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STUDY OF CHANGES UNDER THE MACHINED SURFACE AND ACCOMPANYING PHENOMENA IN THE CUTTING ZONE DURING DRILLING OF STAINLESS STEELS WITH LOW CARBON CONTENT

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This article presents the results of experiments that concerned the verification of machined surface conditions of workpieces from a new austenitic stainless steel with Extra Low Carbon (ELC) Cr22Ni9MoTi compared with stainless steels Cr18Ni8. The results of cutting zone evaluation under cutting speed 80 m/min, depth of cut 2,75 mm and feed 0,08 mm per rev., a definition of shear level angle $\Phi 1$. For Cr22Ni9MoTi steel Φ_1 is 36° to 39°. The acquired results are interesting in that for the defined conditions we can achieve a quality outer surface after cutting with roughness parameters down to around 0,65 μm at cutting speed 80 m/min and feed 0.08 mm per rev.

Key words: steel, surface, tool, drilling, cutting zone

Studija promjena ispod obrađene površine i pridruženi fenomeni u zoni rezanja tijekom bušenja nehrđajućeg čelika s niskim sadržajem ugljika. Rad prikazuje rezultate eksperimentalnog istraživanja koji se odnose na verifikaciju uvjeta strojne obrade radnih komada od austenitnog nehrđajućeg čelika sa posebno niskim sadržajem ugljika (ELC) Cr22Ni9MoTi u usporedbi sa nehrđajućim čelikom Cr18Ni8. Rezultati ocjene rezne površine kod brzine rezanja 80 m/min, dubine reza 2,75 mm i posmaka 0,08 mm po okretaju definiraju vrijednost smičnog kuta Φ_1. Za čelik Cr22Ni9MoTi Φ_1 je 36° do 39°. Prikupljeni rezultati su zanimljivi za definiranje uvjeta pod kojim se može postići kvaliteta hrapavosti vanjske površine nakon rezanja do oko 0,65 μm kod brzine rezanja 80 m/min i posmaka 0,08 mm po okretaju.

Ključne riječi: čelik, površina, alat, bušenje, zona rezanja

INTRODUCTION

Precise and reliable information on the machinability of a material before it enters the machining process is a necessity, and hypotheses must be tested through verification of actual methods. This article presents conclusions of machinability tests on austenitic stainless steels with low carbon content and describes appropriate parameters for the cutting zone during the process of drilling. These trends confirm that the cutting process remains one of the basic manufacturing technologies. In this study presents the conclusions of cutting process analysis on a new austenitic stainless steel with low carbon contents Cr22Ni9MoTi, which applicated in food processing industry, and describes study of changes under the machined surface and accompanying phenomena the process of drilling. The content of this article also focuses on the analysis of selected indicators of steel machinability by [1]: it is quality of machined surface and their parameters (precisions of dimension holes, morphology of surface, residual stresses, plastic deformation, depth of hardening layer, surface roughness, microhardness, defects of surface). The results of the article are conclusions for working theory and practice for drilling of stainless steels.

Automated production of in the sense of machine production has characteristic features: a reduction of production costs, stimulation of the development of cutting tools, and changes in the construction of machine tools, all of which work against the creation of optimal technological methods, which thrusts the technological process of cutting into a more important position by [2]. Stainless steels are fundamentally subdivided by their chemical composition and metallographic structure. Austenitic steels are the most extensive and thus the most important category of stainless steels.

EXPERIMENTAL WORK

The experiments were performed in laboratory conditions and verified in real conditions during manufacture. The set-up used contained the following components: Machine: VMF-100 CNC machining centrum

Tool: a new screw drill design with TiAlN layer, diameter d=5,5 mm, and corner angle $2\kappa_r$=120°, Solid car-

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bide drill were clamped on high accuracy collet hydraulic holder.

Workpiece: the materials to be machined were type of austenitic stainless steels with chemical composition listed in Table 1. The dimension of each piece was *b*x*h*x*l* (50x50x100) mm. The cutting process employed was drilling with dry machining (DM), and the cutting speed was defined at intervals of v_c=50 to 100 m/min, the feed was advanced from intervals of f=0,04 to 0,2 mm per rev., and cutting depth a_p=2,75 mm.

Table 1 **Chemical composition of stainless steels**

Type of Stainless Steel			
Chemical composition / mas. %	CHE	Cr18Ni8	Cr22Ni9TiMo
	C	0,6	0,04
	Cr	18,0	22,0
	Ni	8,0	9,0
	Mn	2,2	1,6
	Ti	-	0,6
	Mo	-	1,8
	P	0,03	1,2
	S	0,03	0,03

RESULTS AND DISCUSSION

Cutting zone (shows in Figure 1) is a summary term from the region during cutting. To properly describe the cutting zone it is necessary to describe the regions and test parameters: primary plastic deformation zone (primarily an examina-tion of phenomena associated with the creation and formation of chips, with the effect of the components of cutting force-the state of strain deformation, the location of the angle of the shear level, chip compression, the temperature field, chip shape, chip formation and separation, the effect of the components of cutting force) by [3-5].

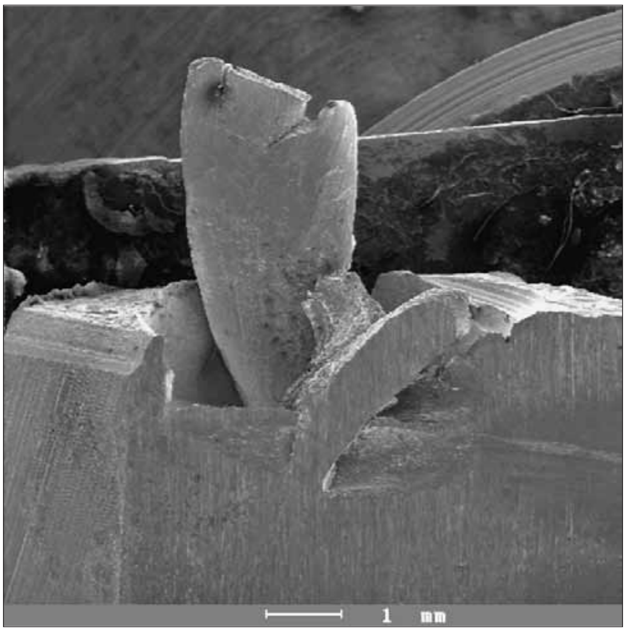

Figure 1 Cutting zone in drilling – chip formatting, v_c= 80 m/min, a_p=2,75 mm and f= 0,08 mm per rev.

Secondary plastic deformation zone (primarily an examination of phenomena associated with friction and cutting wedge wear, and also with the generation of heat and temperature - the location of the grain angle, the contact length of the cutting wedge and the face plate, friction stress and creation of Built Up Edge (BUE), friction, the generation of heat and temperature and the mechanism of tool wear. Tertiary plastic deformation zone (primarily an examination of the phenomena associated with the shaping creation of the machined surface, its profile, morphology, qualities and inherited traits-contact of the machined surface and the worn side plate). Cutting surface, its properties and integrity. The gradually - deformed region of the cut layer.

In tested cutting zone area was defined this areas: non-deformed material structure, plastic deformation zone with defined width (shear volume, central part of the chip, displaying a high level of strain hardening, region of the chip deformed by the action of friction, the loose central part of the chip, irregular in shape, cutting surface of the tool, the contact region between chip and cutting tool face, built up edge on the cutting tool corner, the contact region between the machined surface and cutting tool flank.

Researching the cutting zone (the interaction between the tool, the workpiece, and the chips) is to capture its state at the moment of the creation of the chip (the so-called root of the chip). Cutting zone testing and analysis under a Semi Electron Microscope (SEM), that different regions of smoothly-formed chips can be described. It is important to define the shear level in the cutting zone. The first zone between the chip and the workpiece, called the shear layer, divides the non-deformed region from the deformed chip under the angle of the shear layer, (indicated by Φ_1) which is defined as identical to the boundary angle of deformation. The second zone is the zone where cracks arise and widen. Cracks arise as a result of the strength of the material on the cut level and are caused by the dividing of the material in the form of chips. A chip arises along the entire surface of the tool, and the third zone is the zone of intensive friction between the chip and the cutting tool. The engaged cutting wedge is subject to intensive stress not only in the face plate, but also on the side plate in the fourth zone. The results of cutting zone evaluation under cutting conditions (v_c=80 m/min, a_p=2,75 mm and f=0,08 mm per rev.) are a definition of shear level angle Φ_1 and the texture angle Φ_2. For Cr22Ni9MoTi steel Φ_1 is 36° to 39°, $\Phi_{2,I}$ is 28° to 30° and $\Phi_{2,II}$ is 38° to 44°. Also important are the values of the depth of the plastically-deformed material (of the chip), the Flow zone and the strain hardness of the machined surface. For the defined experimental conditions cutting speed v_c=80 m/min, depth of cut a_p=2,75 mm and feed f=0,08 mm per rev., the values stated in Table 2 were achieved.

Table 2 **Cutting Zone Parameters**

Parameters		Cr22Ni9 TiMo	Cr18Ni8
Cutting width h_t/mm	h_1 /mm	(15-18) %.h_t	(20-22) %. h_t
	h_2 /mm	(75-80) %. h_t	(60-56) %. h_t
	h_{FZ} /mm	(5-7) %. h_t	(20-22) %. h_t
Depth of the hardened machined surf. h_h / mm		0,05	0,12
Depth of the shear layer h_{SP}/ mm		0,01 -0,02	0,02 -0,04

Where h_t is the cutting width, h_t=h_{PD}+ h_{FZ}, h_1 is the depth of the I. zone, h_2 is the depth of the II. zone, h_{FZ} is the depth of the flow zone, h_{PD} is the depth of the plastically-deformed material, h_{PD}=h_1+ h_2, h_h is the depth of the hardened machined surface and h_{SP} is the depth of the shear layer, by [6,7].

The thickness of the cut layer continually varies chip thickness. Chip formation is described through the theory of plasticity. The presence of strain lines in chip formation is depicted in Figure 2. The strain line field extended to the region of plastic deformation, the machined surface, and the cut layer (the chip). Strain lines represent an extensive high-intensity deformation. The process of cutting is the mutual interaction between the tool and the workpiece, which is controlled by many phenomena, which creates a synergistic effect. The edge preparation will determine the residual stress pattern near the machined surface in Figure 3.

Every tool is damaged in the process of cutting by [8,9]. Wear mechanisms are activated in the cutting zone during the interaction of the elements of the cutting edge of the tool and the workpiece, and under the influence of temperature, and by the fact that friction depends on the interaction of the clean metal surface between the front plate of the cutting edge of the tool and the chip, as stated by [10]. According to DIN 50321 it is recognized four fundamental mechanisms of tool wear: adhesive wear, abrasive wear, fatigue wear, tribochemical reaction wear. The mechanism of wear means the synergistic effect of factors that create a change in matter, a change in volume, i.e., a change in cutting edge dimension by [11]. Sintered carbide tools are not as sensitive to temperature on touching plates as high-speed steel, and can be used to attain higher performance, but in this case they have greater pressure stress, which directly influences the process of adhesive wear by [12]. The criterion VB_k=0,3 mm was applied during evaluation. The cutting process conditions were designed based on the needs of the material and on the operation of the finished surface. The results of the long-term test after exhaustive analysis is the Taylor Tool Life Equations for individual types of stainless steels:

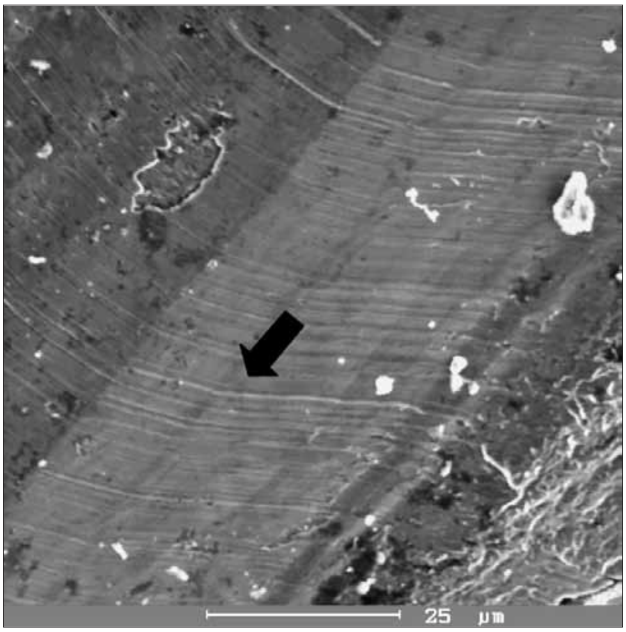

Figure 2 Strain lines in chip formation, v_c= 80 m/min, a_p=2,75 mm, f= 0,08 mm per rev.

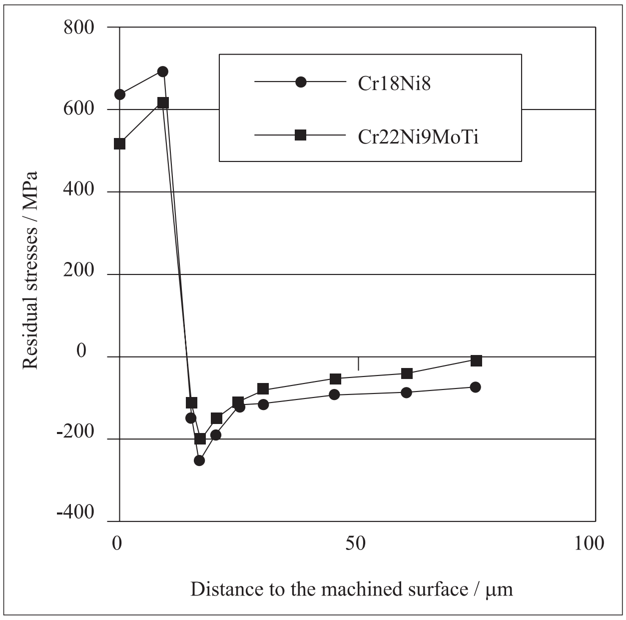

Figure 3 Dependence residual stresses – machined surface, v_c= 80 m/min, a_p=2,75 mm, f= 0,08 mm per rev.

$$T = \frac{1215{,}22 \cdot 10^4}{v_c^{2,4552}} \quad \text{for steel Cr22Ni9MoTi}$$

$$T = \frac{1052{,}36 \cdot 10^4}{v_c^{2,3905}} \quad \text{for steel Cr18Ni8}$$

Damage to the cutting edge of the tool in conditions greater than v_c=80 m/min, a_p=2,75 mm and f= 0,08 mm per rev. is shown in Figure 4. Face plate tool damage is defined by belts that are consistent with the temperature fields on Figure 5.

The micro geometry of the outer surface is characterised by micro geometric chipping. For evaluating the

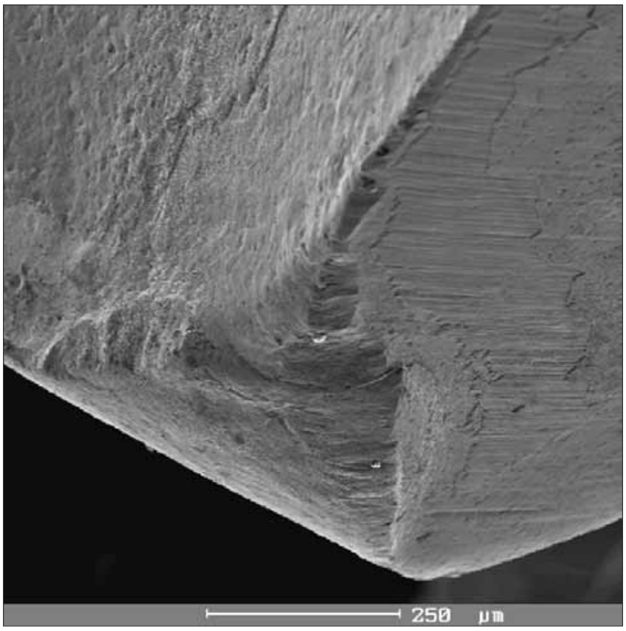

Figure 4 Damage to the cutting edge of the tool, v_c= 80 m/min, a_p=2,75 mm, f= 0,08 mm per rev.

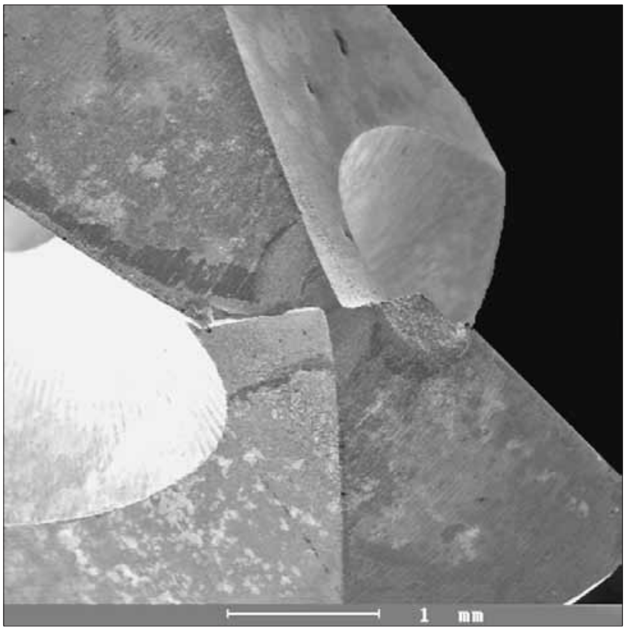

Figure 5 Face plate tool damage, v_c= 80 m/min, a_p=2,75 mm, f= 0,08 mm per rev.

outer surface after drilling and defining the cutting process conditions, the following parameters were used in the investigation: the outer surface roughness parameter *Ra* and *Rz* was measured on measuring tool - Talysurf. Morphology of the outer surface after cutting were evaluated after careful analysis using an SEM.

The acquired results are interesting in that for the defined conditions we can achieve a quality outer surface after cutting with roughness parameters down to around Ra=0,65 μm. When drilling, it is not an advantage to a feed of lower than 0,1 mm for the roughness criteria of the outer surface. Very good results were mainly achieved when cutting speed was 80 m/min and the feed was 0,08 mm per rev. The roughness value for the outer surface, *Ra*, reached around 0,65 μm. Similar roughness in the outer surfaces of the individual type is not based on differences in the quality of the outer surface. The value of *Rz* (following ISO 4287, it is the upper limit of unevenness in outer surfaces) did not exceed a value of 3,0 μm. Before drilling, the hardness of the basic structure of Cr22Ni9MoTi steel was measured at 195 HB. After drilling, outer surface hardness was measured and the results is outer layer hardness increased by 15 to 20 % for Cr22Ni9MoTi steel. It is very significant that the hardness of the outer surface after cutting increases with an increase in cutting speed and decreases with an increase in feed value.

CONCLUSION

It is important for both theory and practical applications that essential conclusions come from measurement and analysis. Results were acquired under laboratory conditions and performed in praxis. The conclusions are as follows: defined tool life equation following Taylor, defined the equation for the cutting strength components, confirmation of surface strain hardening (change in mechanical properties) after cutting. Defined coefficients for kinetic machining of austenitic stainless steels, whereby Cr22Ni9MoTi steel K_v=0,68-0,72, for Cr18Ni8 steel, the coefficient of kinetic machining was K_v=0,65-0,68. It is very important information for process machining.

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Note: The responsibile for English language is the lecturer from TU Košice.

List of symbols

a_p	depth of cut, (mm)
b	width, (mm)
d	diameter, (mm)
f	feed (mm per rev.)
Φ_1	shear angle (°)
Φ_2	texture angle (°)
h	high, (mm)
h_{FZ}	depth of the flow zone, (mm)
h_h	depth of the hardened machined surface, (mm)
h_{PD}	depth of the plast.-def. mat., (mm)
h_{sm}	width of machined surface, (mm)
h_{SP}	depth of the shear layer, (mm)
h_t	cutting width, (mm)
h_1	depth of the I. zone, (mm)
h_2	depth of the II. zone, (mm)
l	length, (mm)
Ra	surface roughness - mean arithmetical deviation, (μm)
Rz	surface roughness, (μm)
VB_k	tool wear criterion, (mm)
v_c	cutting speed , (m/min)
$2\ {}_{r}$	corner angle (°)

Abbreviations

CHE – Chemical Element

Acronyms

DM - Dry Machining
SEM - Semi Electron Microscope