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MICROHARDNESS CHANGES GRADIENT OF THE DUPLEX STAINLESS STEEL (DSS) SURFACE LAYER AFTER DRY TURNING

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The article presents the gradient of microhardness changes as a function of the distance from the material surface after turning with a wedge provided with a coating with a ceramic intermediate layer. The investigation comprised the influence of cutting speed on surface integrity microhardness in dry machining. The tested material was duplex stainless steel (DSS) with two-phase, ferritic-austenitic structure. The tests have been performed under production conditions during machining of parts for electric motors and deep-well pumps.

Key words: microhardness, duplex stainless steel, machining, surface integrity, turning

INTRODUCTION

Duplex stainless steels with double ferritic-austenitic structure are widely applied in industry. Good combination of their mechanical properties (high strength and crack resistance), as well as corrosion resistance, results in that this kind of steel is often used in various branches of industry [1, 2]. In order to take advantage of the two-phase microstructure properties, examination of the quality of machined surfaces is necessary. Surface Integrity (SI) is a measure of the machined surface quality and it is interpreted as a set of elements describing both the structure of the surface and the one under the surface [3]. SI is usually defined by mechanical, metallurgical, chemical and topological surface properties. It is particularly important in production of expensive machine parts of complex shapes. The process of turning ferritic-austenitic steels at high cutting speeds generates heat [4] and the temperature of the machined material can reach the temperature of transformation. The characteristic values describing hardening are: hardening depth, maximum hardness, maximum hardness gradient and hardness increase [5]. The maximum hardness is the one occurring at the machined surface. In the vicinity of the material surface, usually at the depth where the highest stresses were present, the maximum gradient of hardness is located. Hardening as result of deformation degrees of the surface layer depends on the method of manufacturing [6–8]. All the factors resulting in increasing of the cutting force cause increase of hardening. Hardening is particularly strongly influenced by the cutting edge rounding radius [9]. Increase of the rounding results from the wedge blunting, which results in an increase of the surface roughness, too. Two-phase duplex steels are considered to be a hard-to-machine material. Build-up-edge and unstable wedge wear often take place during the process of machining [10]. This deteriorates the quality of the surfaces being machined and reduces the life of the object under machining. Measurements of stainless steel microhardness are the object of investigation of many scientists [11–15]. In those publications, special attention is drawn to the cutting tools and their influence on the condition of the surface layer, but the works do not describe extensively the physical and geometrical parameters of the two-phase steel surface integrity in the process of turning.

This work presents investigation problems concerning surface integrity after turning with coated sintered carbide wedges. The major purpose of the investigation was to determine the geometrical parameters of surface integrity used to establish the utilization properties in the production process. The authors' earlier investigations concerned prediction of the tool life and wear [16, 17], as well as surface roughness during dry machining of DSS. The question of surface integrity has not been considered in those publications.

METHODOLOGY OF INVESTIGATION

The purpose of the article is to present selected features surface integrity of ferritic-austenitic steel after turning with coated sintered carbide wedges. Measurements of surface integrity microhardness for various cutting speeds have been presented and analysed. The work presents the microhardness change gradient, as well as surface roughness.

The material under machining was 1,4462 steel (acc. to DIN EN 10088-1) with ferritic-austenitic structure containing about 50 % of austenite. Its tensile strength

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was R_m = 700 MPa, Brinell hardness 293 HB. The technical data of the cutting tool can be found in Table 1.

Table 1 **Cutting tool specification**

T1	Hardness:	Coatings: Ti(C,N) - (2 μm) (top layer)
	1350 HV3	Al_2O_3 - (1,5 μm) (middle layer)
	Grade:	TiN - (2 μm) (bottom layer)
	M25, P35	Coating technique: CVD

The cutting tool of TNMG 160408 geometry has been fixed in a clamping holder ISO-MTGNL 2020-16. Basing on the industrial recommendations and on the conclusions from our own earlier investigations [17, 18], the range of machining parameters has been selected: v_c = 50 ÷ 150 m/min, f = 0,3 mm/rev, a_p = 2 mm. The tests have been performed under production conditions on a numerically controlled lathe, FAMOT 400 CNC made by Famot – Pleszew plc. The cutting edge rounding radius r_n was 0,047 mm.

ANALYSIS OF THE SURFACE INTEGRITY MICROHARDNESS MEASUREMENT RESULTS

The absolute value of the derivative of the approximating polynomial should be interpreted as the gradient of microhardness changes per the adopted unit of the distance from the material surface. The value of the derivative itself corresponds to the gradient for the point of the middle of the range for which it had been determined. The character of the HV 0,05 gradient changes as a function of the distance from the machined surface for various v_c has been shown separately for ferrite and austenite in Figure 1.

The microhardness changes have been found to be most intensive for low cutting speeds. In the immediate surface layer (up to 10 μm), the gradient reaches a value of over 0,5 $HV_{0,05}$/μm (Figure 1). In relation to higher v_c, it is almost 100% increase. It is interesting that the significant changes of the microhardness gradient shapes are related to the cutting speeds of up to 100 m/min (Figure1 – curves 1 and 2). In that range, one can see some correlation of their characteristics, particularly for the ferritic structure (Figure 1a – curves 1 and 2).

The increase of v_c has determined the acquisition of monotonically decreasing functions of the $HV_{0,05}$ gradients for austenite and ferrite, with clear boundaries of microhardness stabilisation ($HV_{0,05}$ ~ 0 – Figure 1 – area A).

When analysing the results obtained, one can find that the gradient of microhardness changes drop drastically with the increase of the cutting speed. For v_c = 150 m/min, clearly less hardening depth of technological surface layer, has been obtained. In the case of duplex stainless steel, therefore, the cutting speed is an important technological parameter, significantly influencing the depth of hardening of the machined surface layer.

The microhardness gradient changes for both phases of duplex steel as a function of the distance from the material surface have been shown as separate curves in Figure 2. The microhardness of austenite, for all the analysed v_c values, decreased quickest in the zone near the material surface. In the curves of Figure 2, one can clearly distinguish two zones of microhardness changes.

The first one, near the surface, with high values of $HV_{0,05}$ changes (Figure 2 – zone I), monotonically decreasing, and the other where the $HV_{0,05}$ gradient stabilizes or fluctuates insignificantly till it reaches the hardness of the core (Figure 2 – zone II).

It has been observed that, in zone II, the gradient of ferrite microhardness grows and is larger than that of austenite. This concerns mainly lower speeds v_c = 50 and 100 m/min. This can be due to the larger hardness of austenite and, consequently, the necessity of apply-

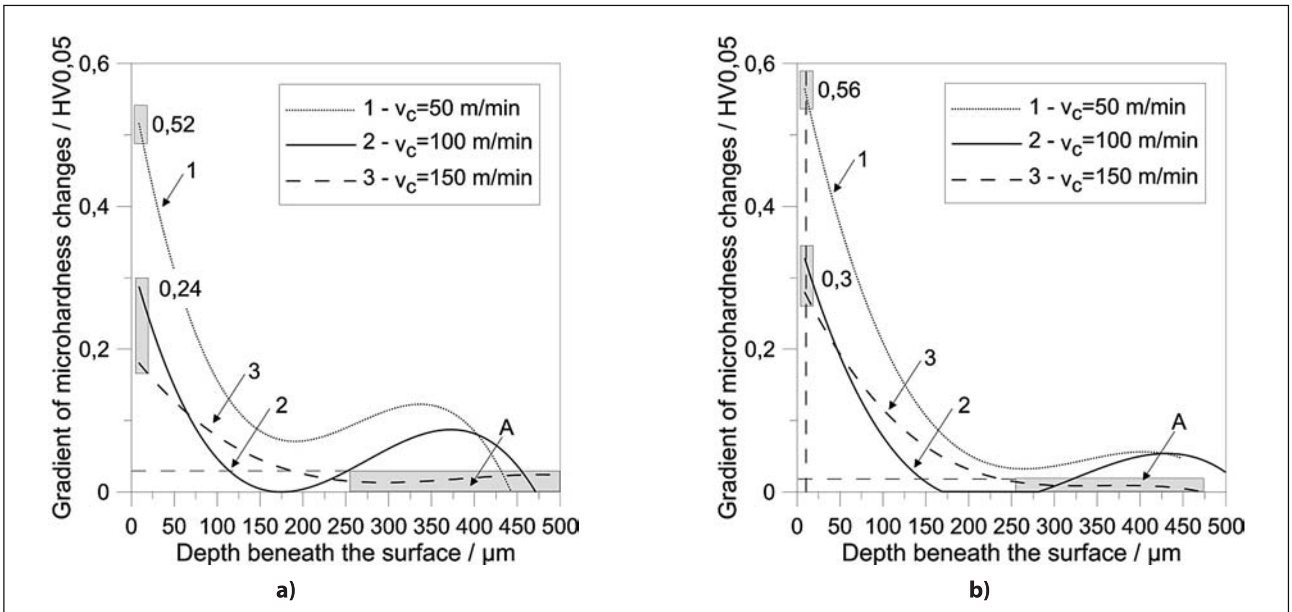

Figure 1 Gradient of microhardness changes as a function of the distance from the material surface for various cutting speeds for ferrite (a) and austenite (b), with f = 0,3 mm/rev, a_p = 2 mm

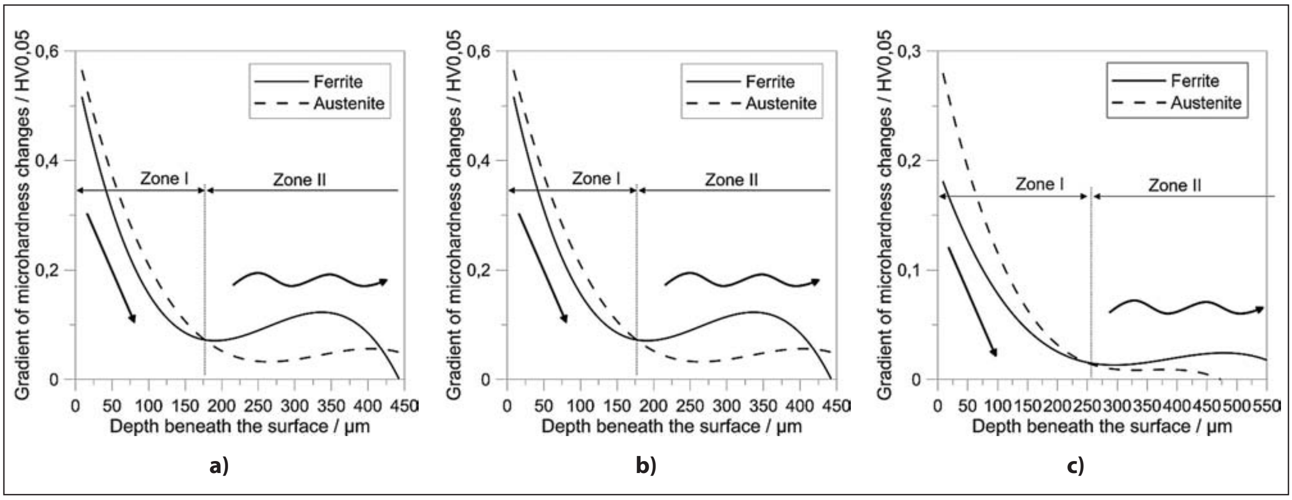

Figure 2 Comparison of microhardness changes gradient of ferrite and austenite as a function of the distance from the material surface for the cutting speed of 50 m/min (a), 100 m/min (b) and 150 m/min (c) (f = 0,3 mm/rev, a_p = 2 mm)

ing higher energies to increase the hardening of this phase of duplex steel. In the deeper SI layers, the stream of supplied energy is smaller. However, the energy which gets to those layers suffices to increase the intensity of deformation consolidation of ferrite. It is additionally favourably influenced by the significant reduction of austenite deformation.

Basing on the investigation performed so far and mathematical analyses, it can be stated that cutting speed has a significant influence on the distribution of microhardness in the individual duplex stainless steel phases within the technological surface layer. It has been observed that $HV_{0.05}$ value of austenite and ferrite decreases with the increase of v_c. The cutting speed influences also the depth of SI hardening. The depth of the hardened layer decreases with the increase of v_c.

Moreover, using the simple mathematical tool in the form of the function of approximation of experimental points and determination of the first order derivative, it was possible to establish the intensity of microhardness changes. Their highest intensity has been observed for v_c = 50 m/min in the surface layer. Increase of v_c up to 100 and 150 m/min resulted in the gradient reduction even by as much as 50 % for both phases under investigation. The cutting speed is, therefore, a technological parameter which can be applied to control the depth and intensity of microhardness changes of DSS.

CONCLUSIONS

Basing on the analysis of SI microhardness of duplex steel after turning with a coated carbide wedge with an intermediate ceramic layer, one can draw the following conclusions and make investigation observations:

1. The highest intensity of microhardness changes has been observed for v_c = 50 m/min in the surface layer.
2. Cutting speed increase up to 100 and 150 m/min resulted in the gradient reduction by as much as 50 % in the case of both duplex stainless steel phases under investigation.
3. Two characteristic zones of the microhardness gradient changes have been observed.

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Note: The responsible translator for English language is lecturer from Poznan University of Technology, Poland