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EFFECT OF THE CUTTING PARAMETERS IMPACT ON TOOL LIFE IN DUPLEX STAINLESS STEEL TURNING PROCESS

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Original scientific paper
The purpose of the study is to determine the coated carbide tool life and the tool point surface topography. The study included determining cutting conditions in the process of turning the DSS and designating the wear curve. In case of machining greater resistance to abrasive wear of the tools which were coated with Al_2O_3 has been demonstrated. Metallographic microscopy has been used for the microstructure of the surface layer analysis.

Keywords: *Duplex Stainless Steel, machining, tool life, turning, wear*

Utjecaj parametara obrade na vijek alata u procesu tokarenja dupleks čelika otpornog na koroziju

Izvorni znanstveni članak
Ova je analiza provedena kako bi se odredio vijek alata presvućenog karbidom i topografija površine vrha alata. Analiza je uključila određivanje uvjeta rezanja u postupku tokarenja dupleks čelika otpornog na koroziju (DDS) i označavanje krivulje trošenja. Kod strojne obrade pokazala se veća otpornost na abrazivno trošenje onih alata koji su bili presvućeni Al_2O_3. Analiza mikrostrukture površinskog sloja je izvršena pomoću metalografskog mikroskopa.

Ključne riječi: *dupleks čelik otporan na koroziju, strojna obrada, tokarenje, trošenje, vijek alata*

1 Introduction

According to companies producing construction materials - duplex stainless steel is gaining importance, which is reflected in the wide range of these products available in the market. However, the manufacturing process, the machining in particular, poses considerable difficulties. One limitation of the efficiency of turning this type of steel is the wear of the tool point. The wearing process of the tool point, which is largely dependent on cutting parameters, is an important factor. The wear of the tool point leads to deterioration in quality of machined surface and, consequently, to lower efficiency and productivity. Machining DSS due to the characteristic two-phase microstructure is difficult and in order to overcome occurring problems, materials with high durability, reliability and efficiency should be used. In recent years, machinability of austenitic steels has been dealt with by researchers such as Paro, J. et al., Akasawa T. et al., Abou-El-Hossein K. A. et al., Charles J. et al., Kosmač A., Cunat P. J. and Ciftci I. [1 ÷ 8], while machining of DSS has been described by Bouzid Sai W. and J. L. Lebrun [9]. Many production companies use coated carbide tools or high speed steel for processing of DSS. According to Gunn'a [10] low-alloyed DSS such as S32304 while being machined by tools from high speed steels behave in a manner similar to austenitic types such as 316 or 317. However, during the machining of coated carbide tools steel behaves in a manner similar to 317LN and 317LMN. Modern types of DSS are harder to machine than the types produced before this one. The reason for this is higher content of austenite phase and nitrogen. The increase in content of alloying elements such as nitrogen and molybdenum makes machinability of these steels less effective. The use of coated carbide tools for machining of DSS requires a deeper study of tool wear and associated wear mechanisms. The article focuses on basic research problems of tool wear of coated carbide with a layer of CVD-Ti (C, N)/Al_2O_3/TiN in turning DSS of ferritic-austenitic structure. The main purpose of this study was to determine the effect of cutting speed as a key process factor controlling tool life. Increasing cutting speed to a scope greatly exceeding conventional machining is now recognized as the primary direction of production capacity and efficiency growth as well as quality and accuracy improvement [11]. As the method of rational selection for DSS machining a static determined selective-multivariate uniform static - rotatable PS/S-P:λ program has been selected [12 ÷ 14]. The research program included an assessment of influence of cutting parameters impact onto tool life, rake face as well as flank wear in the process of turning. Tool wear data were used to determine characteristic wear curves.

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 R_m = 700 MPa, Brinell hardness - 293±3 HB. The elemental composition of the machined material and technical details of the cutting tools are given in Tabs. 1 and 2 respectively. Cutting tool inserts of TNMG 160408 designation clamped in the tool shank of ISO-MTGNL 2020-16 type were employed.

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.	0,03	1,00	2,00	0,030	0,020	21,0 23,0	4,50 6,50	2,50 3,50	0,10 0,22	-

Based on the industry recommendations a range of cutting parameters T1: v_c = 50 ÷ 150 m/min, f = 0,2 ÷ 0,4 mm/rev, a_p = 1 ÷ 3 mm was selected. The experiments performed with the tool point T2 were comparative studies and that is why the cutting parameters were: v_c =

50, 100 and 150 m/min, f = 0,2; 0,3 and 0,4 mm/rev, a_p = 2 mm. The study was conducted within a production facility. The research program was carried out on a CNC lathe 400 CNC Famot Pleszew plc.

Table 2 Cutting tool specification

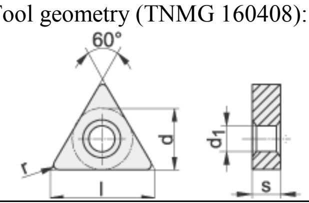
Tool	Substrate	Others
T1 MM 2025	Hardness: 1350 HV3 Grade: M25, P35	Coatings: Ti(C,N)-(2 μm) (Top layer) Al_2O_3-(1,5 μm) (Middle layer) TiN-(2 μm) (Bottom layer) Coating technique: CVD
T2 CTC 1135	Grade: M35, P35	Coatings: TiN-(2 μm) (Top layer) Ti(C,N)-(2 μm) Ti(N,B)-(2 μm) TiN-(2 μm) Ti(C,N)-(2 μm) Ti(C,N)-(2 μm) (Bottom layer) Coating technique: CVD
Tool geometry (TNMG 160408): 		l = 16,50 mm d = 9,52 mm s = 4,76 mm d_1 = 3,81 mm r = 0,8 mm

Table 3 Coded indications of the study plan

No.	x_1	x_2	x_3	v_c / m/min	f / mm/rev	a_p / mm
1	−1	−1	−1	70	0,24	1,4
2	−1	−1	+1	70	0,24	2,6
3	−1	+1	−1	70	0,36	1,4
4	−1	+1	+1	70	0,36	2,6
5	+1	−1	−1	130	0,24	1,4
6	+1	−1	+1	130	0,24	2,6
7	+1	+1	−1	130	0,36	1,4
8	+1	+1	+1	130	0,36	2,6
9	−1,682	0	0	50	0,3	2
10	1,682	0	0	150	0,3	2
11	0	−1,682	0	100	0,2	2
12	0	1,682	0	100	0,4	2
13	0	0	−1,682	100	0,3	1
14	0	0	1,682	100	0,3	3
15	0	0	0	100	0,3	2
16	0	0	0	100	0,3	2
17	0	0	0	100	0,3	2
18	0	0	0	100	0,3	2
19	0	0	0	100	0,3	2
20	0	0	0	100	0,3	2

2.2 Tool life plan

The required number of experimental points is $N = 2^3 + 6 + 6 = 20$ (Tab. 3). There are eight factorial experiments (3 factors on two levels, 2^3) with added 6 star points and centre point (average level) repeated 6 times to calculate the pure error [15]. For the purpose of the experiment a program that estimates parameters of the model second-order polynomial in the form $y = (a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_3)^2$ has been developed. The program was written in Matlab and it allows generating three-dimensional graphs and plots of one variable. The tests were performed on a CNC lathe, hence the test plan had been adjusted to the GE Fanuc Series 0 - T controlled machine program.

2.3 Wear analysis

After cutting attempts values of flank wear were measured with the use of an optical microscope.

3 Results and discussion

3.1 Wear curves

The examination of the process of the tool point wear particularly in industrial processes showed that the most common type of wear was the average and maximum wear bandwidth of abrasive wear on the major flank in zone B - respectively VB_B (Fig. 1) and VB_{Bmax} (Fig. 2). Therefore, the experiment adopted this kind of criterion. Tool-life curves were determined for the center parameters of a research program for the T1 tool point. As one may notice, the VB_B curve (Fig. 1) is typical of the steel machining with the average cutting speed, with no special cooling or of little intense cooling. This may indicate a three discernible, typical periods of tool wear. While analysing the results for VB_{Bmax} wear curve (Fig. 2), a greater value of wear can be noticed; this may indicate irregularly worn major flank.

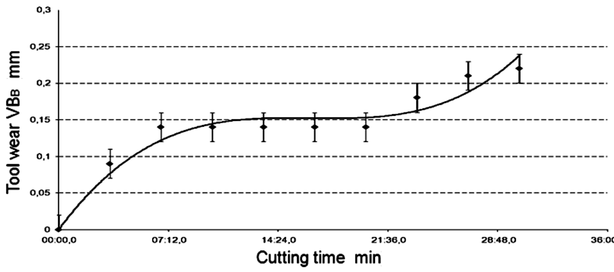


Figure 1 Tool wear VB_B for coated carbide tools T1

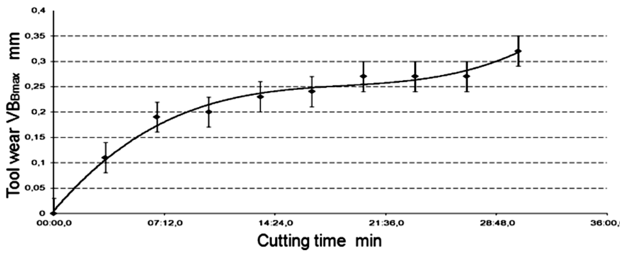


Figure 2 Tool wear VB_{Bmax} for coated carbide tools T1

3.2 Tool life

Fig. 3 shows the tool life after machining DSS with T1 tool under dry cutting conditions. The results obtained by modelling on the basis of adopted program PS/DS-P:λ were presented as a three-dimensional plot and two plots of one variable in sequence showing the depth of cut and cutting speed for the parameters from the point of the centre. For a f = 0,3 mm/rev feed and cutting speed of v_c = 100 m/min the tool life of the tool point takes the greatest value for the depth of cut a_p = 1 mm and a_p = 3 mm and amounts to T = 31 min and T = 23 min. The minimum value was observed for the depth of cut of a_p = 2,3 mm at the tool life amounting to T = 20 min. For the f = 0,3 mm/rev feed and cut depth of a_p = 2 mm, the greatest tool life values were observed for v_c = 50 m/min and v_c = 150 m/min and they amounted to T = 44 min and T = 24 min. The minimum value of the tool life T = 19 min was v_c = 118 m/min.

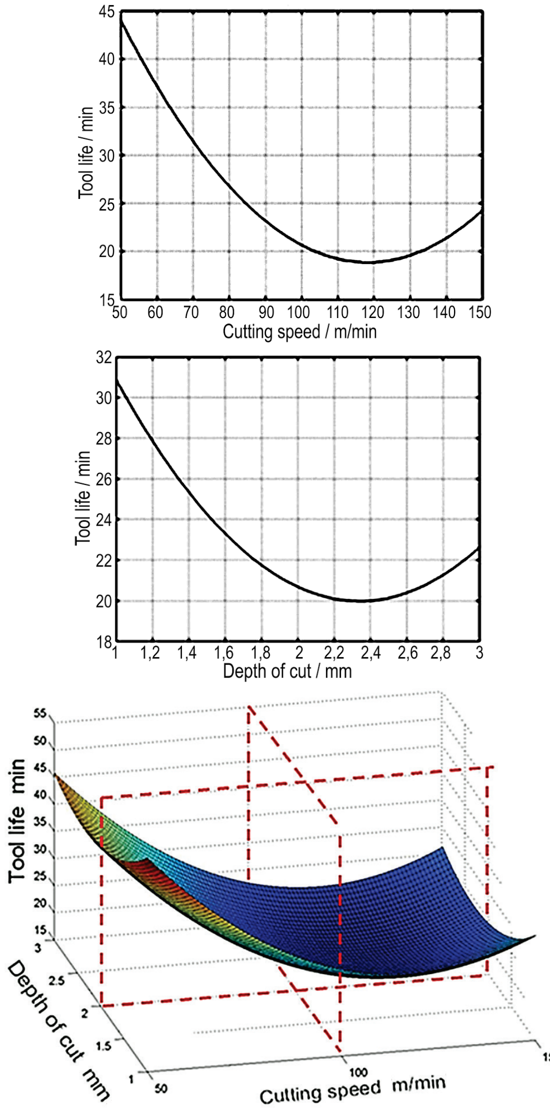


Figure 3 Tool life for centre point parameters (T1)

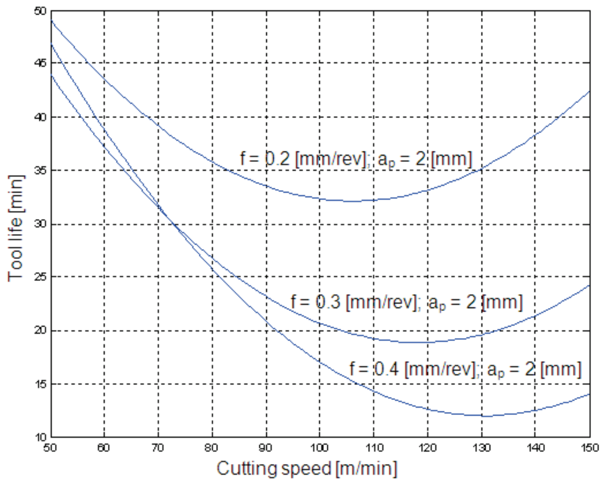


Figure 4 Tool life in dry machining of DSS with coated carbide tools T1

Analysing the impact of cutting speed onto the tool life for a T1 tool point (Fig. 4) and T2 tool point (Fig. 5), it can be noticed that with the increasing cutting speed the tool life decreases for each of the feeds. The tool life decreases for the cutting speed of 100 to 130 m/min depending on the feed value. The higher the feed, the less the function moves to the v_c axis increasing its value. Tool life takes larger values for the T1 tool point. The reason for this is probably a greater resistance to abrasive wear of tools with an Al_2O_3 coating.

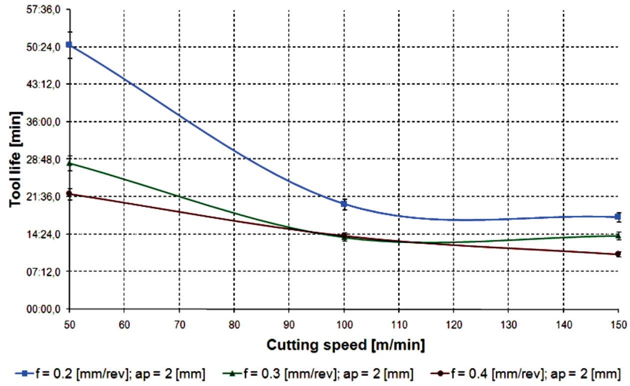


Figure 5 Tool life recorded in dry machining of DSS with coated carbide tools T2

3.3 Metallographic structure

In Figs. 6 to 11 metallographic structures of surface layer of DSS are presented and shown in 100× and 200× magnification in each case.

All the figures show correct metallographic structure of duplex stainless steel i.e. ferrite and austenite. One can also see that no secretions that could arise between the grains of the two phases have appeared. The influence of temperature is not visible in the photos of the metallographic structure, probably for two reasons: the machining temperature has not exceeded 300 ÷ 450 °C or the exposure of the samples to the temperature above 300 °C has not been long enough to cause secretions between the grains of austenite and ferrite. The samples under investigation have been made of 1.4462 steel which contains from 0,08 to 0,20 % of nitrogen. Nitrogen added to duplex stainless steel causes higher stability of austenite and reduces the rate of secretion of disadvantageous intermetallic phases. Secondary phases have disadvantageous influence on mechanical properties and on corrosion resistance. The above mentioned properties of duplex stainless steel are the reason for its increased application. It should also be kept in mind, however, that duplex stainless steel has intermetallic phases (σ, χ) rich in Cr and Mo, which precipitate in ferrite. The sigma phase σ and the chi chase χ reduce the pinhole corrosion resistance and the intercrystallic corrosion resistance. They also cause the increase of brittleness. What is more, the authors of works [16] and [17] have found microhardness changes of the phases after machining in the process of turning super duplex stainless steel. This is related to the mechanisms of work hardening of the phases in the top layer. Deformation of austenite takes place as a result of grain contour rearrangement and has the character of plastic flow. Such rearrangement depends on the time of machining influence. In the light of the statements above, execution of further investigation aiming at the identification of the DSS top layer features, particularly microhardness, seems necessary.

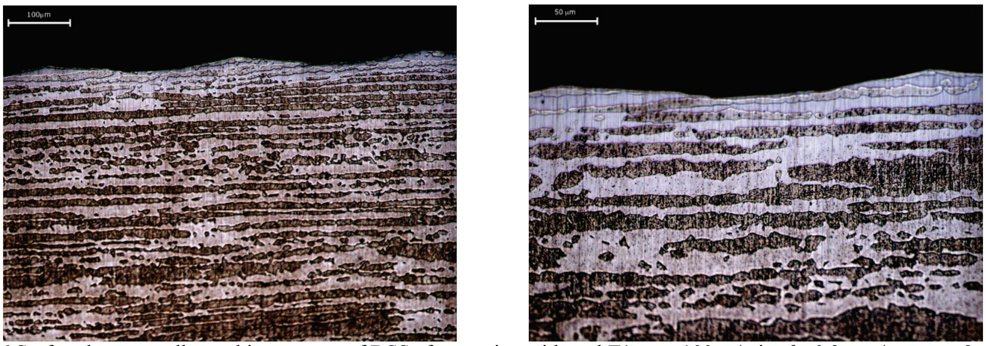


Figure 6 Surface layer metallographic structure of DSS after turning with tool T1: v_c = 100 m/min, f = 0,3 mm/rev, a_p = 2 mm, dry

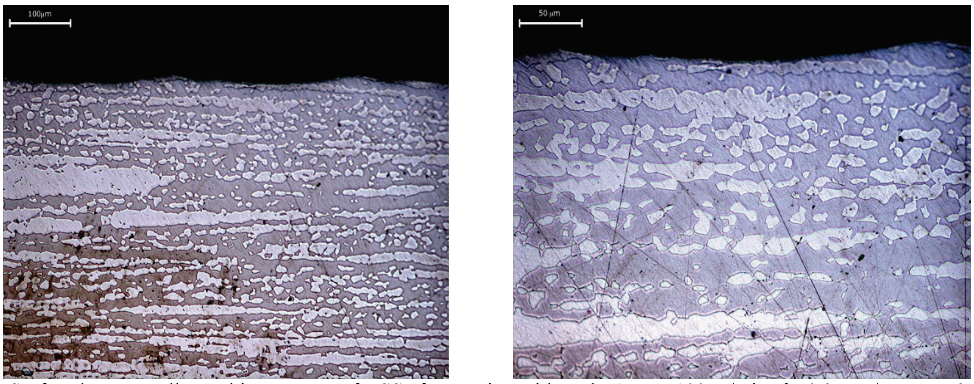


Figure 7 Surface layer metallographic structure of DSS after turning with tool T1: v_c = 100 m/min, f = 0,3 mm/rev, a_p = 2 mm, wet

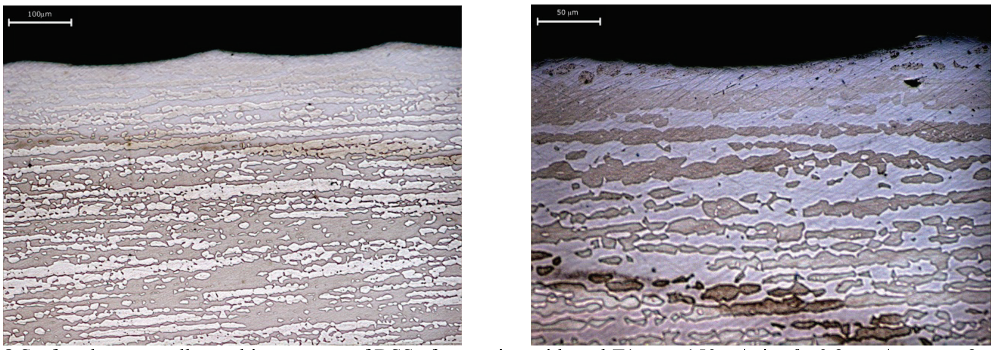


Figure 8 Surface layer metallographic structure of DSS after turning with tool T1: v_c = 150 m/min, f = 0,3 mm/rev, a_p = 2 mm, dry

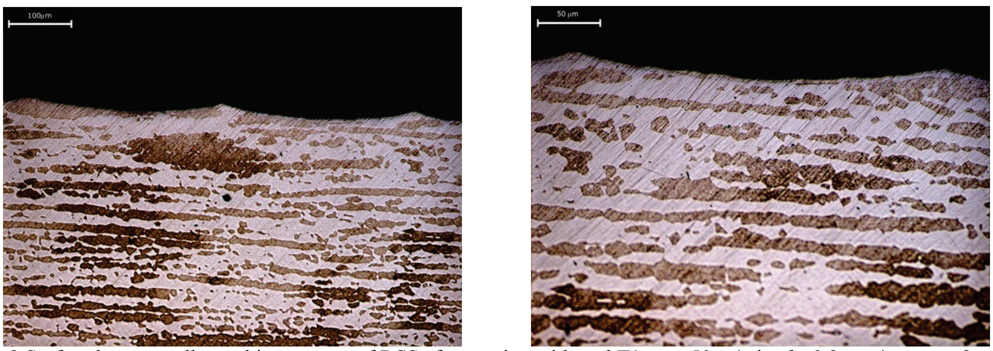


Figure 9 Surface layer metallographic structure of DSS after turning with tool T1: v_c = 50 m/min, f = 0,3 mm/rev, a_p = 2 mm, dry

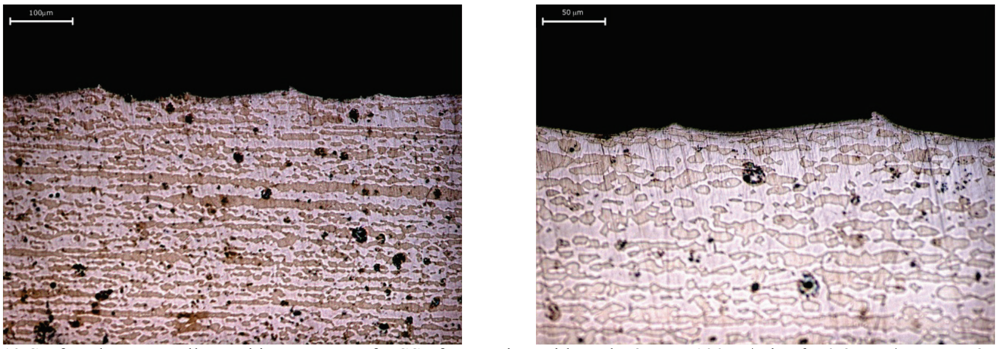


Figure 10 Surface layer metallographic structure of DSS after turning with tool T2: v_c = 100 m/min, f = 0,3 mm/rev, a_p = 2 mm, dry

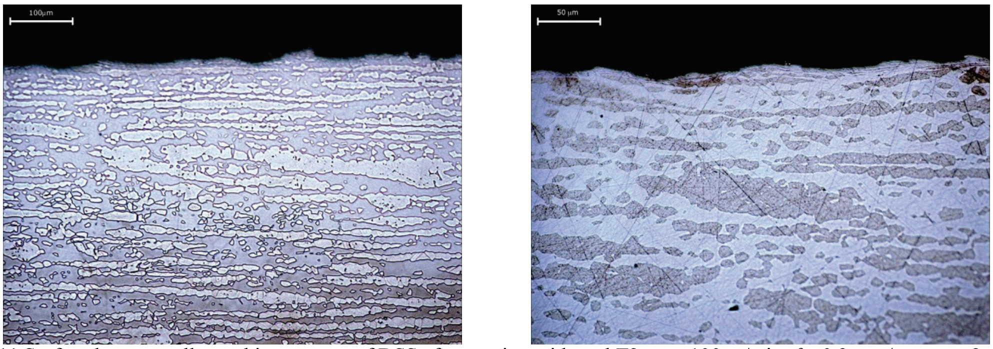


Figure 11 Surface layer metallographic structure of DSS after turning with tool T2: v_c = 100 m/min, f = 0,3 mm/rev, a_p = 2 mm, wet

4 Conclusions

During duplex stainless steel turning, the following difficulties occur: it is difficult to control the chip, there are excessive thermal and mechanical loads onto the tool point, strong adhesive interaction leading to the formation of built-up edge occur, and accelerated wear of cutting edge happens. These lead to:

I. In the process of DSS turning the course of coated carbide tool point wear for the parameters of a test centre program shows a typical shape of the normal wear curve.
II. Increasing the cutting speed increases the intensity of wear of the cutting edge.
III. CVD - Ti(C, N)/Al_2O_3/TiN coated carbide tools indicate higher resistance to abrasive wear and they can be recommended to roughing machining of DSS, optimally with cutting speeds of 130 ÷ 150 m/min.
IV. In the process of DSS turning no effect has been found of cutting speed and cooling on metallographic structure.

5 References

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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
T – tool life in min
VB_B – width of flank wear in mm
VB_{Bmax} – the maximum width of the flank wear in mm
DSS – Duplex Stainless Steel

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