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INVESTIGATIONS INTO SURFACE INTEGRITY IN THE TURNING PROCESS OF DUPLEX STAINLESS STEEL

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Summary

The objective of the investigation was to identify surface roughness and surface topography parameters after the turning of Duplex Stainless Steel (DSS) with wedges of coated sintered carbide. The auto correlation and gradient distributions for variable cutting parameters were compared. An Infinite Focus Measurement Machine (IFM) was used for the surface texture analysis. The study was performed within a production facility during the machining of electric motor parts and deep-well pumps.

Key words: *Duplex Stainless Steel, optical microscopy, surface integrity, surface roughness, surface texture, turning*

1. Introduction

Engineering surfaces generated by machining processes are usually intended for tribological applications such as bearings and shafts. Achieving the desired surface quality is of great importance for the functional behaviour of a part [1]. Machining process is the most common process in the production of machine parts [2]. Surface integrity measurements of any workpiece are among the most important ones in the length and angle metrology, both in theory and practice. A surface is not only a geometric entity but also a layer with its own structure and properties [3]. According to Zeleňák et al. [4], there is a growing demand for research on mechanical and tribological properties of surface layers of materials. The finishing operation is connected with the precision of produced parts, surface integrity, and required surface roughness [5]. According to Benardos and Vosniakos [6], surface roughness is a widely used index of product quality and in most cases a technical requirement for mechanical products. Roughness is a sum of surface imperfections measured on a small area [7]. The most commonly used surface roughness parameter in production is the arithmetic average deviation from the average line profile [8]. According to Mahovic Poljacek et al. [9], a precise characterization of roughness and surface topography is of prime importance in many engineering industries. Quality is defined as the scope of implementation of expected functions [10]. To ensure a better surface integrity, special attention must be paid to the selection of cutting parameters [11, 12], tool material and geometry [13], and tool coatings [14]. Surface integrity is important for the components adapting to high thermal and mechanical loads during their applications [15–17].

Development and application of new materials in mechanical engineering practice create a lot of questions concerning their technological applications. This paper focuses on research problems related to the surface integrity after the turning process performed by coated carbide tools. The main purpose of this study was to determine the quality of surface integrity by using a novel method of analysis. The workpiece material is duplex stainless steel because this stainless steel is widely used in many industrial applications due to its unique properties. The good combination of its mechanical properties and corrosion resistance makes the duplex stainless steel suitable for a wide range of applications. Due to its poor machining property, the surface and subsurface are easily damaged during the machining process.

2. Experimental techniques

2.1 Workpiece

The machined material was 1.4462 (DIN EN 10088-1) steel with a ferritic-austenitic structure containing about 50% austenite. The ultimate tensile strength was UTS=700 MPa, and the Brinell hardness 293 HB. The elemental composition of the machined material and technical details of the cutting tools are given in Tables 1 and 2, respectively.

Table 1 Chemical composition of 1.4462 duplex stainless steel [%]

Element	C max	Si max	Mn max	P max	S max	Cr	Ni	Mo	N	Others
wt. [%]	max 0.03	max 1.00	max 2.00	max 0.030	max 0.020	21.0 23.0	4.50 6.50	2.50 3.50	0.10 0.22	-

Table 2 Cutting tool specification

Tool	Substrate	Coatings	Coating technique
MM 2025 Code: T1	Hardness: 1350 HV3 Grade: M25, P35	Ti(C,N)-(2 μm) (Top layer) Al_2O_3-(1.5 μm) (Middle layer) TiN-(2 μm) (Bottom layer)	CVD
CTC 1135 Code: T2	Grade: M35, P35	TiN-(2 μm) (Top layer) Ti(C,N)-(2 μm) Ti(N,B)-(2 μm) TiN-(2 μm) Ti(C,N)-(2 μm) Ti(C,N)-(2 μm) (Bottom layer)	CVD

Cutting tool inserts of TNMG 160408 designation clamped in the tool shank of ISO-MTGNL 2020-16 type were employed. Based on industry recommendations and conclusions from the earlier own investigations [8, 11], a range of cutting parameters were selected:
v_C = 100 m/min, f = 0.3 mm/rev, a_p = 2 mm. The study was conducted within a production facility. The research program was carried out on a CNC 400 CNC Famot Famot - Pleszew plc lathe.

2.2 Surface integrity analysis

Surface integrity analysis was performed using an Infinite Focus Measurement Machine (IFM). The IFM is an optical 3D measurement device, similar to a Scanning Electron Microscope (SEM), which allows the acquisition of datasets at a high depth of focus. The IFM method allows for the capture of images with a lateral resolution down to 400 nm and a vertical resolution down to 20 nm [18]. The IFM 3.2 software version was used for the measurements.

3. Results and discussion

3.1 Surface roughness

By analysing the machined surface (Figs 1 and 2), one can state that it has an anisotropic and periodical structure. A structure of this type occurs on contactless surfaces, mostly unloaded ones and co-acting with various kinds of wave interaction. On loaded faces, this surface is often found in contacts between undeformable bodies and deformable ones. Such a structure is typical of the structure obtained after machining by turning.

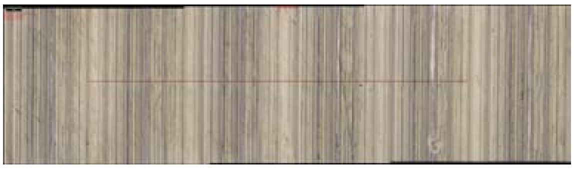

Fig. 1 Surface texture of a sample turned with the T1 tool point in real colour

Fig. 2 Surface texture of a sample turned with the T2 tool point in real colour

The shape of the load capacity curve mainly depends on the shape of irregularities in the direction perpendicular to the reference surface. A comparison of the load capacity curves depending on the cutting speed can be seen in Figure 3. Nielsen [19] found that the honing process can be controlled by *Rk* parameters. According to Sedlacek et al. [20], the *Rvk* and *Rpk* parameters could have an influence on friction. The representative measured values of roughness parameters and material ratio parameters (*Rk* parameters group) are listed in Tables 3 and 4 (the results are presented in the table as the arithmetic mean of three measurements). The contact angle was recorded at least thrice for each sample and at least two samples for each experimental condition were prepared. The biggest differences in the surface parameters due to the change of the cutting wedge were observed for the *Rvk* parameter. The *Rvk* parameter is a measure of the valley depths below the core roughness. By comparing the various parameters one may assess the uniformity of the surface peak and valley distributions relative to a particular direction. The *Rvk* parameter (Reduced valley height) is a parameter which is found from a measure of the valley depths below the core roughness. *Rvk* is a measure of the valley depths below the core roughness and is related to debris entrapment and lubricant retention.

Table 3 Material ratio parameters

Cutting tool	*Rk* µm	*Rpk* µm	*Rvk* µm	*Rmr1* %	*Rmr2* %
T1	11.329	3.3707	0.2316	12.19	99.2
T2	11.322	5.3377	2.2227	16.21	90.91

Table 4 Roughness parameters

Cutting tool	*Ra* µm	*Rq* µm	*Rt* µm	*Rz* µm	*Rmax* µm	*Rp* µm	*Rv* µm	*Rc* µm
T1	3.4281	3.9656	14.772	12.305	14.175	8.2603	6.5116	14.270
T2	3.8218	4.7549	20.657	13.994	18.346	12.125	8.5316	19.237

Figure 4 shows the differences in roughness profiles of both analysed cases. The roughness profile of the duplex stainless steel surface after the turning with the T2 wedge has slightly deteriorated, which can be seen through tribological disturbances or through the wear of the cutting tool point. The higher values of the *Rt*, *Rp*, and *Rv* parameters on surface after the turning process using T2 wedge cause the occurrence of a sharp spike or burr on the surface. The sharp spike and burr cause damage to the seals and can cause cracks.

a)
b)

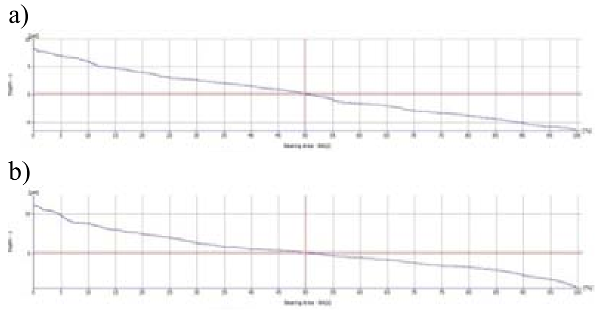

Fig. 3 Load capacity curves after turning a) T1 tool point b) T2 tool point

a)
b)

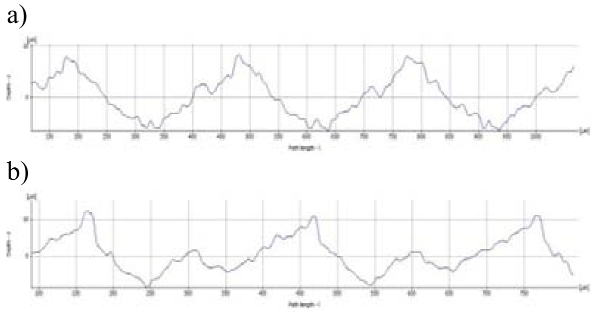

Fig. 4 Surface roughness profiles after turning a) T1 tool point b) T2 tool point

Figures 5 and 6 show histograms of the distribution of vertices and upgrades located on the analysed surfaces. It can be seen that the distribution of machined sample after the turning with the T1 wedge is characterized by a larger range of changes in the values of *R* group parameters.

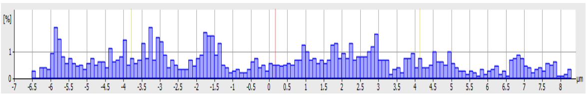

Fig. 5 Parameter histogram of roughness profile of a sample turned with the T1 tool point

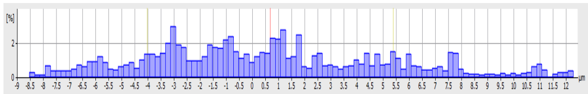

Fig. 6 Parameter histogram of roughness profile of a sample turned with the T2 tool point

3.2 Surface textures

The surface texture analysis has been performed by means of an Infinite Focus Measurement Machine. The geometrical structures of the surface shown below have been observed after longitudinal turning. Fig. 7a shows the preferential direction of a periodically iterated surface structure whereas Fig. 7b shows the surface dominated by low frequencies. *Sal* parameter (Table 5) after the turning with the T2 wedge has a higher value. *Str* and *Stdi* parameters have higher values after the turning with the T1 wedge; therefore, Fig. 7a presents the surface without the dominated preferred direction.

Table 5 Calculated parameters for auto correlations

Cutting tool	*Sal* [µm]	*Str*	*Std* [°]	*Stdi*
T1	63.31	0.26833	-90	0.22242
T2	142.86	0.18289	0	0.09157

a)
b)

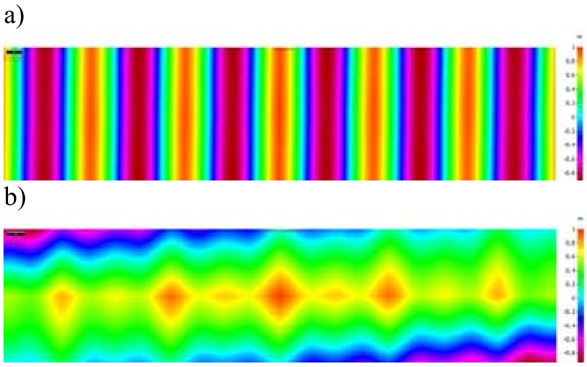

Fig. 7 Auto correlation of primary model after turning a) T1 tool point b) T2 tool point

a)
b)

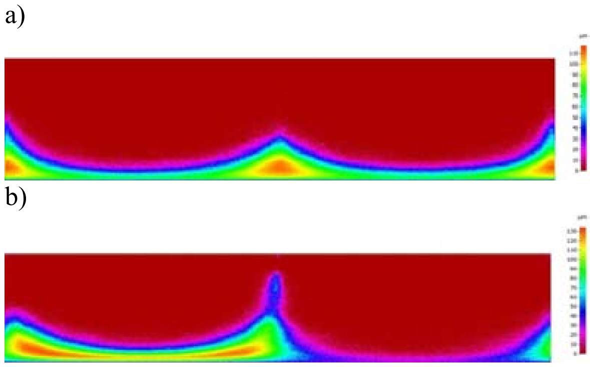

Fig. 8 Gradient distributions of primary model after turning a) T1 tool point b) T2 tool point

Fig. 8 shows the gradients of the surface of ISO Gradient Distribution. Both samples exhibited surfaces with steep gradients.

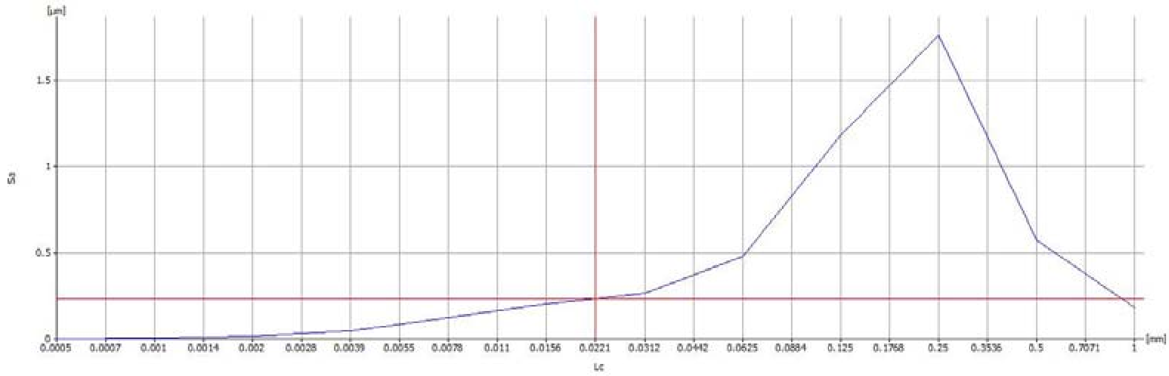

Fig. 9 Spectrum of sample after the turning with the T1 tool point of primary model

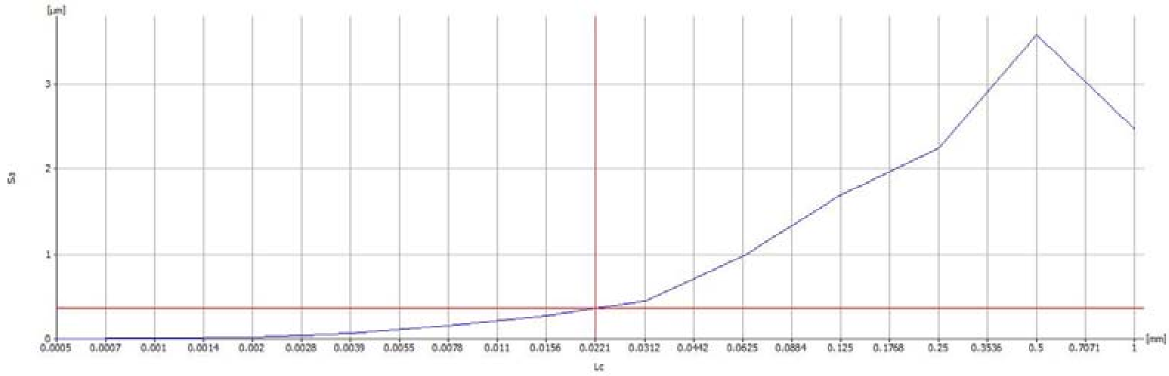

Fig. 10 Spectrum of sample after the turning with the T2 tool point of primary model

Figs 9 and 10 show two views of spectral distributions (Surface Texture Spectrum) of the selected region. The selected parameter was the *Sa* parameter (average height of selected area). Figs 9 and 10 show the selected parameter *Sa* in certain wavelength ranges. Due to the same machining parameters, the analysed surfaces have similar wavelength ranges but the sample turned with the T2 wedge is characterized by steep slopes.

4. Conclusions

Duplex stainless steel surfaces were machined by wedges with different cutting tool specification and with the same technological parameters. The machined surfaces were analysed using the novel method of analysis of surface integrity.

I. The examined surfaces are characterized by an anisotropic and periodical structure.
II. The roughness profile of the duplex stainless steel surface after the turning with the T2 wedge has slightly deteriorated, which can be seen through small tribological disturbances.
III. Distribution of machined sample after the turning with a cutting tool coated with a ceramic intermediate layer is characterized by a larger range of changes in the values of *R* group parameters.
IV. The surface after the turning with a cutting tool coated with a ceramic intermediate layer is characterized by preferential direction of a periodically iterated surface structure whereas the surface after the turning with the T2 tool point is characterized by a surface dominated by low frequencies.
V. The turning process with analysed parameters of machined surface is characterized by steep slopes.

REFERENCES

[1] Hloch, S., Valíček, J., Kozak, D.: Preliminary results of experimental cutting of porcine bones by abrasive waterjet, Tehnički Vjesnik - Technical Gazette, 18, 3, 467-470, 2011.

[2] Krolczyk, G., Legutko, S., Krolczyk, J., Tama, E.: Materials flow analysis in the production process – case study, Applied Mechanics and Materials, 474, 97–102, 2014.

[3] Madl, J., Razek, V., Koutny, V., Kafka, J.: Surface integrity in notches machining, Manufacturing Technology, 2, 13, 188-193, 2013.

[4] Zeleňák, M., Valíček, J., Hloch, S., Kozak, D., Samardžić, I., Harničárová, M., Klich, J., Hlaváček, P., Cincio, R.: Comparison of mechanical properties of surface layers with use of nanoindentation and microindentation tests, Metalurgija, 51, 3, 309-312, 2012.

[5] Neslušan, M., Mrkvica, I., Čep, R., Kozak, D., Konderla, R.: Deformations after heat treatment and their influence on cutting process, Tehnički Vjesnik - Technical Gazette, 18, 4, 601-608, 2011.

[6] Benardos, P.G., Vosniakos, G.C.: Predicting surface roughness in machining: a review, International Journal of Machine Tools & Manufacture, 43, 833–844, 2003.

[7] Čep, R., Janásek, A., Martinický, B., Sadílek, M.: Cutting tool life tests of ceramic inserts for car engine sleeves, Tehnički Vjesnik - Technical Gazette, 18, 2, 203-209, 2011.

[8] Krolczyk, G., Legutko, S., Gajek, M.: Predicting the surface roughness in the dry machining of duplex stainless steel (DSS), Metalurgija, 52, 2, 259-262, 2013.

[9] Mahovic Poljacek, S., Risovic, D., Furic, K., Gojo, M.: Comparison of fractal and profilometric methods for surface topography characterization, Applied Surface Science, 254, 3449–3458, 2008.

[10] Krolczyk, J., Tukiendorf, M.: Research on the impact mass fractions of Multi-element granular structure on the mixing process, International Agrophysics, 22, 45-52, 2008.

[11] Krolczyk, G., Gajek, M., Legutko, S.: Predicting the tool life in the dry machining of duplex stainless steel, Eksploatacja i Niezawodnosc – Maintenance and Reliability, 15, 1, 62–65, 2013.

[12] Krolczyk, G., Gajek, M., Legutko, S.: Effect of the cutting parameters impact onto tool life in duplex stainless steel turning process, Tehnički Vjesnik - Technical Gazette, 20, 4, 587-592, 2013.

[13] Krolczyk, G., Legutko, S., Raos, P.: Cutting wedge wear examination during turning of duplex stainless steel, Tehnički Vjesnik - Technical Gazette, 20, 3, 413-418, 2013.

[14] Yao, C.F., Jin, Q.C., Huang, X.C., Wu, D.X., Ren, J.X., Zhang, D.H.: Research on surface integrity of grinding Inconel 718, International Journal of Advanced Manufacturing Technology, 65, 1019–1030, 2013.

[15] Axinte, D.A., Dewes, R.C.: Surface integrity of hot work tool steel after high speed milling experimental data and empirical models, Journal of Materials Processing Technology, 127, 325–335, 2002.

[16] Krolczyk, G., Nieslony P., Legutko S.: Microhardness and Surface Integrity in turning process of duplex stainless steel (DSS) for different cutting conditions, Journal of Materials Engineering and Performance, 23, 3, 859–866, 2014.

[17] Grzesik, W., Bartoszuk, M., Nieslony, P.: Finite difference method-based simulation of temperature fields for application to orthogonal cutting with coated tools, Machining Science and Technology, 9, 4, 529-546, 2005.

[18] Schroettner, H., Schmied, M., Scherer, S.: Comparison of 3D Surface Reconstruction Data from Certified Depth Standards Obtained by SEM and an Infinite Focus Measurement Machine (IFM), Microchimica Acta, 155, 279–284, 2006.

[19] Nielsen, H.S.: New approaches to surface roughness evaluation of special surfaces, Precision Engineering, 10, 4, 209–213, 1988.

[20] Sedlacek, M., Podgornik, B., Vizintin, J.: Influence of surface preparation on roughness parameters, friction and wear, Wear, 266, 482–487, 2009.

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