Proceedings in Manufacturing Systems, Vol. 5 (2010), No. 2 ISSN 2067-9238

STUDY OF ANALYASIS OF TEMPERATURE AND STRESSES OF CUTTING TOOLS DURING DRILLING OF STAINLESS STEELS

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Abstract: *The article deals with the cutting process analysis with CA-X systems for drilling. This paper presents the results of experiments that concerned the verification of temperatures and stresses of cutting tool during drilling of a part from a new Stainless Steel with low carbon and analysis of cutting tool wear. The results of cutting zone evaluation were obtained under cutting conditions – cutting speed* v_c = *50 m/min, depth of cut equals one half of cutting tool diameter* a_p = *2.75 mm, and feed f= 0.05 mm/rev. For a new stainless steels, the acquired results are interesting because for the defined conditions we can achieve a surface quality after cutting having the roughness parameters reduced to around 0.72 μm. Very good results were mainly achieved when cutting speed was 50 m/min and feed was 0.05 mm/rev.*

Key words: *simulation, drilling, cutting zone, cutting tool, wear, stainless steels*

1. INTRODUCTION

The rapid development of industry is marked by the development and application of new materials with characteristics that broaden their applicable uses. 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 by actual methods. This article presents conclusions of machinability tests on new austenitic stainless steels X3Cr17Ni8Mo with Extra Low Carbon (ELC) and verified with software of CA-X systems. The characteristics of stainless steels raised from the austenitic structure are high toughness, low thermal conductivity and high workhardening coefficient. From a machinability point of view the most important characteristic is the workhardening.

Stainless steel X3Cr17Ni8Mo is an attractive new engineering material because of its outstanding properties such as corrosion resistance, weldability, high strength, and good formability. The basic properties of stainless steel have been studied and can be found in the materials. The strain-rate effect plays an important role in plastic deformation of materials, several investigators have focused on the strain-rate effect for X3Cr17Ni8Mo stainless steel at low rates. Over the past decades, many researchers have indicated that the plastic deformation of materials under dynamic loading was very different from that under static loading. Dynamic plastic behavior is often found during the metal-forming process, vehicular accidents, and unexpected foreign impacts. Products made from X3Cr17Ni8Mo steel are not infrequently subjected to dynamic loading. Although some investigators [1 and 7] have studied the impact and shock-loading behavior of X3Cr17Ni8Mo stainless steel, its dynamic plastic deformation, mechanical behavior, and associated microstructural evolution, this is still insufficient.

Because of the low thermal conductivity, the chips are formed on the basis of catastrophic failure in narrow shear surfaces [5 and 6]. When carbide tools are used, these characteristics cause the formation of BUE and low values of tool life. The machinability studies are often carried out by tool wear tests in drilling operation, thermal analysis with thermovision camera. Tool wear is studied by using optical microscopy to define the amount of flank and crater wear. The interaction between tool and chip can be effectively studied using Scanning Electron Microscopy (SEM). There are several tendencies affecting the technology and methods used in the metalworking industry.

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2. ANALYSIS OF CUTTING PROCESS

Wear rate models are suitable for integration with FEM calculations. Tool wear involves a combination of different wear mechanisms: abrasion, adhesion, diffusion, chemical wear (oxidation), and others [8 and 9]. In general, wear of carbide tools is dominated by abrasive, adhesive and diffusive wear [10 and 11] shown in Fig. 1. Takeyama & Murata´s wear model (considering abrasive wear and diffusive wear) is given by Eq. (1):

$$\frac{dW}{dt} = G(v_c, f) + D\exp\left(\frac{-E}{RT}\right). \tag{1}$$

Usui´s wear model (considering adhesive wear) is described by Eq. 2:

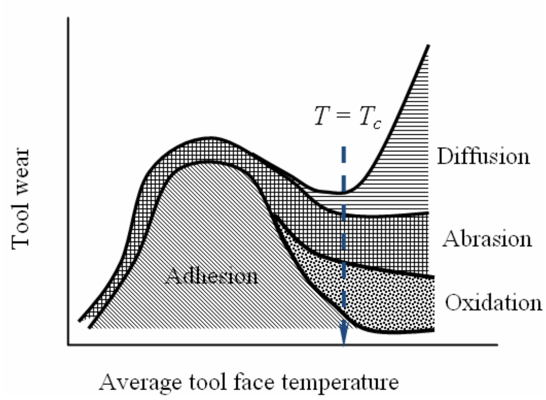

Fig. 1. Tool wear mechanisms for average tool temperature.

$$\frac{dW}{dt} = A.\sigma_n v_s \exp\left(\frac{-B}{T}\right), \qquad (2)$$

where:

G, D	- constants;
E	- process activation energy;
R	- universal gas constant;
v_c	- cutting speed [m/min];
v_s	- sliding velocity [mm/min];
f	- feed rate [mm per rev];
a_p	- depth of cut [mm];
$\frac{dW}{dt}$	- wear rate (volume loss per unit contact area per unit time);
T	- cutting temperature [^{o}C];
BHN	- workpiece hardness;
σ_n	- normal stress [MPa];
A, B	- constants.

In general, the tool wear models in literature can be classified into two types:

- Tool Life Model (TLM): as a function of input cutting parameters (v_c, f, a_p, etc.).
- Wear Rate Model (WRM): as a function of output state variables (T, v_c, σ_n, τ, etc.).

The generation of heat during the cutting process causes a change in temperature. The temperature field is defined in spite of the lack of temperature gradient, as described in [6, 12, and 13]. Temperature gradient means a change in temperature along one precise dimension in the direction of the greatest change (fall) of temperature. An understanding of the significance and interpretation of the temperature gradient is indispensable to describe momentary temperature and temperature fields in cutting geometrically-defined cutting edge, as described by the Fourier-Kirchhoff equations. The average temperature grows under the influence of cutting speed only in the zone of secondary plastic deformation (the interaction of the chip with the face plate of the tool cutting edge). On the chip and the machined surface the change in average temperature is less marked.

This maximum plastic strain model assumes that material separation occurs when an element reaches a critical plastic strain for the material model of the workpiece. The element is then split into two elements and a chip is formed. One can argue whether drilling actually produces smooth separation. Regardless, the maximum plastic strain criterion has been implemented and this has been the most accepted method of failure criteria to model burr formation in drilling. Historically, the two standard FEM meshes are Eulerian and Lagrangian. There are also combinations such as the Arbitrary Lagrangian Eulerian (ALE) and the Coupled Eulerian Lagrangian (CEL) meshes. Although the Lagrangian mesh is not as comprehensive as the Eulerian mesh, it has much better simulation cycle times as a result. Lagrangian mesh in simulating drilling processes is the ability to know the entire time history of the key variables at every point during the simulation. That means, if a simulation crashes for any reason, a new simulation can start where the crashed simulation stopped. This is particularly useful because nearly every simulation has some sort of problem during the run. This is possible because the Lagrangian mesh is reformulated at nearly every time step, in order to manage the deformation of the material. Several different types of machining operations can be accomplished with Proengineer including drilling, turning, and milling. If the tool geometry can be modeled, the machining operation can be simulated. One of the most difficult problems faced with modeling drilling operations is obtaining an accurate model of a drill bit. Author [7] both presents how this can be done and latter developed a program to do this quickly and easily.

3. EXPERIMENTAL PART

The experiments were performed in laboratory conditions and verified in real conditions during manufacture.

The set-up used contained the following components: VMF-100 CNC machining centre and a cutting tool – a new screw drill design, diameter d = 5.5 mm, and corner angle $2\kappa_r$ = 120^o. Solid carbide drills were clamped on high accuracy collet hydraulic holder. The materials to be machined were of austenitic stainless steels type with chemical composition listed in Table 1 and Fig. 2 showing the structure of the stainless steel. The dimension of each piece was $b \times h \times l$ (30 × 60 × 120) mm. The cutting process employed was drilling with dry machining (DM), and the cutting speed was defined at intervals of v_c = 40 to 80 m/min, the feed was increased from intervals of f = 0.02 to 0.1 mm/rev, and depth of cut a_p = 2.75 mm.

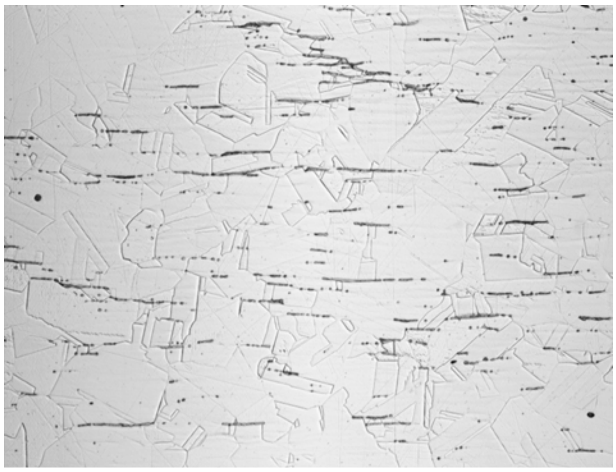

Fig. 2. Structure of X3Cr17Ni8Mo stainless steel, Magn. 200 x.

Table 1

Chemical composition in wt [%]

Chemical Element	Stainless Steel Cr17Ni8Mo
C	0.03
Cr	17.5
Ni	8.2
Mn	1.5
Cu	0.08
Mo	0.1
P	0.04
S	0.003

Table 2

The cutting zone parameters

Parameter		Stainless Steel X3Cr17Ni8Mo
h_t [mm]	h_I [mm]	(20–24 %) h_t
	h_{II} [mm]	(65–68 %) h_t
	h_{FZ} [mm]	(15–8 %) h_t
h_h [mm]		0.05
h_{SP} [mm]		0.01–0.02

Elementary, the cutting process analysis of the characterized machined surface by drilling showed the influence on the cutting tool wear [2]. It results from analysis, that the experiment data is minimizing vibration, instead of going easy on tools by reducing feed pressure. Too light feed allows the tool slipping and it is just as prone to generate vibration as too heavy a feed pressure. It is recommended to use the recommended loading by the tool supplier to minimize chatter and maximize tool life.

Increasing feed rate. Machine operators commonly respond to a vibration problem by reducing the cutting speed and leaving the table feed alone. Speeding up the machine or the feed may seem like a recipe for disaster. It is important to define the shear level in the cutting zone, by [6] states, the depth of the shear level following the formula $0.03h \leq h_{SP} \leq 0.06\,h$, where h is the thickness of the cut section and h_{SP} – depth of the shear level. The size of this local region was determined through the help of electron microscope analysis, and the results are displayed in Table 2, where h_t is the cutting width, $h_t = h_{PD} + h_{FZ}$, h_{I} – depth of the zone I, h_{II} – depth of the zone II, h_{FZ} – depth of the flow zone, h_{PD} – depth of the plastically-deformed material, $h_{PD} = h_{\mathrm{I}} + h_{\mathrm{II}}$, h_h – depth of the hardened machined surface, and h_{SP} – depth of the shear layer [6 and 7]. The thickness of the cut layer varies continually influencing the chip thickness h_t.

However, an increase in feed at the same rpm may be the ideal solution. Anyone who has experienced harmonic vibrations in a car on the highway knows either speeding up or slowing down can end the noise. Similar experimentation can prevent the complex harmonics of drilling chatter.

Photographs from CA-X analysis of thermodynamic phenomena are shown in Figs. 3 and 4, each photograph including the information of the thermo-plastic deformation.

One of the associated phenomena in the measurement of dynamic characteristics is the testing of thermal effects in the cutting zone, mainly measured on the cutting

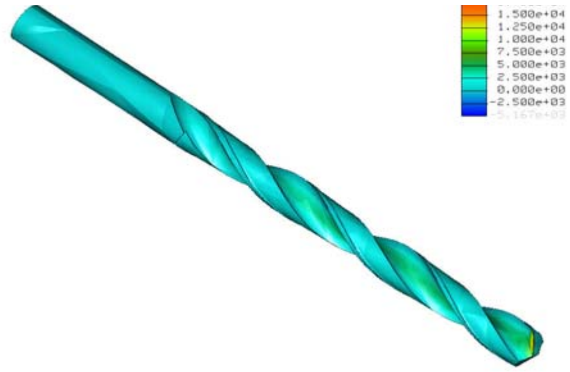

Fig. 3. Drillbit model – cutting tool wear
f = 0.1 mm/rev, a_p=2.75 mm, and v_c=80 m/min.

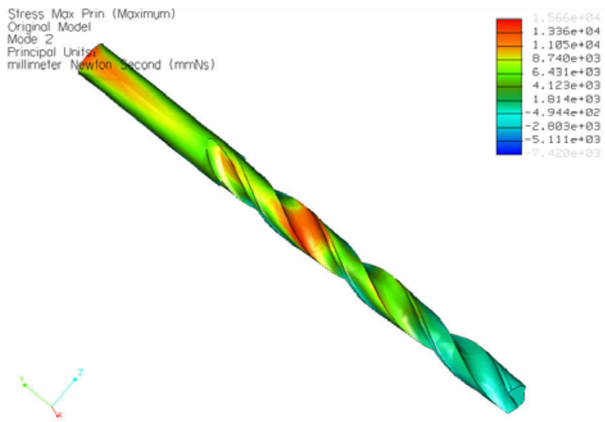

Fig. 4. Drillbit model – stress analysis
f = 0.1 mm/rev, a_p = 2.75 mm, and v_c = 80 m/min.

section of the tool [3 and 4]. Heat in the cutting zone influences deformation and friction in the removal of the cut layer. The magnitude of the heat depends on the cutting time, but after a certain interval it no longer increases in the tool (this is characteristic of turning). This effect of heat has an important significance in the study of damage to the tool cutting edge and cutting wedge wear. The produced heat is associated with the heat field distribution in the chip (72–75 %), on the machined surface (12–18 %), on the tool cutting edge (12–5 %) and into air (4–2 %). Figure 5 shows the stress effect on the tool cutting edge under defined cutting conditions and with markings from the thermal camera, which document the dispersal of temperature on the face plate. The final markings document a temperature range of 60–560° C.

4. CONCLUSIONS

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: we defined the cutting tool wear (Fig. 7), designed a model to stress and thermal analysis for the cutting process (shown in Fig. 6) on the cutting tool and the cutting zone, and got confirmation of surface strain hardening (change in mechanical properties) after cutting.

We also defined coefficients for kinetic machining the austenitic stainless steels, for X3Cr17Ni8Mo steel obtaining K_v = 0.62–0.65, and for C45 steel the coefficient of kinetic machining being K_v = 1.0. The machinability of austenitic stainless steel X3Cr17Ni8Mo

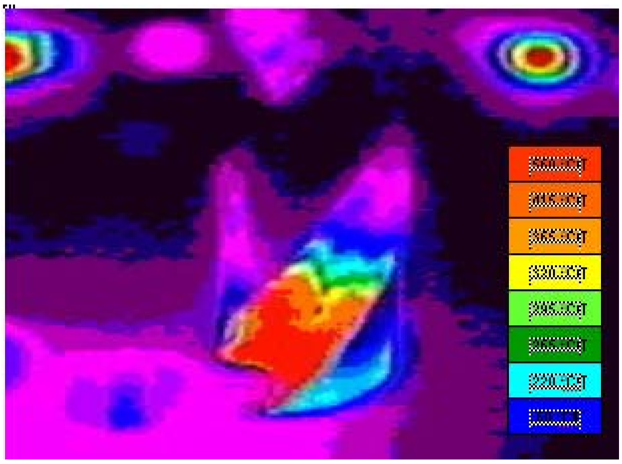

Fig. 5. Thermally influenced tool cutting edge, machined surface and chip,
f = 0.1 mm/rev, a_p = 2.75 mm, and v_c = 80 m/min.

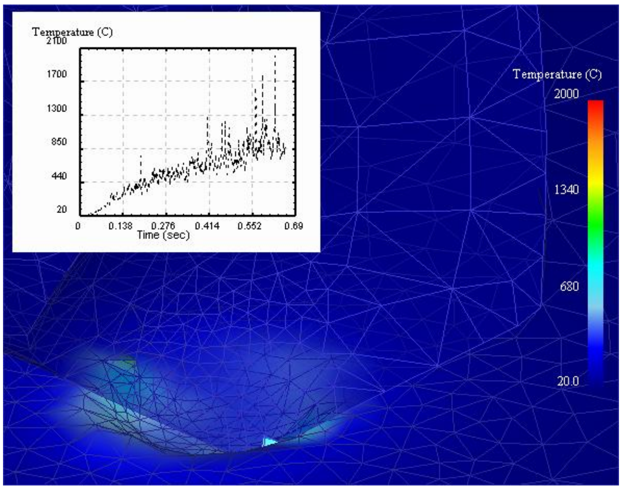

Fig. 6. Thermal analysis – define of average cutting temperature in interaction cutting tool-workpiece
f = 0.1 mm/rev, a_p = 2.75 mm, and v_c = 80 m/min.

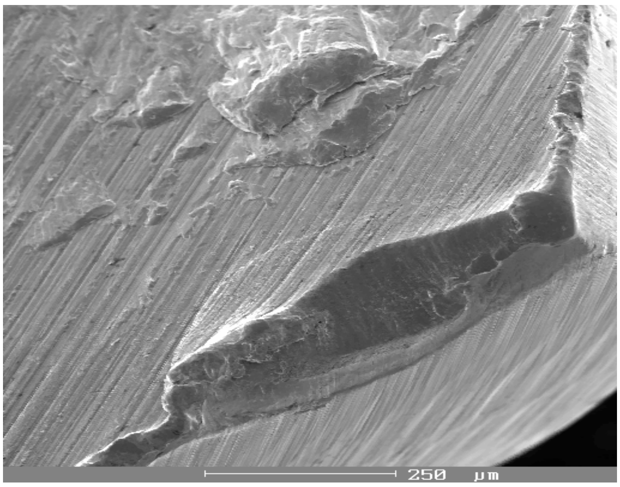

Fig. 7. Tool wear at corner for hard of cutting conditions,
f = 0.1 mm/ rev, a_p = 2.75 mm, and v_c = 80 m/min.

is 1/3 times worse that than for C45 on the basis of its chemical components: mainly chromium, nickel and other component elements. The basic factor involved with oversized blunt tools is high temperature in the cutting zone.

This article is the result of much more research work carried out by the authors in this field and the article presents actual conclusions that are currently being successfully implemented in machine shops.

ACKNOWLEDGEMENTS: The authors would like to thank the VEGA grant agency for supporting research work and co-financing the projects having numbers: #01/3173/06, #3/7166/09 and #1/0048/10.

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