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INFLUENCE OF CUTTING PARAMETERS AND CONDITIONS ONTO SURFACE HARDNESS OF DUPLEX STAINLESS STEEL AFTER TURNING PROCESS

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Original scientific paper
The aim of the study was to determine the hardness of the steel surface after the turning of duplex coated carbide tools. The study included measuring the hardness of the machined surface in the turning process of duplex stainless steel for different cutting conditions. Hardness measurements were performed for different cutting speeds and for wet and dry cutting conditions. The measurement results were compared for test cutting tools: T1 tool coated with a ceramic intermediate layer and T2 multilayer coating tool. The study was performed for the HV10 hardness and the results were statistically analysed.

Keywords: *cutting parameters, Duplex Stainless Steel, hardness, machining, turning*

Utjecaj parametara i uvjeta rezanja na tvrdoću površine duplex čelika nakon tokarenja

Izvorni znanstveni članak
Cilj ispitivanja je utvrđivanje tvrdoće površine duplex nehrđajućeg čelika nakon tokarenja prevučenim pločicama iz tvrdih metala. Istraživanje sadrži mjerenje tvrdoće duplex nehrđajućeg čelika, koji je obrađen postupkom tokarenje pri različitim reznim uvjetima. Mjerenje tvrdoće se izvodilo za različite brzine rezanja, u uvjetima obrade sa i bez hlađenja. Rezultati mjerenja su uspoređeni za različite rezne alate: T1 alat prevučen keramičkim slojem srednje debljine i višeslojno prevučen T2 alat. Istraživanje je provedeno mjerenjem tvrdoće HV10, a rezultati mjerenja su statistički obrađeni.

Ključne riječi*: duplex nehrđajući čelici, obradivost, parametri rezanja, tokarenje, tvrdoća*

1 Introduction

Engineering surface is generated within the machined surface layer through the cutting process. Cutting conditions such as the nose radius of the tool, feed rate and shape of cutting edge at the finishing operation affect the residual stresses, surface hardness and surface roughness [1]. This paper shows that machined surface hardness could be controlled by the setting of the cutting conditions. Workpiece material is duplex stainless steel because this stainless steel is widely used for many industrial applications due to its unique properties. Despite the broad use of the term difficult-to-machine or hard-to-cut materials, the area of these types of materials and their properties are not clear yet [2]. Duplex stainless steels have a mixed microstructure consisting of ferrite and austenite phases. When duplex stainless steels have the optimum phase balance, which is usually approximately equal proportions of ferrite and austenite phases, they exhibit higher resistance to stress corrosion cracking and higher strength than austenitic stainless steels [3]. Good combination of their mechanical properties (high strength and toughness) and corrosion resistance makes them of great interest for a wide range of applications especially in the oil, chemical and power industry [4, 5]. Higher hardness in these materials is directly associated with high sigma phase concentration in the microstructure, precipitated in the ferrite/austenite interface [6]. According to Beddoes and Bibby [7] as the hardness of the machined part increases, its machinability is reduced and difficulties may arise in the implementation of conventional machining operations related to the surface finish. As the machinability decreases, the tool life decreases as well. The work hardening capability of stainless steel together with its mentioned mechanical and thermal properties results in severe cutting tool wear and low surface quality of the machined surface [8 ÷ 15]. The wear of the cutting tool wedge leads to a deterioration in the quality of the machined surface, and in the most commonly used surface roughness parameter in production which is the arithmetic average deviation from the average line profile [11, 16, 17].

2 Experimental techniques

2.1 Workpiece and cutting tool materials

Machined material was 1.4462 (DIN EN 10088-1) steel with a ferritic-austenitic structure containing about 50 % of austenite. The ultimate tensile strength *UTS*=700 MPa, Brinell hardness - 290±2 HB. The chemical composition of the machined material and some technical data of the cutting tools are given in tables 1 and 2 respectively. Tests were performed with cutting tool inserts of TNMG 160408 designation clamped in the tool shank of ISO-MTGNL 2020-16 type.

Table 1 Chemical composition of 1.4462 duplex stainless steel / % wt.

Element	C	Si	Mn	P	S	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	-

Based on the theory, industry recommendations and conclusions from the earlier investigations [16]: "cutting speed is the main influencing factor on the tool life" a range of cutting parameters T1: v_C = 50, 100 and 150 m/min, f_n= 0,3 mm, a_p = 2 mm was selected. The experiments performed with the tool T2 were comparative studies and that is why the cutting parameters were: v_C = 100 m/min, f_n = 0,3 mm, a_p= 2 mm. The study was conducted within a production facility. The research program was carried out on a lathe CNC 400 CNC Famot - Pleszew plc.

Table 2 Cutting tool specification

Tool	Substrate	Others
T1 MM 2025	Hardness: 1350 HV3 Grade: M25, P35	Coatings: Ti(C,N)-(2 µm) (Top layer) Al_2O_3-(1,5 µm) (Middle layer) TiN-(2 µm) (Bottom layer) Coating technique: CVD
T2 CTC 1135	Grade: M35, P35	Coatings: 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) Coating technique: CVD

2.2 Hardness analysis

To determine the effect of the cutting parameters on the surface hardness after turning, a measure of the surface hardness of duplex stainless steel was performed. The samples for research of the surface hardness of duplex stainless steel after turning dependable on the machining parameters were made of a steel rod characterized by 1.4462 (DIN EN 10088-1) steel and Ø35 diameter. The code of the tested samples is presented in Tab. 3. Miscible with water was used as a cooling - lubricant liquid, containing no chlorine-based refrigerant mineral oils Blasocut 4000CF, universal emulsion for medium - heavy and hard machining of steel. According to V. S. Sharma et al. [17] a good understanding of the methods of lubrication/cooling at the cutting zone, reduction of heat generation will lead to efficient and economic machining of these modern materials.

Table 3 Coding of the tested samples

Sample code	Tool	Cutting parameters			Lubricant
		v_C / m/min	f_n / mm/rev	a_p / mm	
1A	T1	100	0,3	2	NO
2A	T1	100	0,3	2	YES
3A	T1	150	0,3	2	NO
4A	T1	50	0,3	2	NO
5A	T2	100	0,3	2	NO
6A	T2	100	0,3	2	YES

3 Results and discussion

3.1 The effect of the cutting parameters and conditions on the surface hardness after turning a tool T1 of duplex stainless steel

Based on the obtained results of the hardness of duplex stainless steel after the machining of tool T1; graphs are shown in Fig. 1 and Fig. 2.

After analysing the results shown in Fig. 1, it can be concluded that the hardness of duplex stainless steel increases by increasing the cutting speed. This may probably be attributed to an increase in the cutting force that occurs when increasing cutting speeds. However, Fig. 2 shows the effect of cooling on the hardness of the machined surface. From the obtained results, no observation was made of the influence of cooling on the hardness of duplex stainless steel after the turning of parameters v_C = 100 m/min, f_n = 0,3 mm and a_p = 2 mm. For data included in Fig. 1, the normality was checked using the Shapiro – Wilk test. Due to the fact that the variables 3A and 4A are not from a population of normal distribution, a nonparametric Kruskal – Wallis test was applied. As $p = 0{,}0672 > \alpha = 0{,}05$ the three variables (1A, 3A, 4A) distribution hypothesis lacks the basis for rejection. Detailed results were presented in Tabs. 4 ÷ 5.

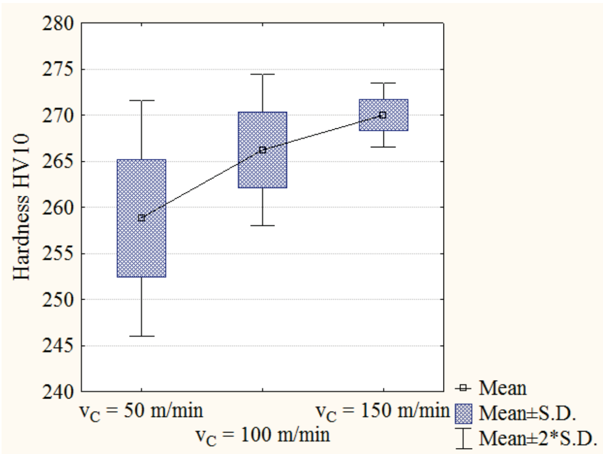

Figure 1 The influence of the cutting speed on the surface hardness, after the turning of duplex stainless steel of tool T1

For data presented in Fig. 2, statistical significance of differences between averages of surface hardness after the turning of duplex stainless steel for tool T1 for sample 1A (μ_1) and sample 2A (μ_2) was checked. T-statistic for two mean values of populations with normal distributions and homogeneous variances was used. At the significant level where α = 0,05, the hypothesis of equal means was rejected. The hypothesis was formulated as follows: H0:

$\mu_1 = \mu_2$ (there are no differences between the first and second group of results obtained for surface hardness after the turning of duplex stainless steel of tool T1; the results of the first and second group come from a population of the same average, and therefore, values of the surface hardness after the turning of duplex stainless steel of tool T1 for sample A1 do not differ significantly from the second group - the results of surface hardness of the duplex stainless steel tool T1 for sample 2A). Nevertheless an alternative hypothesis was formulated: H1: $\mu_1 \neq \mu_2$ (the average surface hardness after the turning of duplex stainless steel with T1 tool for sample 1A differs significantly from the average surface hardness after the turning of duplex steel blade for tool T1 for sample 2A). Because $p = 0{,}9450 > \alpha = 0{,}05$, there is no reason to reject the hypothesis of equal average surface hardness after the turning of duplex stainless steel with a tool T1 for samples 1A and 2A. Verification of normal distribution and homogeneity of variance are presented in detail in Tabs. 4, 6 and 7. Homogeneity of variance was tested using the Fisher test.

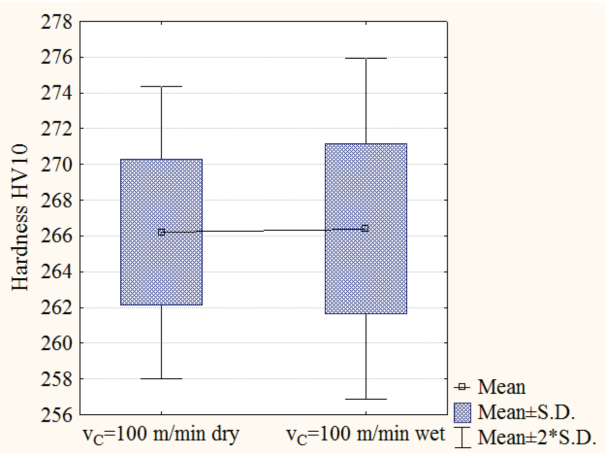

Figure 2 The influence of cooling on the surface hardness, after the turning of duplex stainless steel of tool T1

Table 4 Tests of normal distribution for the duplex stainless steel hardness

Variable	*n*	*W*	*p*
Sample 1A	5	0,8809	0,3137
Sample 2A	5	0,9245	0,5596
Sample 3A	5	0,7007	0,0097
Sample 4A	5	0,7024	0,0101
Sample 5A	5	0,8810	0,3140
Sample 6A	5	0,8713	0,2717

Table 5 Kruskal-Wallis test for the duplex stainless steel hardness

H	5,3996
p	0,0672

Table 6 The results of t-statistic model calculations on the surface hardness after turning tool T1 of duplex stainless steel for 1A and 2A samples

t	-0,0711
p	0,9450

Table 7 The results of F-statistic model calculation on the surface hardness after turning tool T1 of duplex stainless steel for 1A and 2A samples

F	1,3653
p	0,7702

3.2 Influence of cutting parameters and conditions on the surface hardness after turning tool T2 of duplex stainless steel.

Fig. 3 shows the effect of cooling on the hardness of duplex stainless steel after the turning of tool T2. As is the case for tool T1, and also for tool T2, small changes were observed for the effect of cooling on the surface hardness HV10 duplex steel turning parameters $v_C = 100$ m/min, $f_n = 0{,}3$ mm and $a_p = 2$ mm.

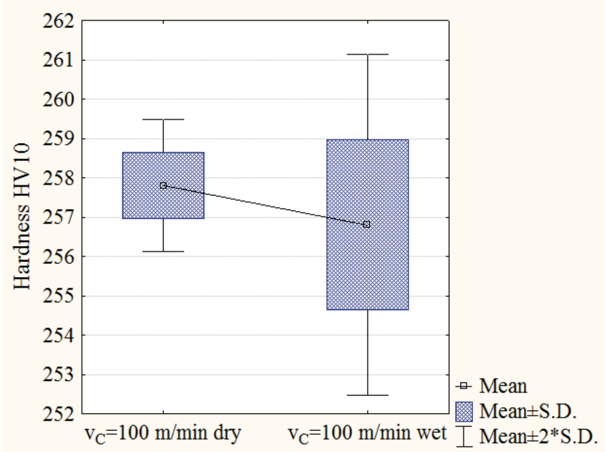

Figure 3 The influence of cooling on the surface hardness, after the turning of duplex stainless steel of tool T2

To assess the impact of cooling on the surface hardness after the turning of duplex stainless steel with tool T2 for the data shown in Fig. 3, statistical significance of differences was checked in the averages of the surface hardness after the turning of tool T2 for sample 5A (μ_1) and for sample 6A (μ_2). The t-statistic for two values of average populations with normal distributions and homogeneous variances was applied. At the significant level where $\alpha = 0{,}05$, the hypothesis of equal means was rejected. The hypothesis was formulated as follows: H0: $\mu_1 = \mu_2$ (there are no differences between the first and second group of results obtained for surface hardness after the turning of duplex stainless steel of tool T2; the results of the first and second group come from a population of the same average, and therefore, values of the surface hardness after the turning of duplex stainless steel of tool T2 for sample 5A do not differ significantly from the second group - the results of surface hardness of the duplex stainless steel tool T2 for sample 6A).

Table 8 The results of t-statistic model calculations on the surface hardness after turning tool T2 of duplex stainless steel for 5A and 6A samples

t	0,3641
p	0,9622

Table 9 The results of F-statistic model calculation on the surface hardness after turning tool T2 of duplex stainless steel for 5A and 6A samples

F	6,7143
p	0,0921

Nevertheless an alternative hypothesis was formulated: H1: $\mu_1 \neq \mu_2$ (the average surface hardness after the turning of duplex stainless steel with T2 tool for sample 5A differs significantly from the average surface hardness after the turning of duplex steel blade for tool T2 for sample 6A). Because $p = 0,9622 > \alpha = 0,05$, there is no reason to reject the hypothesis of equal average surface hardness after the turning of duplex stainless steel with a tool T2 for samples 5A and 6A. Verification of normal distribution and homogeneity of variance are presented in detail in Tabs. 4, 8 and 9. Homogeneity of variance was tested using the Fisher test.

4 Conclusions

In this work, hardness measurement for six surfaces and two tools material combinations were investigated. It was concluded that:

1) Increasing the cutting speed in the range of 50 to 150 m/min increases the hardness of the duplex stainless steel, but not to the extent that it is statistically significant.
2) No effect was observed on the change to its hardness when applying the cooling during the turning of duplex stainless steel.
3) Cutting tool coated with a ceramic intermediate layer hardens the surface of duplex stainless steel more than a multilayer coating tool.

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Symbols and abbreviations

a_p – depth of cut in mm
f – feed rate in mm/rev
v_C – cutting speed in m/min
DSS– Duplex Stainless Steel

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