaching tool in a straight line through the workpiece, the desired shape is produced. This is the negative contour of the tooth shape of the broaching tool on the workpiece. The workpiece, after the production operation of broaching is completed, may have, in terms of further requirements, either the final design of the internal form surface or this form surface is machined in further production operations. The technology of stretching internal molded surfaces enables high productivity to be achieved in the production process. Procurement costs for broaching tools are higher. For these reasons, it is suitable for use in series and high-volume production. A depiction of the principle of the internal contour surface stretching technology and an example of an internal contour surface is shown in Fig. 1. Inner forming surface - is a flange-shaped hub. The inner hole was first turned.



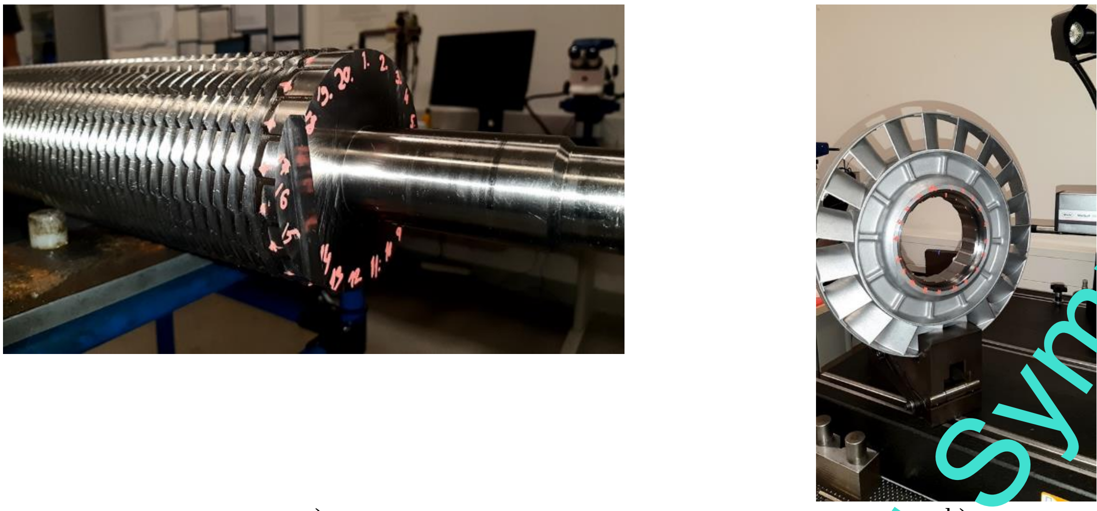
a) b)

Fig. 1. Broaching of the inner-shaped grooves
a) Illustration of the principle b) Example of an internal shaped face on a girth

Experimental conditions

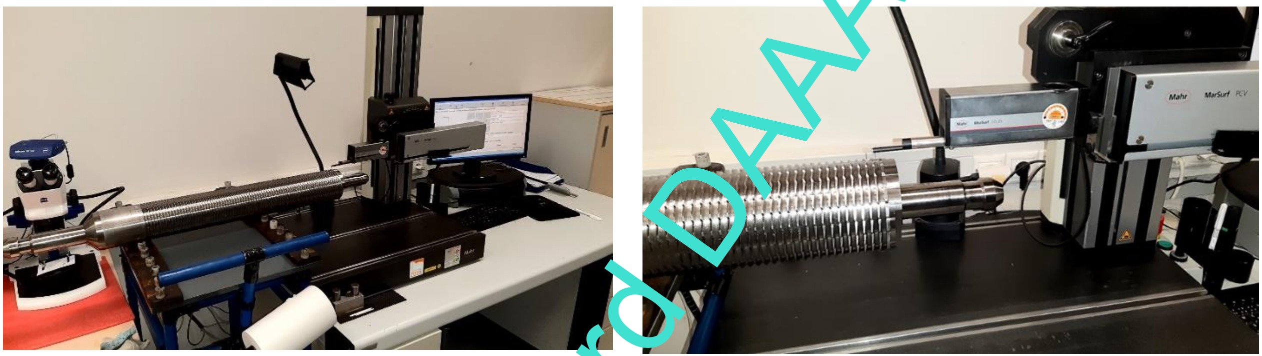
The experiment was carried out on a 7B66 broaching machine, under series production conditions in an emulsion liquid environment. The workpiece material was C45 (or 1.0503 according to DIN standard). The chemical composition of the material in [%] is as follows: C 0.43-0.5, Mn 0.5-0.8, P max 0.045, Si max 0.4, Ni max 0.4, S max 0.045, Cr max 0.4, Mo max 0.1. The tensile strength Rm is defined for the workpiece blank at 750-900 [N/mm^2].

Comparison of the roughness of the calibration teeth of the broaching mandrel and the workpiece. The relative position of the tool relative to the workpiece was marked on the broaching mandrel and the workpiece. After performing the broaching operation of the internal form surface, the cutting edges of the broaching mandrel Fig. 2 (a) and the internal form surfaces of the workpiece after broaching Fig. 2 (b) were subsequently numbered. The roughness of all the teeth of the last row of teeth was measured on the broaching mandrel, Fig. 4. Roughness measurements were performed in the middle part of the teeth of the broaching mandrel and also on the workpiece in the middle part.



a) b)

Fig. 2. Numbering of teeth and grooves
a) numbering of the last row of teeth, b) numbering of internal form surfaces after broaching on the workpiece



a) b)

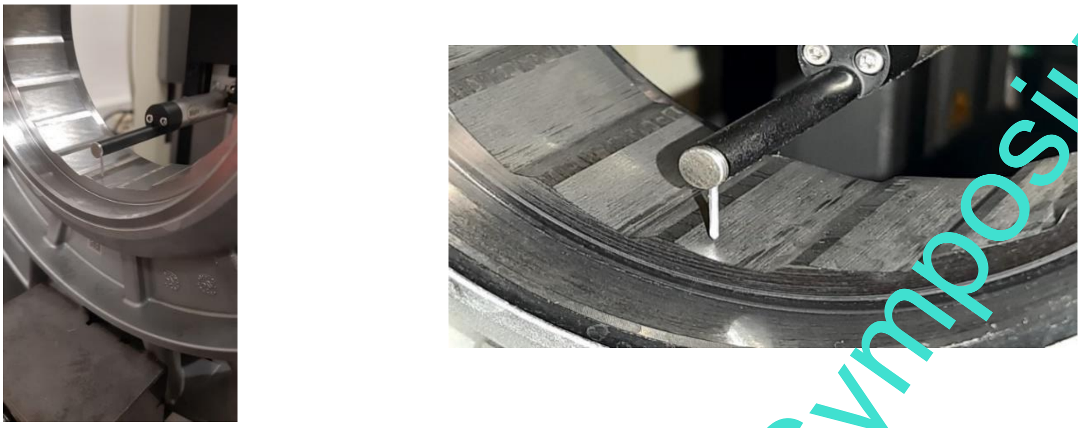
Fig. 3. Preparation and measurement of the teeth of the broaching mandrel
a) preparation of the measurement of the roughness of the teeth of the broaching mandrel
b) measurement of the roughness of the last row of teeth

Type of broaching machine, manufacturer	7B66, Minsk Maschine Company
Cutting speed	2.5 [m.min^{-1}]
Length of broaching mandrel	1100 [mm]
Workpiece materiál	C45
Number of shaped workpiece surfaces	20
Emulsion liquid	Blaser 4000 Strong
Emulsion liquid concentration	15 [%]
Roughness measuring device	Mahr Marsurf XCR20

Table 1. The experimental conditions of broaching

Results

The measurements of the roughness of the internally shaped surfaces of the workpiece were carried out in the central part of the grooves. A detail of the contact tip of the roughness measuring device is shown in Fig. 4. The results of the roughness measurements of the mandrel teeth and the workpiece are shown in Table 2.



a) b)

Fig. 4. Measuring the roughness of the internal form surface of the workpiece
a) measurement of the workpiece in the central part of the groove, b) detail of the measurement

Broaching mandrel		**Workpiece**			
Tooth serial number	**Roughness Rz**	**Groove serial number**	**Roughness Rz**	**Difference = Column 2 - Column 5**	**Max a Min**
[--]	[µm]	[--]	[µm]	[µm]	[µm]
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
1.	4.34	1.	5.35	-1.01	1.01
2.	3.18	2.	3.19	-0.01	0.01
3.	5.05	3.	5.66	-0.61	
4.	4.57	4.	5.21	-0.64	
5.	6.32	5.	6.42	-0.10	
6.	5.47	6.	5.90	-0.43	
7.	6.75	7.	6.84	-0.09	
8.	4.55	8.	5.32	-0.77	
9.	6.86	9.	7.10	-0.24	
10.	4.01	10.	4.05	-0.04	
11.	5.88	11.	5.98	-0.10	
12.	5.75	12.	5.97	-0.05	
13.	5.97	13.	5.28	0.69	
14.	8.08	14.	8.44	-0.36	
15.	7.13	15.	7.47	-0.34	
16.	6.81	16.	7.18	-0.37	
17.	5.74	17.	6.06	-0.32	
18.	5.71	18.	5.78	-0.07	
19.	5.21	19.	5.44	-0.23	
20.	6.12	20.	6.25	-0.13	

Table 2. Resulting roughness parameter Rz

Discussion

From the table Table 1. we can see the following:

- the roughness of the broaching mandrel, i.e. its teeth (except for one tooth) was less than the roughness of the manufactured grooves,
- the maximum roughness deviation between the roughness of the tooth of the broaching mandrel and the roughness of the manufactured groove was 1.01 μm and the minimum was 0.01 μm,
- no increase was observed on the machined surfaces,
- no traces of tool oscillation were observed on the machined surfaces (the design of the machine and the tool practically do not allow oscillation to occur).

We can say that in this case of machining both physical causes of the roughness of the machined surface, namely chatter and surge, are eliminated. Further, since this technological method is implemented with only one movement, namely the straight-line movement of the broaching mandrel, there is also no first (usually the greatest) physical cause of roughness of the machined surfaces, namely the copying of the shape of the cutting part of the tool into the workpiece. In this case, we are left with the only physical cause of roughness and that is the copying of the cutting-edge roughness itself into the workpiece. Experiments have shown that, given the above, and the results of the roughness measurements in Table 2, we can sufficiently prove that in this method of machining a new surface is formed only by copying the roughness of the cutting edges of the cutting part of the tool itself.

This statement is significant in that, for cases where high-quality machined surfaces are required after broaching in terms of roughness, we as technologists have in our hands a tool for improving the roughness of machined surfaces. In this case, to achieve the best roughness on the workpiece, we ensure the best roughness on the cutting wedge surfaces of the broaching mandrel teeth.

1.2 Turning a deep internal hole in hardened steel

The second technological method to investigate the physical causes of the roughness of the machined surface was the internal turning of hardened steel. The reader will ask why this particular technology was chosen. This technology was chosen because it is a technology where the cutting tool operates in the so-called non-incremental cutting zone, i.e. where no growth is formed, and for two reasons. The first reason is that sufficiently high cutting speeds are used (use of CBN cutting materials) at which, from a theoretical point of view, no build-up is formed. The second reason is the thermal condition of the workpiece - it is hardened steel with a high proportion of martensitic structure, which, as we know, again does not form a surge when cutting.

These assumptions allow us to say that the following physical causes will have a decisive influence on the resulting roughness of the machined surface: copying the shape of the cutting part of the tool, copying the roughness of the cutting edge, and the existence of chatter. Since the technological method of turning internal cylindrical surfaces implies the use of a cutting tool with certain greater unloading, its rigidity is the weakest point of the technological system. This gives the assumption that it is the physical cause - the existence of tool oscillation - that will have a decisive influence on the formation of the roughness of the machined surface.

Experimental conditions

The main concern of this experiment consisted of the effect of the L/D ratio on the roughness of the workpiece while using different internal turning tools [10]. All the internal turning experiments of this project were performed using a DMG CTX alpha 500 CNC turning center with 20/27 kW (100/40 % ED) of power in the main motor and a maximum spindle rotation of 5000 rpm. The selected tools for the experiments were 16 mm in diameter: one with high hardenability ANSI 4140 steel – code A16R SCLCR 09-R, one with carbide – code E16R SCLCR 09 R and the last one was an antivibration tool (Silent tool) code 570-SCLCL-16-06 for the support and code 570-3C 16 156 for the anti vibrational bar – It was supplied by Sandvik Coromant [11]. As for the tool insert, an adequate insert for finishing operations on smooth surfaces of hardened steel was chosen. It was composed of CBN (50 % wt.) and a ceramic phase of TiCN and Al_2O_3; it is the ISO code is CCGW09T308S01020F 7015 (class ISO H10) for Steel and Carbide tools while for the Silent tool the code is CCGW 060208S01030F 7015 [11]. The advantage of the chosen tool inserts, when compared to others with a greater CBN content, is their chemical stability about iron. Besides, its toughness is enough to preserve its cutting edge, even though it is reduced when compared to other inserts with a greater CBN content. The DIN EN 1.2842 (ISO 90MnCrV8) steel used in the fabrication of the test specimens is a widely employed material in the metal mechanical industry. It presents high hardenability, bad weldability, and reasonable machinability, as well as good resistance to torsion and fatigue –it's hardened to hardness 58 HRC. The cutting conditions and the machine setup (tool overhang) were tested in maximum flank wear (VBmax) of 0.2 mm according to ISO 3685 [12]. The DOI 10.2478/rput-2022-0003 25 tests were carried out without a cooling system and constant cutting parameters, with a cutting speed (v_c) of 360 m/min, feed rate (f) of 0.14 mm/revolution, and depth of cutting (ap) 0.1 mm. The conditions for clamping the boring bar in the turret were determined considering the distance from the tool tip to the beginning of the tool holder. The condition of clamping the tool was according to the following distribution in the L/D ratio parameter (ratio between the length "L" and the diameter "D" of the tool): 3 to 8 with intervals of 0.25. The roughness of the cylindrical surface of the workpiece was measured 5 times and verified at three equidistant points (120°) at a controlled laboratory temperature of 20 °C. Therefore, to quantify the finish obtained during the turning process, a profilometer SURFCOM 1900SD2 model, Accretech brand, was used, with resolution on the X axis and Z axis equal to 0.04 μm, measuring force of 0.75 mN and expanded uncertainty of 0.01 μm (k=2), following the DIN 4768 (1990-2005) [13] standards. In addition, to treat the roughness profile, a Gauss filter was used, and the sampling length (cut-off) used was equal to 0.8 mm, following the ISO 4288:1996 [14] parameters. The arithmetic means deviation of the profile (Ra) and the total height of the profile (Rz) were chosen.

Results

In the case of internal turning, the tool overhang is, together with the cutting parameters, fundamental to obtaining a high finish surface on the workpiece. Figure 5 shows the behavior of the roughness represented by parameters Ra and Rz, as a function of the L/D ratio for three different tool types (steel, carbide, and silent tool (antivibration tool)).

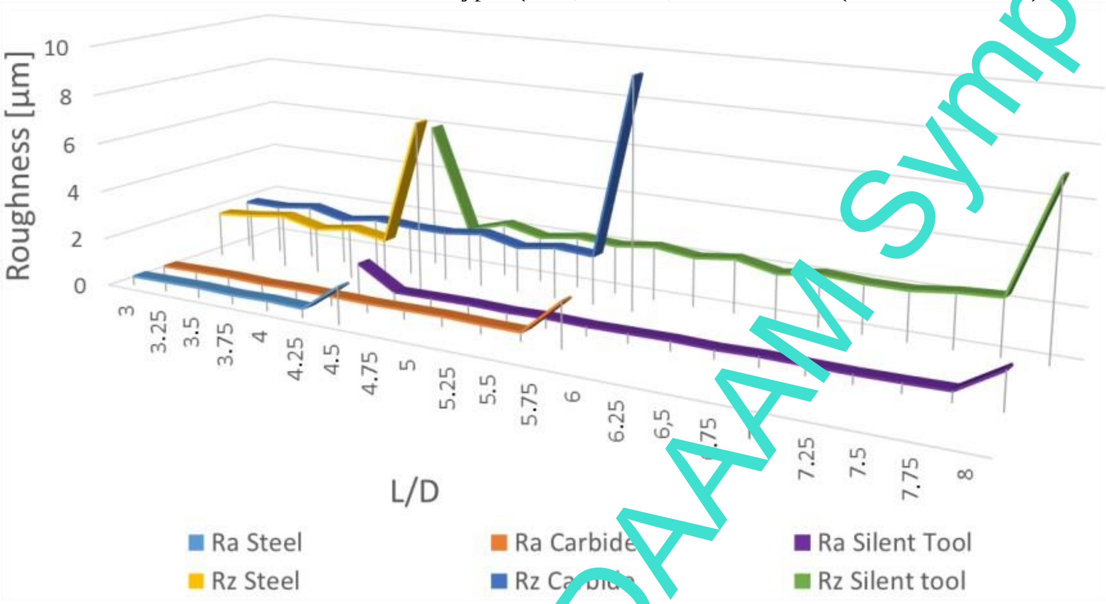


Fig. 5. Effect of the L/D ratio over the roughness in the workpiece with different types of boring bars with a standard deviation of Ra ±0.02 µm and Rz ±0.06 µm [13]

As a general result of this experiment, Table 3 summarizes the findings describing the overhang limits of each tool during internal turning operation for constant cutting parameters. To define the critical L/D ratio of the boring bar, the dynamic stability of internal turning was experimentally observed and classified as stable: arithmetic average roughness (Ra) was lower than 0.8 µm and no chatter marks in the workpiece surface or unstable: arithmetic average roughness (Ra) was higher than 0.8 µm and chatter marks were present in the workpiece surface due to the self-excited vibration, as illustrated by Figure 6.

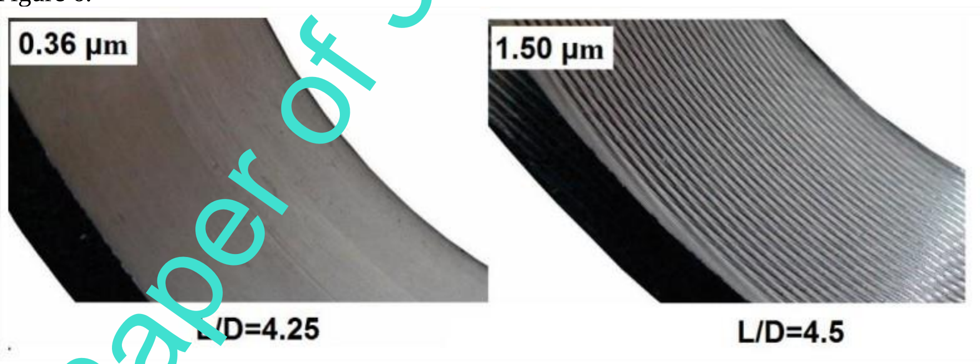


Fig. 6 The surface textures in boring with the same cutting conditions, steel boring bar, and different L/D ratios

Tool	Overhang (L/D)	Overhang [mm]	Stability	Ra [µm]	Rz [µm]
Steel	4.25	68	Stable	0.36	1.86
	≥ 4.50	≥ 72	Unstable	1.50	7.00
Carbide	5.50	88	Stable	0.35	2.00
	≥ 5.75	≥ 92	Unstable	1.83	9.44
Antivibration (Silent Tool)	L/D_{min} = 4.50	72	Stable	0.36	1.73
	L/D_{max} = 7.75	124		0.41	2.29
	$L/D_{min} \leq$ 4.25	≤ 68	Unstable	1.30	6.01
	$L/D_{min} \geq$ 8.00	≥ 128		1.48	7.00

Table 3. Resulting values of the roughness parameter of the machined surface Ra, Rz

Discussion

It can be seen in Figure 2 that, for measured parameters, the workpiece roughness is independent of the tool overhang up to a certain value, from which the roughness increases abruptly.

It was also observed that in the range of overhangs in the stable limits (Steel L/D = <4.25, Carbide L/D = 5.5, and Silent tool 4.5≥L/D ≥7.75), the roughness parameter Ra and Rz are very close and below 0.8 µm, while for unstable limits Steel L/D ≥ 4.5, Carbide L/D ≥ 5.75, and Silent tool 4.25≤ L/D≥8) is where the influence of tool vibration over the roughness.

Since the feed rate, depth of cut, and the tip radius of the tool, which form the theoretical roughness of the part (geometric contribution of the feed rate and tip radius to the roughness), were constant during the tests, the vibration was observed. The main factor that affects the stability of the machining process is the static stiffness of the toolbar which was tested in a variety of overhangs. Therefore, it is possible to say that the stability of the machine-tool-workpiece system has a huge impact on the surface finish and not, for this time the cutting conditions.

One recommendation to keep the roughness values to a minimum is to adjust the tool clamp to the smallest overhang (L/D = 3) possible for the operation. As pointed out by Thomas et al. [15], among other efficient techniques to increase the stability of the system and reduce vibration in internal turning operation with deep holes.

5. Conclusion

This study is based on which of the physical causes contributes decisively to the roughness of the machined surface for selected technological methods of machining. Two technological methods were selected: broaching the internal groove and turning a deep internal hole in hardened material. In conclusion:

- We have confirmed the theoretical assumptions with experimental results,
- For the technology of internal groove broaching, the physical cause of the roughness of the machined surface is decisive: the copying of the roughness of the cutting edge of the broaching mandrel tooth,
- For the technology of turning an internal hole in hardened material, the decisive physical cause of the roughness of the machined surface is the existence of chatter.

These statements are a very important guideline for technological practice. They give us practical guidance on how to achieve the prescribed roughness of machined surfaces in these technologies and how to improve (deteriorate) or control the achieved roughness of machined surfaces.

Conclude as follows:

- the problem addressed was the confirmation/non-confirmation of the theoretical physical causes of the roughness of machined surfaces with a defined cutting edge. For this purpose, we selected two very specific machining methods - broaching of internal grooves and turning of internal holes in hardened steel.
- The results of the research confirmed the existence of two physical causes of the roughness of machined surfaces, namely: the copying of the roughness of the cutting edge itself into the machined surface and also the effect of chatter (if any).

In the future, we want to extend our research to other very specific machining methods, in the first step will be the technology of copy milling with different lengths of clamping part unloading.

6. Acknowledgments

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7. References

[1] Kubatova, D. (2020). Problems of Defining and Subsequently Measuring Surface Roughness in Aperiodic Surfaces, Proceedings of the 31st DAAAM International Symposium, pp.0236-0243, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-29-7, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/31st.daaam.proceedings.033

[2] Peterka, J. (2004). A new approach to calculating the arithmetical mean deviation of a profile during copy milling, Strojniski Vestnik-Journal of Mechanical Engineering, Vol. 50, Issue 12, pp. 594-597

[3] Milde, J., Peterka, J., Jurina, F., Dobrovszky, P., Hrbal, J., Pitek, P. & Martinovic, J. (2021). Influence of Selected Photopolymers on the Resulting Accuracy and Surface Roughness of the Component in Digital Light Processing Technology, Proceedings of the 32nd DAAAM International Symposium, pp.0235-0245, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-33-4, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/32nd.daaam.proceedings.034

[4] Nexhat Qehaja, Ilir Doci, Mirlind Bruci, Fitore Abdullahu, Kaltrine Jakupi & Fatlume Zhujani. (2016). Mathematical Modelling of Surface Roughness Through Machining Parameters and Machining Time During the Dry Milling Process, Proceedings of the 27th DAAAM International Symposium, pp.0187-0194, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-08-2, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/27th.daaam.proceedings.028

[5] Piska, M. & Kolomy, S. (2021). On the effective substitution of turning by peripheral milling, Proceedings of the 32nd DAAAM International Symposium, pp.0016-0021, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-33-4, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/32nd.daaam.proceedings.003

[6] Hronek, O. & Zetek, M. (2017) The influences of cutting edge radius on surface roughness when milling nickel alloy. Proceedings of the International DAAAM Symposium. pp. 1037-1043. Katalinic, (Ed.), ISSN 1726-9679, ISBN 978-3-902734-08-2. Vienna, Austria. DOI:10.2507/28th.daaam.proceedings.144

[7] Piska, M. & Sliwkova, P. (2015). Surface parameters, tribological tests and cutting performance of coated HSS taps, Proceedings of the 25th DAAAM International Symposium, vol. 100, pp.125-124, Published by Elsevier Ltd. This is an open-access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/). Peer-review under responsibility of DAAAM International Vienna, doi: 10.1016/j.proeng.2015.01.350

[8] Hutyrova, Z., Zajac, J., Michalik, P., Mital, D., Duplak, J. & Gajdos, S. (2015). Study of Surface Roughness of Machined Polymer Composite Material, International Journal of Polymer Science, vol. 2015, Art. Num. 303517, pp. 1-6, DOI: 10.1155/2015/303517

[9] Hutyrova, Z., Harnicarova, M., Zajac, J., Valicek, J. & Mihok, J. (2014). Experimental Study of Surface Roughness of Wood Plastic Composites after Turning, Material Science and Engineering Technology II, Book Series: Advanced Materials Research, Vol. 856, pp. 108+, DOI: 10.4028/www.scientific.net/AMR.856.108

[10] Peterka, J.; Walyson, T. de S.; Straka, R.; Vopát, T.; Hrbál, J. & Kritikos, M. (2022). Analysis of form error and roughness of hardened steel workpieces internally turned with different tools in long overhangs. Research Papers, Vol. 30, No. 50, pp. 21-29, ISSN 1338-0532 (online), DOI 10.2478/rput-2022-0003

[11] Sandvik, 2017. Silent tool for turning: overcome vibrations in internal turning. 4 Feb. 2021 <https://tibp.blob.core.windows.net/coromant/a9d341b5-16cc-4f7c-8e60-2f927ea651fa.pdf?sv=2014-02-14&sr=b&sig=gd6yrZv9dnCJrT4OJpY7FuBrp2rINAFabaFTmn79nBo%3D&st=2021-02-04T15%3A08%3A41Z&se=2031-02-02T15%3A13%3A41Z&sp=r&rsct=application%2Fpdf&rscd=inline%3B%20filename%3DC2920-40.pdf>.

[12] ISO 3685:1993Tool-life testing with single-point turning tools.

[13] DIN 4768, 1990-2005. Determination of values of surface roughness parameters Ra. Rz, Rmax using electrical contact (stylus) instruments Concepts and measuring conditions.

[14] ISO 4288:1996 Geometrical Product Specifications (GPS) - Surface texture: Profile method - Rules and procedures for the assessment of surface texture - revised by ISO 21920-3:2021

[15] Wallyson, T. de S.; Fulop Z. & Szilágyi, A. 2021. Passive Damping Techniques for Vibration Suppression in Boring Operation with Long Overhangs. In: Vehicle and Automotive Engineering 3, Károly Jármai & Katalin Voith (Ed.), pp. 256 – 264, Springer, ISSN 2195-4356 ISSN 2195-4364 (electronic), Lecture Notes in Mechanical Engineering ISBN 978-981-15-9528-8 ISBN 978-981-15-9529-5 (eBook), https://doi.org/10.1007/978-981-15-9529-5.