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STUDY OF THE SURFACE INTEGRITY MICROHARDNESS OF AUSTENITIC STAINLESS STEEL AFTER TURNING

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Original scientific paper
The objective of the investigation was to determine the surface integrity (SI) microhardness of austenitic stainless steel after turning with coated carbide tool point. Surface integrity is important in determining corrosion resistance, and also in fatigue crack initiation. The investigation included analysis of microhardness of SI for different cutting parameters in dry turning process of 1.4541 austenitic stainless steel. It has been shown that increase of cutting speed leads to the increase of SI hardening depth. The study has been performed within a production facility during the production of electric motor parts and deep-well pumps.

Keywords: *austenitic stainless steel, coated inserts, machining, microhardness, surface integrity*

Analiza mikrotvrdoće integriteta površine austenitnog nehrđajućeg čelika nakon tokarenja

Izvorni znanstveni članak
Cilj je istraživanja bio odrediti mikrotvrdoću integriteta površine (SI) austenitnog nehrđajućeg čelika nakon tokarenja vrhom alata obloženog karbidom. Integritet površine je važan kod određivanja otpornosti koroziji kao i pojave pukotine kod zamora materijala. Istraživanje je obuhvatilo analizu mikrotvrdoće SI za različite parametre rezanja u postupku suhog tokarenja austenitnog nehrđajućeg čelika 1.4541. Pokazalo se da povećanje brzine rezanja dovodi do povećanja dubine kaljenja SI. Analiza je provedena u proizvodnoj hali tijekom proizvodnje dijelova električnog motora i dubinskih pumpi.

Ključne riječi: *austenitni nehrđajući čelik, integritet površine, mikrotvrdoća, obloženi umetci, strojna obrada*

1 Introduction

Machining process is the most common process in the production of machine parts [1]. Machining process causes usually highly tensile stresses in the machined surface. The machining of stainless steel inherently generates high cutting temperature, which not only reduces tool life but also impairs the workpiece surface quality [2]. Obtaining the desired surface quality is very important for the functional maintenance of a part. One of the stainless steel family materials most commonly used in the production facility is steel with austenitic structure. The austenitic stainless steels structure is a combination of good mechanical properties and good corrosion resistance. To utilize the useful properties of austenitic microstructure is necessary to study surface integrity of dry machined stainless steels. Surface integrity can be defined as a set of various properties (superficial and in-depth) of an engineering surface that affect the performance of this surface in service [3]. Byrne et al. [4] consider that the machining process of various types of steel can be performed under dry cutting conditions eliminating environmental problems associated with cutting fluids and this trend of dry machining will continue. To ensure better surface integrity, special attention must be paid to choosing cutting parameters [5 ÷ 10], tool material and geometry [11, 12] and tool coatings [13]. Surface integrity is important for the components adapting to high thermal and mechanical loads during their applications [14, 15]. One of surface integrity physical parameters is microhardness. According to Solomon and Solomon [16] in the case of materials with austenitic structure plastic deformation can induce transformation of austenite into martensite. The material properties of austenitic stainless steel are highly dependent on the transformation of the FCC system (Face Centered Cubic) in BCC system (Body Centered Cubic). The transformation may occur during the heat treatment or under the influence of mechanical deformation [17]. According to Kundrak et al. [18] turning performed at high speed is an intensive technology in terms of the heat generated in the process. The temperature of the workpiece material in the cutting edge area may reach the transformation temperature. Sasahara [19] demonstrated, using 0,45 % C steel test material that the feed rate did not affect the surface hardness for values between 0,05 and 0,4 mm/rev. Ezugwu et al. [20] demonstrated that the cutting tool geometry in machining nickel-based alloys represents an important parameter in tool life and in the quality of the machined surface. Ezugwu and Tang [21] have found that machined surface obtained with the rhomboid shaped insert has a higher microhardness as compared to the round inserts. Pawade et al. [22] based on the microhardness measurements of Inconel 718, showed that the sub-surface microhardness at a depth of 30 μm varies between 370 and 490 HV. Coelho et al. [23] investigated surface and sub-surface microhardness of Inconel 718 and observed that the microhardness values were slightly higher at cutting speed 70 m/min. Javidi et al. [24] showed that plastic deformation of the grain boundaries was found in the subsurface layer. They also confirmed that no significant variation in hardness was observed beneath the machined surface obtained by different cutting conditions. The study of surface parameters and cutting force in the turning of austenitic steels was described by Fernández-Abia et al. [25]. Their research did not provide the results of the influence of machining on microhardness of SI (Surface Integrity). Such a study for 1.4301 steel was presented by Yan et al. [26], but without researching the impact of cutting speed on microhardness of SI.

This paper focuses on research problems related to the microhardness as a physical parameter of surface integrity after turning by coated carbide tools in dry turning process of stainless steel 1.4541. The main purpose of this study was to determine the effect of cutting parameters as a key process factor in controlling surface microhardness.

2 Experimental techniques

The machined material was stainless steel 1.4541 (DIN EN 10088-1), steel with austenitic structure. 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 1.4541 austenitic stainless steel

Element	C	Si	Mn	P	S	Cr	Ni	Ti
wt. %	0,014	0,55	1,67	0,031	0,012	17,76	9,1	0,1

Table 2 Cutting tool specification

Tool	Coatings
MM 2025 Grade: M25, P35 Coating technique: CVD	Top layer - Ti(C,N) – 2 µm Middle layer - Al_2O_3 – 1,5 µm Bottom layer - TiN – 2 µm

Cutting tool inserts of TNMG 160408 designation clamped in the tool shank of ISO-MTGNL 2020-16 type were employed. Based on the industry recommendations a range of cutting parameters was selected: v_C = 50 ÷ 150 m/min, f = 0,2 ÷ 0,4 mm/rev, a_p = 1 mm. The study was conducted within a production facility. The research program was carried out on a lathe CNC 400 CNC FamotFamot - Pleszew plc.

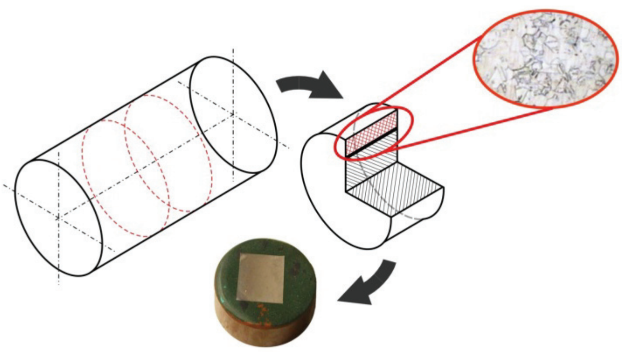

Figure 1 Method of sample preparation for microhardness testing

The Fig. 1 shows how the pieces were separated from the initial specimen for the microhardness measurements analysis (from bar material to microhardness sample). The measurements of microhardness have been performed into the depth of material along a straight line perpendicular to the machined surface (radially). In the testing schedule, it was assumed that microhardness would be measured down to the depth for which hardness comparable to that of the core was obtained. The first point of microhardness measurement was located at the distance of up to 20 µm from the machined surface, depending on the profile hump or caving. The second measurement was performed at the depth of 40 µm, the successive ones were performed at 20 µm intervals till the hardness of the core was obtained. The microhardness measurements were effected by MHV-2000. The load of an intender was adopted in accordance with the standard PN-EN ISO 6507-1. The standard limits the time of the load increase until the required force F is obtained to 15 s. Therefore, the safe time of 10 s and the intender's load 0,49 N were assumed. After the cutting made in a cut-off machine with abundant abrasive disc and water fluid, the samples were prepared using standard metallographic techniques (grinding, polishing and etching).

3 Results and discussion

The microhardness as a physical parameter of SI characteristics depends on numerous factors, technological parameters, stereometry and micro-geometry of a cutting edge, among others. In the process of the surface layer formation, the speed of machining is very important. It is a parameter which significantly determines the intensity of heat generated in the machining zone. It can be assumed that heat penetrating the surface layer of the machined material will influence the functionality of its surface, microhardness, among others. Therefore, the research focused on establishing an influence of the feed and cutting speed on the microhardness of Surface Integrity.

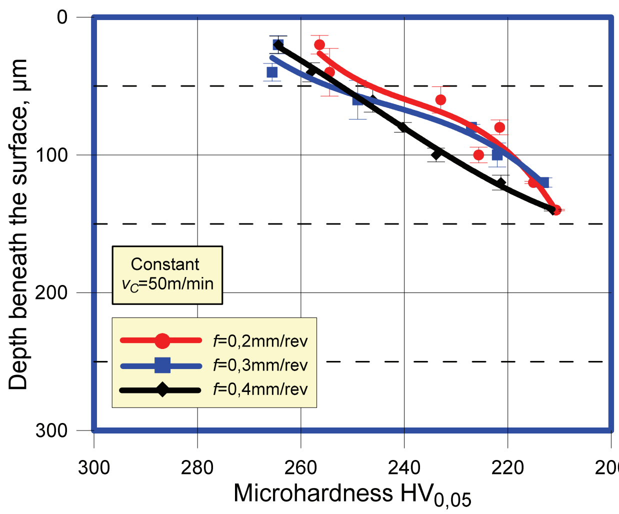

Figure 2 Influence of the feed on the microhardness of surface layer after turning austenitic stainless steel (v_C = 50 m/min, a_p = 1 mm, dry cutting)

Fig. 2 presents the influence of feed on SI microhardness for constant speeds and depths of cut (v_C = 50 m/min, a_p = 1 mm). The biggest values of microhardness were obtained for the feed f = 0,3 and 0,4 mm/rev, the smallest ones for f = 0,2 mm/rev. The microhardness values fluctuate within the range from 250 to 270 $HV_{0,05}$. The value of the hardening depth for constants v_C = 50 m/min and a_p = 1 mm for the analysed feeds is 140 µm.

Another analysed case presented in Fig. 3 concerns the measurements of SI microhardness for variable feed and constants v_C = 100 m/min and a_p = 1 mm, analogously to the previously analysed cases for machining without the use of a cooling and lubricating substance. For the discussed feeds within the range from 0,2 to 0,4 mm/rev no significant changes in SI microhardness were observed, that is the depth of hardening for all the studied feed values was 220 µm. The initial measured value of microhardness situated under the machined surface of the studied austenitic steel is within the range from 270 to 290 $HV_{0,05}$. For the analyzed value of feed we can observe a monotonic and moderate drop of the value of SI microhardness. Moreover, the results of the presented experiments characterize small fluctuations of changes, which is proven by the standard deviation values. In the analyzed case, we can observe the lack of an influence of feed on SI microhardness. There is no influence on the depth of hardening of the biggest value of microhardness $HV_{0,05}$.

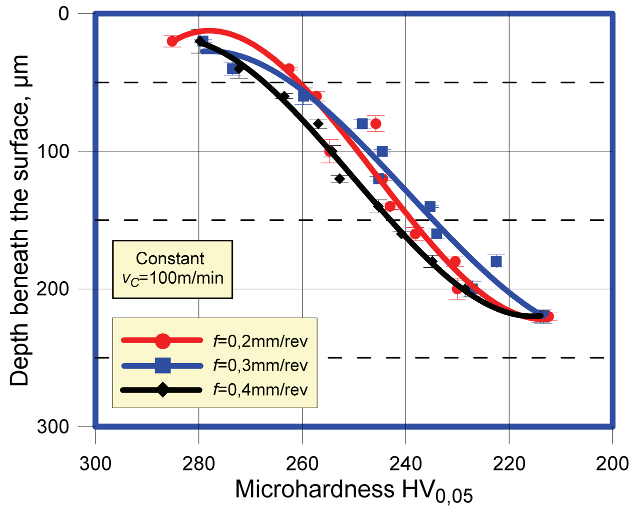

Figure 3 Influence of the feed on the microhardness of surface layer after turning austenitic stainless steel (v_C = 100 m/min, a_p = 1 mm, dry cutting)

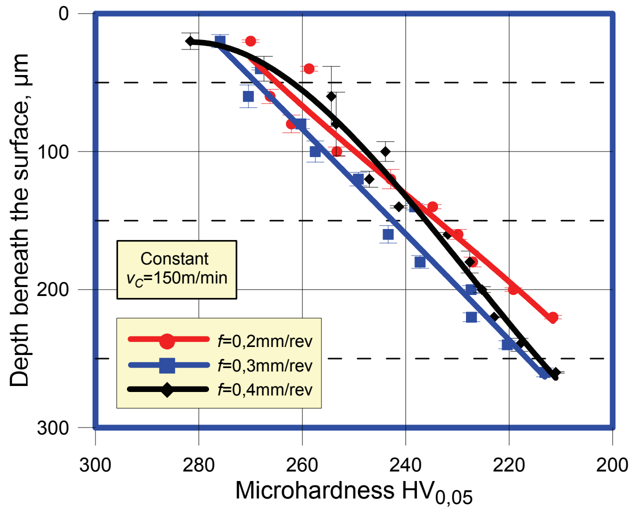

Figure 4 Influence of the feed on the microhardness of surface layer after turning austenitic stainless steel (v_C = 150 m/min, a_p = 1 mm, dry cutting)

The other analyzed case illustrated in Fig. 4 concerns the measurements of SI microhardness for variable feed and constants v_C = 150 m/min and a_p = 1 mm. For the biggest studied speed of machining, the microhardness values do not basically differ in the angle of the drop of values of microhardness $HV_{0,05}$ and the depth of hardening shapes on the similar level as for the value v_C = 100 m/min, namely at the level of 220 ÷ 260 µm. The average value of the biggest microhardness fluctuates as for v_C = 100 m/min within the range from 270 to 290 $HV_{0,05}$.

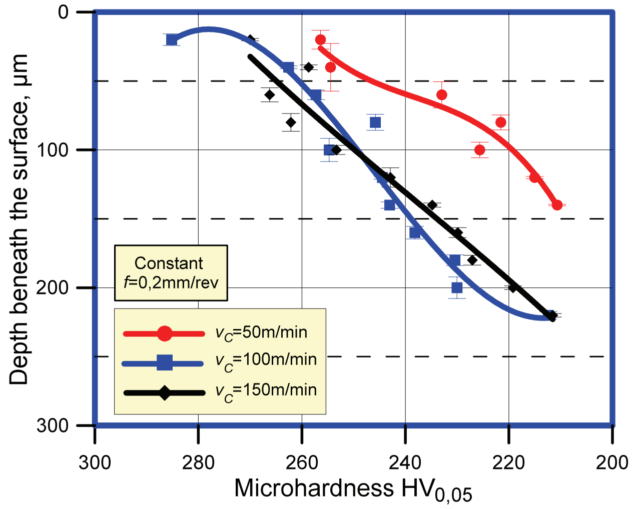

Figure 5 Influence of the cutting speed on the microhardness of surface layer after turning austenitic stainless steel (f = 0,2 mm/rev, a_p = 1 mm, dry cutting)

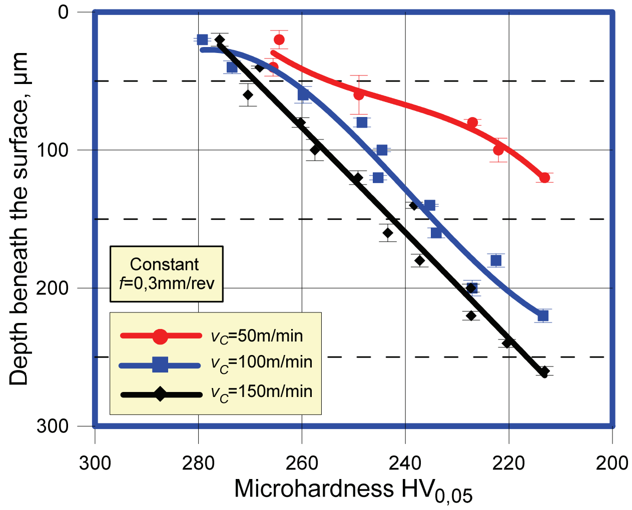

Figure 6 Influence of the cutting speed on the microhardness of surface layer after turning austenitic stainless steel (f = 0,3 mm/rev, a_p = 1 mm, dry cutting)

The findings of the research into the influence of the machining speed on the microhardness of the studied austenitic steel surface layer are presented in Fig. 5. Turning took place with the use of an edge of cemented carbide covered with a coating with an intermediate ceramic layer, for the feed f = 0,2 mm/rev and the constant depth of cut a_p = 1 mm; dry machining. The results are presented in the form of graphs, as the arithmetic mean of three measurements of microhardness with standard deviation. The biggest values of microhardness were obtained for the speed v_C = 100 m/min. They were obtained for the layer closest to the machined surface, namely at the depth of up to 20 µm. In this case, microhardness was over 280 $HV_{0,05}$. For the speed of machining 150 m/min, the microhardness obtained in this area was by 15 % smaller on average, whereas for v_C = 50 m/min, the observed microhardness was smaller by 30 %. Alongside departing from the surface, the SI microhardness decreases, in the analyzed case reaching the hardness of the core at the depth of about 140 µm for v_C = 50 m/min and 220 µm for v_C = 100 and 150 m/min. In Fig. 4, we can observe a monotonic and smooth decrease in the SI microhardness values for

v_C = 150 m/min, whereas the microhardness for the remaining analysed speeds of machining (v_C = 50 and 100 m/min) is characterized by a sharp angle of the drop of values to the depth of 60 µm. The reason for that may be a non-uniform deformation of the material, and thus the strengthening of austenite in the subsurface layer.

Fig. 6 presents the results of the measurements of SI microhardness as a function of machining speed after turning with the edge MM 2025, for the feed f = 0,3 mm/rev and the constant depth of cut a_p = 1 mm, also for the machining without the use of a cooling and lubricating substance. The biggest values of microhardness were obtained for the speed v_C = 100 and 150 m/min – at the level of 275 $HV_{0,05}$, whereas SI microhardness for a smaller speed of machining shapes at the level of about 265 $HV_{0,05}$. Alongside an increase in the speed of machining, microhardness after turning steel 1.4541 for the feed f = 0,3 mm/rev goes up, reaching hardness of the core at the depth of 120 µm for v_C = 50 m/min, 220 µm for v_C = 100 m/min and 260 µm for v_C = 150 m/min. For the speed of machining v_C = 100 and 150 m/min, we can observe a monotonic decrease in the value of SI microhardness, whereas in case of the speed of machining v_C = 50 m/min, there are considerable fluctuations of changes in the values and their sharp drop. Bigger depth of hardening for an increase in the speed of machining is probably caused by a higher temperature in the machining process. Alongside an increase in the machining speed a bigger amount of heat is generated, and the heat penetrates the machined material deeper.

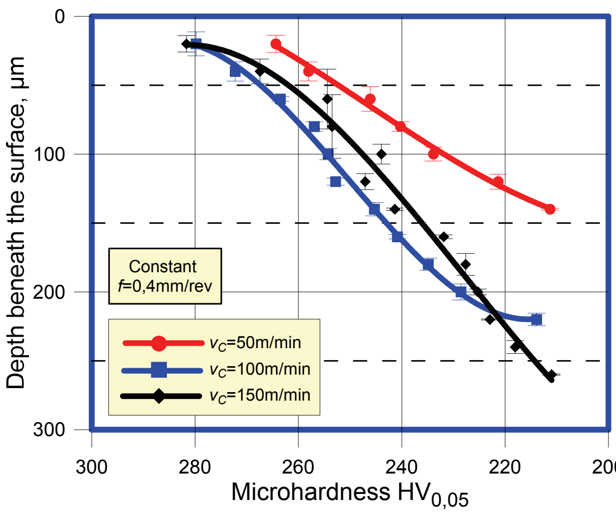

Figure 7 Influence of the cutting speed on the microhardness of surface layer after turning austenitic stainless steel (f = 0,4 mm/rev, a_p = 1 mm, dry cutting)

Last analyzed case illustrated in Fig. 7 concerns the results of the SI microhardness measurements for the variable speed of machining and constants f = 0,4 mm/rev and a_p = 1 mm. For the biggest studied feed, the depth of hardening shapes at the level of 140 ÷ 260 µm, namely the range of the depth of hardening shapes in a similar way like for the average values of the analysed feeds. The biggest average values of microhardness were obtained for the speed v_C = 100 and 150 m/min and they were equal to 280 $HV_{0,05}$. On the other hand, the smallest values of microhardness 265 $HV_{0,05}$ were obtained for the speed of machining v_C = 50 m/min. For the studied speeds of machining we can observe a monotonic decrease in the value of SI microhardness. For the analysed values of machining speed and the biggest feed, we can observe big fluctuation of changes in the biggest values of SI microhardness within the range from the surface of the machined material to 80 µm.

4 Conclusions

In machining of austenitic stainless steel, the following difficulties occur: it is difficult to control the chip, there are excessive thermal and mechanical loads on the tool point. The results obtained in the present work allow us to draw the following conclusions:

1) Maximum microhardness for turning austenitic steel within the studied range of technological parameters reaches the value of up to 285 $HV_{0,05}$.
2) The depth of SI hardening after turning austenitic steel 1.4541 with the edge of cemented carbide covered with a coating with an intermediate ceramic layer for the studied range of technological parameters reaches 260 µm.
3) An increase of the machining speed within the range from 50 to 150 m/min brings about an increase of the value of the maximum SI microhardness of 1.4541 steel to 5 % but raises the depth of hardening by an average value of 83 %.
4) No significant influence of feed on the value of SI microhardness of steel 1.4541 with austenitic structure was observed.
5) It would be necessary to conduct research into the SI structure for the studied ranges of machining parameters, which would enable presentation of physical interpretation of the achieved results.

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