G. KROLCZYK, P. NIESLONY, S. LEGUTKO, I. SAMARDZIC

ISSN 0543-5846
METABK 54(1) 87-90 (2015)
UDC – UDK 669.15:620.178.1:621.9=111

INVESTIGATION OF THE PHYSICAL PARAMETERS OF DUPLEX STAINLESS STEEL (DSS) SURFACE INTEGRITY AFTER TURNING

Received - Primljeno: 2014-02-07
Accepted – Prihvaćeno: 2014-07-20
Original Scientific Paper – Izvorni znanstveni rad

The article presents the influence of machining parameters on the microhardness of surface integrity (SI) after turning by means of a coated sintered carbide wedge with a coating with ceramic intermediate layer. The investigation comprised the influence of cutting speed on the SI microhardness in dry machining. The material under investigation was duplex stainless steel with two-phase ferritic-austenitic structure. The results obtained allow for conclusions concerning the exploitation features of processed machine parts.

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

INTRODUCTION

Among the methods of checking the properties of materials being formed, the most often used ones are hardness measurements. The wide use of hardness measurements is due to the simple design of the devices necessary to measure hardness, low labour consumption of the measurement, possibility of measurement performing on relatively small samples or directly on the ready-made object [1, 2]. It is an unquestioned advantage of the hardness measurements that, basing on them, one can draw conclusions concerning of the mechanical properties. In microhardness tests, the plunger is loaded with a force lower than 9,8 N. The application of so small loads is due to the necessity of measuring the hardness of the individual structural components of alloys [3]. SI microhardness of metal parts influences the exploitation features of the machined parts. Hardening of metal surfaces as the result of various forming methods is due to excessive plastic deformation, as well as to residual stresses [4, 5] and is an effect of surface deformation. Hardening changes the exploitation features of parts during their operation, too, e.g. shafts or air valves, hence checking machine parts hardness in micro scale is necessary. Maximum hardness is the hardness of material usually appearing near the machined surface. Hardening as result of cold work of the surface layer depends on the machining conditions. All the factors causing increase of the cutting force cause an increase of hardening. Hardening is particularly influenced by the radius of the cutting edge rounding [6]. Increase of the cutting edge rounding results from the wedge blunting, which results in an increase of the surface roughness, too. Surface hardness checking is not difficult in the case of metals with one-phase structure; checking of parts made of two-phase materials, on the other hand, requires manual selection of the measurement location. DSS belong to this kind of materials. DSS with ferritic-austenitic structure are widely used in industry. Good combination of their mechanical properties (high strength and crack resistance) as well as corrosion resistance result in that DSS is widely used, particularly in the oil, chemical industry, as well as in power industry [7-10]. Two-phase DSS are considered to be a hard-to- machine material. Build-up-edge and unstable wedge wear often take place during the process of machining [11]. This deteriorates the quality of the surfaces being machined and reduces the life of the object under machining. In order to take advantage of the two-phase microstructure properties, examination of the machined surface quality is necessary. According to Jang et al [12], 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. 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. It is very important to check the steel microstructure, as well as its physical and mechanical properties. According to [13], in the case of materials with austenitic structure, plastic deformation can cause transformation of austenite into martensite. The process of turning with high cutting speeds generates heat [14] and the temperature of the material under machining in the cutting edge area may rise as high as the temperature of transformation. Sasahara [15] has shown in his investigations of steel with 0,45 % C content, using cutting wedges of various corner radius values, that the hardness of the surface being

G. Krolczyk, Opole University of Technology, Faculty of Production Engineering and Logistics, Opole, Poland; P. Nieslony, Opole University of Technology, Department of Manufacturing Engineering and Production Automation; S. Legutko, Poznan University of Technology, Institute of Mechanical Technology, Poznan, Poland; I. Samardzic, J.J. Strossmayer University of Osijek, Mechanical Engineering Faculty of Slavonski Brod, Slavonski Brod, Croatia.

machined increases with the reduction of the wedge corner radius. Moreover, he has proved that the feed does not influence hardness for the values between 0,05 and 0,4 mm/rev.

METHODOLOGY OF INVESTIGATION

The purpose of the paper is to present one of the physical parameters of SI of ferritic-austenitic DSS after turning with coated sintered carbide wedges. SI microhardness measurements for various cutting speeds have been presented and analysed. The examination results have been presented separately for each of the examined steel phases. The article presents also the functions approximating the sets of microhardness changing points together with their mathematical models. The material under processing was 1.4462 steel (DIN EN 10088-1) with ferritic-austenitic structure containing about 50 % of austenite. The technical data of the cutting tool can be found in Table 1.

Table 1 **Cutting tool specification**

Tool	Substrate	Others
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 with the geometry TNMG 160408 has been fixed in a clamping holder, MTGNL 2020-16. Basing on the industrial recommendations and on the conclusions from our own earlier investigations [16 – 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.

Microhardness measurements have been performed in points located on a straight line from the turned surface into the depth of the material till a microhardness value close to that of the tested sample has been obtained. Ferrite and austenite hardness were measured. The first measurement point was at the distance of 1 to 10 μm from the surface, depending on the profile rise or indentation. The next measurements were performed at the depth of 25 μm and the subsequent ones every 50 μm. The microhardness measurements have been performed by microhardness tester MHV-2000. The plunger load has been in accordance with the standard PN-EN ISO 6507-1. The time of load 10 s and plunger load of 0,49 N have been adopted during the tests. In order to avoid mutual influence of indentations on each other, the distances between two neighbouring indentation centres should be at least three times larger than the average diagonal of an indentation.

SI MICROHARDNESS MEASUREMENT RESULTS AND THEIR ANALYSIS

One of the major aspects of the investigation was the determination of the correlation between the cutting speed and the change of SI microhardness. The microhardness was measured separately for the individual phases of DSS, i.e. for austenite and for ferrite. The measurement results for three cutting speeds, separately for the individual phases, are shown in Figure 1.

The distribution of SI microhardness, regardless of the cutting speed v_c was characterized by visible fluctuations. In Figure 1, the points represent average values of five measurements; confidence intervals have also been marked. The analysis of so defined microhardness change curves is problematic. That is why mathematical approximation of the set of experimental points with 4th degree polynomial curves has been performed. The selection of this kind of function was determined by the acquisition high matching coefficient R^2, for all the tested sets. The shape of the appropriate approximating functions can be seen in Figure 2. Math-

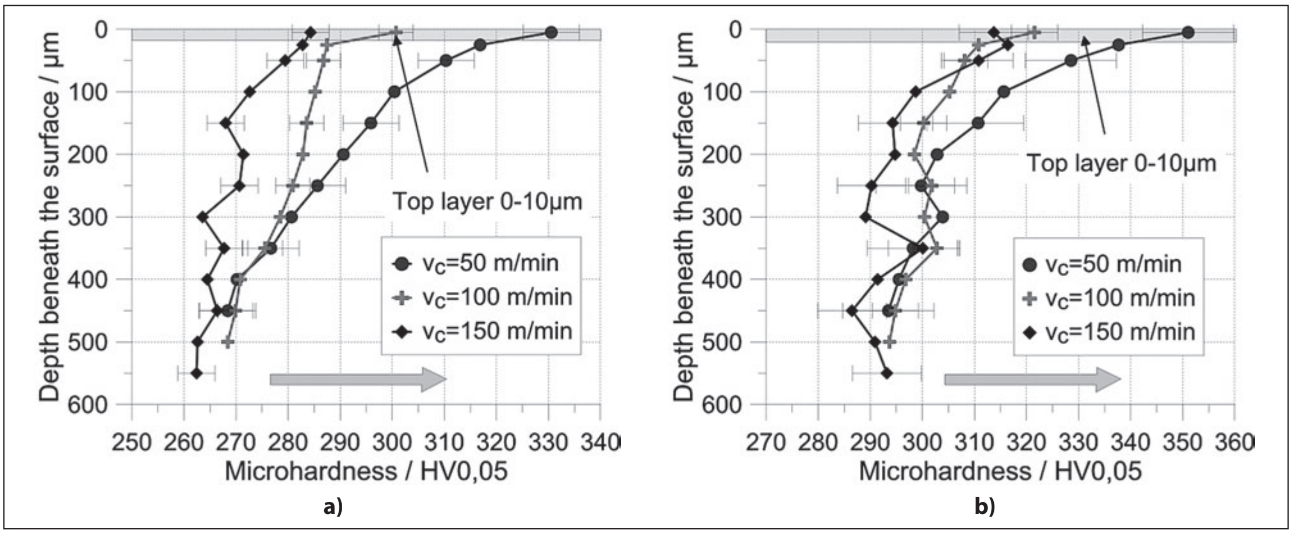

Figure 1 Comparison of DSS microhardness for various cutting speeds as a function of the distance from the machined surface measured for the grains of ferrite (a) and austenite (b) (f = 0,3 mm/rev, a_p = 2 mm)

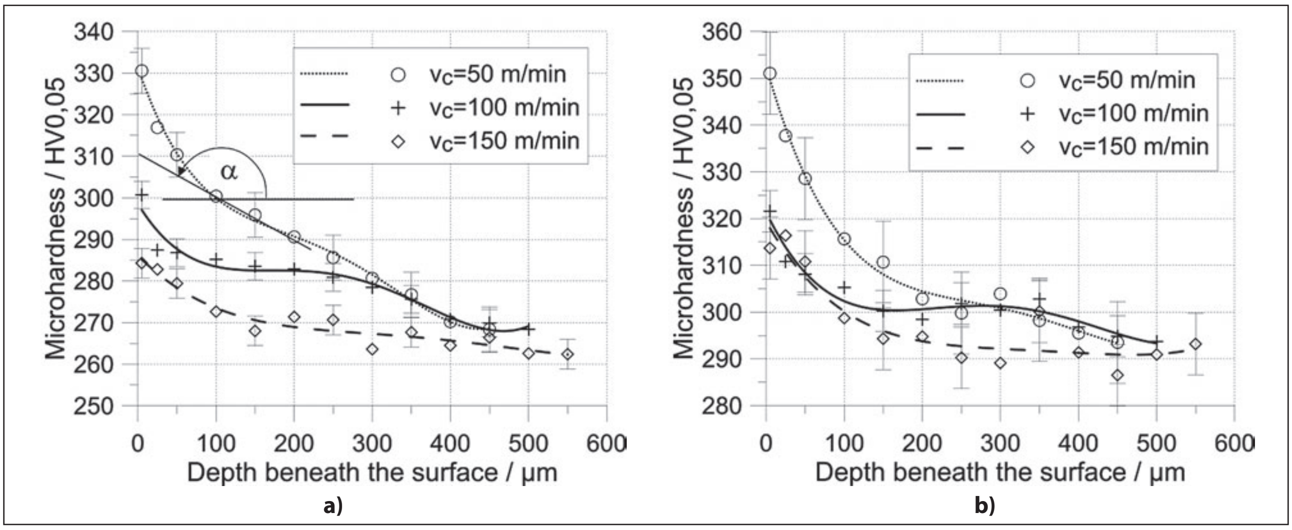

Figure 2 The course of functions approximating the sets of microhardness change points as a function of the distance from the material surface for various cutting speeds for ferrite (a) and for austenite (b) with f = 0,3 mm/rev, a_p = 2 mm

ematical models of the individual curves are assembled in Table 2, including the R^2 coefficients.

Table 2 **Mathematical models of functions approximating the experimental points of SI measurement (parameter g) of $HV_{0,05}$ microhardness together with the equations of the first degree derivatives**

Ferrite		
v_c = 50 m/min	HV0,05 = f(g)	HV0,05 = 331,32 – 0,5493 · g + 3,143 10^{-3} · g^2 – 8,737 10^6 · g^3 + 8,392 10^{-9} · g^4 R^2 = 0,996
	$\frac{d(HV0,05)}{d(g)}$	(HV0,05)´ = - 0,5493 + 6,286 10^{-3} · g – 0,0262 10^{-3} · g^2 + 3,357 10^{-8} · g^3 Real root: 439,3391
v_c = 100 m/min	HV0,05 = f(g)	HV0,05 = 298,596 – 0,310 · g + 2,143 10^{-3} · g^2 – 6,108 10^{-6} · g^3 + 5,653 10^{-9} · g^4 R^2 = 0,951
	$\frac{d(HV0,05)}{d(g)}$	(HV0,05)´ = - 0,310 + 4,286 10^{-3} · g – 18,3 10^{-6} · g^2 + 2,261 10^{-8} · g^3 Real root: 467,810; 175,297; 167,226
v_c = 150 m/min	HV0,05 = f(g)	HV0,05 = 286,121 – 0,188 · g + 0,756 10^{-3} · g^2 – 1,395 10^{-6} · g^3 + 9,106 10^{-10} · g^4 R^2 = 0,935
	$\frac{d(HV0,05)}{d(g)}$	(HV0,05)´ = - 0,188 + 1,512 10^{-3} · g – 4,2 10^{-6} · g^2 + 3,642 10^{-9} · g^3 Real root: 603,163
Austenite		
v_c = 50 m/min	HV0,05 = f(g)	HV0,05 = 352,603 – 0,593 · g + 2,749 10^{-3} · g^2 – 5,803 10^{-6} · g^3 + 4,388 10^{-9} · g^4 R^2 = 0, 991
	$\frac{d(HV0,05)}{d(g)}$	(HV0,05)´ = - 0,593 + 5,498 10^{-3} · g – 17,4 10^{-6} · g^2 + 1,755 10^{-8} · g^3 Real root: 501,991
v_c = 100 m/min	HV0,05 = f(g)	HV0,05 = 321,37 – 0,348 · g + 2,008 10^{-3} · g^2 – 4,656 10^{-6} · g^3 + 3,615 10^{-9} · g^4 R^2 = 0,946
	$\frac{d(HV0,05)}{d(g)}$	(HV0,05)´ = - 0,348 + 4,017 10^{-3} · g – 14,0 10^{-6} · g^2 + 1,446 10^{-8} · g^3 Real root: 522,473; 277,245; 166,237
v_c = 150 m/min	HV0,05 = f(g)	HV0,05 = 319,363 – 0,292 · g + 1,22 10^{-3} · g^2 – 2,319 10^{-6} · g^3 + 1,644 10^{-9} · g^4 R^2 = 0,868
	$\frac{d(HV0,05)}{d(g)}$	(HV0,05)´ = - 0,292 + 2,44 10^{-3} · g – 7,0 10^{-6} · g^2 + 6,576 10^{-9} · g^3 Real root: 469,36

The determination of the mathematical functions of approximation of the set of experimental points has allowed for performing a wider mathematical analysis. An important technological criterion is the rate of microhardness changes as a function of the distance from the machined material surface in relation to the cutting speed. Those values for the individual curves can be determined on the basis of the first degree derivative. For this reason, the corresponding equations of the derivatives have been shown in Table 2.

The determination of actual roots of the differential equations has allowed us to find the ranges of the function monotonicity, i.e. whether $HV_{0,05}$ gradient was decreasing or increasing. In fact, for almost all values of cutting speed a gradient of uniform, monotonic shape has been obtained. The single actual roots shown in Table 2 have comprised the distance ranges of about 430 – 600 µm, which corresponds to the depth SI location in the machined material. Only for v_c = 100 m/min, the equations of the first degree derivatives have given 3 values of actual roots. This concerned both the shapes determined for ferrite and austenite. Like in the case of the other v_c speeds, one of the roots has defined the extreme depth of SI. The two others were in the middle part of the SI depth range. This means that, in the SI depth under analysis, the characteristics of the gradient function has changed (from drop to rise). However, those values were of minor importance.

The results of analytical investigation have been assembled in Table 2. Two separate groups of functions have been established for ferrite and austenite. The matching coefficient of the R^2 polynomial has been stated and, for the first degree derivative functions, the values of their corresponding actual roots have been recorded.

CONCLUSIONS

– Cutting speed, as a parameter significantly determining the intensity of heat generated in the zone of machining, has a major influence on the distribution of microhardness of the individual phases of duplex steel in the area of the technological surface layer. A significant drop of austenite and ferrite microhardness with the increase of v_c has been observed.

– The way of performing experimental measurements of $HV_{0,05}$ microhardness determines their stochastic character. For that reason, it is correct to apply mathematical procedures, mainly approximation functions, in order to obtain statistically acceptable curves presenting the HV changes as a function of the distance from the surface of the machined material.
– It is possible to assess the intensity of microhardness changes in the machined material and its shape on the basis of the equation of the first degree derivative of the function approximating the set of $HV_{0,05}$ microhardness points obtained in the experiment.
– The cutting speed influences the depth of SI hardening. The depth of the hardened layer decreases with the increase of v_c. This observation can be practically used in planning the individual operations of the technological process.

REFERENCES

[1] T. Pelczynski, Twardość metali i ich stopów z uwzględnieniem fizyki odkształceń plastycznych. WPL, Lublin 2008.
[2] M. Zelenak, J. Valícek, S. Hloch, D. Kozak, I. Samardzić, M. Harnicarova, J. Klich, P. Hlavacek, R. Cincio, Comparison of mechanical properties of surface layers with use of nanoindentation and microindentation tests, Metalurgija, 51 (2012) 3, 309-312.
[3] S. Joniak, Badania eksperymentalne w wytrzymałości materiałów. WPP, Poznań 2006.
[4] D. Ulutan, T. Ozel, Machining induced surface integrity in titanium and nickel alloys: a review. International Journal of Machine Tools and Manufacture, 51 (2011), 250-280.
[5] B. Matesa, D. Kozak, A. Stoic, I. Samardžić, The influence of heat treatment by annealing on clad plates residual stresses. Metalurgija, 50 (2011) 4, 227-230.
[6] W. Olszak, Obrobka skrawaniem. WNT, Warszawa 2008.
[7] J. M. Cabrera, A. Mateo, L. Llanes, J. M. Prado, M. Anglada, Hot deformation of duplex stainless steels. Journal of Materials Processing Technology, 143-144 (2003), 321-325.
[8] Y. H. Park, Z. H. Lee, The effect of nitrogen and heat treatment on the microstructure and tensile properties of 25Cr–7Ni–1.5Mo–3W–xN duplex stainless steel castings. Materials Science and Engineering: A, 297 (2001), 78-84.
[9] G. Krolczyk, P. Nieslony, S. Legutko, Microhardness and Surface Integrity in turning process of duplex stainless steel (DSS) for different cutting conditions, Journal of Materials Engineering and Performance, 23 (2014) 3, 859-866.
[10] G. Krolczyk, S. Legutko, M. Gajek, Predicting the surface roughness in the dry machining of duplex stainless steel. Metallurgy journal, 52 (2013) 2, 259-262.
[11] J. Paro, H. Hanninen, V. Kauppinen, Tool wear and machinability of X5 CrMnN 18 18 stainless steels. Journal of Materials Processing Technology, 119 (2001), 14-20.
[12] D. Y. Jang, T. R. Watkins, K.J. Kozaczek, C. R. Hubbard, O. B. Cavin, Surface residual stresses in machined austenitic stainless steel. Wear, 194 (1996), 168-173.
[13] N. Solomon, I. Solomon, Deformation induced martensite in AISI 316 stainless steel. Revista de Metallurgy journal, 46 (2010) 2, 121-128.
[14] J. A. Kundrak, G. Mamalis, K. Gyani, V. Bana, Surface layer microhardness changes with high-speed turning of hardened steels. International Journal of Advanced Manufacturing Technology, 53 (2011), 105-112.
[15] H. Sasahara, The effect on fatigue life of residual stress and surface hardness resulting from different cutting conditions of 0.45%C steel. International Journal of Machine Tools and Manufacture, 45 (2005) 2, 131-136.

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