RESISTANCE OF SINTERED CARBIDE MATERIALS AGAINST HEAT SHOCKS INDUCED BY CUTTING PROCESS

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Abstract

The contribution deals with testing of exchangeable cutting inserts from coated sintered carbide and determining of chemical composition for their production. The experimental part was based on evaluation of cutting edge insert resistance against heat waves during milling process of stainless steel 1.4301 (X5CrNi18-10). It was determined amount, types and measured lengths each cracks occurred because of heat waves during the milling process for evaluation of proper chemical composition and Cobalt contain for their production.

Keywords: Cutting process, inserts, sintered carbide, thermal shock, cracks

1. INTRODUCTION

With increasing trend of chip machining and increasing demands on quality and durability of produced parts, a share of used special property materials, like, for example, titanium and special alloys based on nickel and cobalt, increases. However, machining of these materials brings about a number of problems, and demands on specific machining technologies, cutting tools and materials and selection of cutting conditions increase. Nevertheless, the chip machining technology underwent huge development lately, which has been documented by its massive use in industrial practice. Development in the area of stainless steel chip machining definitely targets increase of productivity during machining. Machining of stainless steels is influenced by five basic material properties: ductility, tendency to deformation strengthening, heat conductivity, hardness and abrasiveness. Since stainless steels are not exceptionally hard, then their high strength under increased temperatures, high durability and lower temperature conductivity cause their worse ability to be machined in comparison with regular carbon steels. Stainless steels have higher tendency for deformation hardening during machining process, which results in high temperature and mechanical loads on machining tools and also on machined surface. [1, 12]

2. ANALYSIS OF THE CURRENT STATUS

A large number of experts occupied themselves with machining of stainless steels, and produced several monographies and professional contributions listed in the Scopus and Sciencedirect databases. In their work Mastuda T. and Kimura T. [4] determined effects of temperature shocks on wear of cermet cutting tools. In their contribution Cep R. and Binder M. [5] proposed a tool and suitable cutting materials for machining of ISO M materials, according to ISO 513, and determined influence of cutting conditions on wear and durability of used tools. Fernandez-Abia A. I and Barreiro, J. [6] experimentally verified suitability of PVD coating use on advanced cutting tools for machining of austenitic stainless steels. Also manufacturers of cutting tools share in the research on machining of stainless steels by following with a number of experimental analyses with the goal to achieve productive and cost effective machining process. They wanted to achieve longer durability of machining tools primarily by adjusting structure and chemical composition of replaceable cutting edges.

Cutting tool material is exposed to high mechanical and temperature loads during machining that significantly affect its wear and durability. For selection of the right kind of machining material, load on the tool cutting edge is crucial. Primarily high strength of cutting edge is required, therefore it is suitable to use sintered carbide tools with higher cobalt content or fine-grained carbide ones for machining of stainless steels. Sintered carbides containing primary WC and Co bond combine resistance against wear and durability well, and belong to the most significant group of materials to machine wide assortment of stainless steels. Also selection of cutting tool geometry is a significant factor. Its significance comes from high strength and lower heat conductivity of corrosion resistant steels, and their tendency to deformation strengthening during machining. The cutting geometry must meet tool requirements for sufficient strength of cutting edge, smooth cutting action without vibrations, and maximum tool durability with minimum wear. [1, 3]

During machining of stainless steels cutting edge wear is characterized by creation of a notch at the back at the location of tool exit from the stroke. The creation of the notch at the back at the location of tool exit from the stroke is primarily caused by cutting edge that in this location bites into a layer of strengthened material, whose mechanical properties are significantly different from the basic material. Very often there are mechanical and intensive temperature loads that significantly affect sintered carbide tool durability. During these loads there are nicks caused to the tool cutting edge or the cutting edge is broken. If we magnify the tool cutting edges, we can observe cracks that occurred on the front and back planes. [1, 9]

3. TEMPERATURE SHOCKS CAUSED WHEN THE TOOL IS LEAVING THE MACHINED PART

In comparison with C45 standard carbon steel corrosion resistant steels show lower values of heat conductivity. This lower heat conductivity is the cause of high concentration of heat in areas, where it is created, and this causes extremely high temperatures and heat overload of the tool cutting part. This condition is also a reason for diffusion reactions that cause unwanted diffusion of elements in the contact part of tool cutting area. Due to fast changing cutting phase, during which the cutting edge heating and consequent cooling, while exiting the cut, occurs, cutting edge is exposed to cyclical loads by temperature shocks. These temperature shocks are a cause of alternate changes in pressure and tension stresses in the surface layers of exchangeable cutting inserts. The cyclical changes can cause microscopic cracks in the cutting edge area also. These cracks can cause brittle failure of the cutting edge due to their notch effect. [2, 12]

The cutting edge gets heated, when it penetrates into a machined part, which causes temperature of surface layers to increase very quickly. The neighboring layers that lay further from the surface are cooler and prevent the surface layers' extension that would correspond to their temperature. This causes surface tension at the surface that, in certain distance from the surface, changes into tension stress. At the moment when the cutting edge leaves the stroke, the surface layers start cooling intensively. Since temperature decrease of layer that are distant from the surface is not taking place this quickly, the surface layer experiences tension stress that changes into pressure stress within certain distance from the surface. This stress oscillation can, in superposition with mechanical shock stresses, cause occurrence of cracks and the follow-up brittle failure of the cutting edge. [2]

3.1 Cutting Edge Heat Cracks

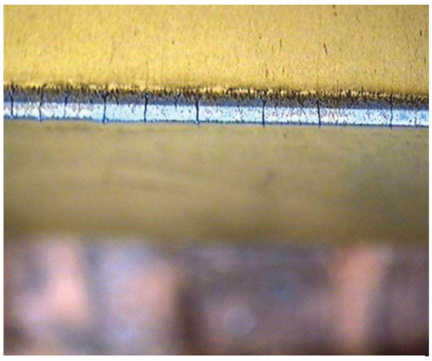

Fig. 1 Wear - cutting edge heat cracks [7]

According to the ISO 3685:1993 standard that deals with wear monitoring, cutting edge heat cracks are a form of wear fatigue that is caused by combination of temperature cycles (very fast changes in cutting edge temperatures), heat loading (differences in temperatures between hot and cool zones) and mechanical loads. Cracks occur along the whole length of the cutting edge, carbide particles can also be broken out, which is followed by chipping of the cutting edge. Heat cracks most often occur during milling and interrupted machining, and they present themselves by several cracks that are perpendicular to the cutting edge. It is important to recognize heat cracks before the wear causes crumbling of the cutting edge and bad quality of the machined surface. [7, 10]

4. EXPERIMENTAL ANALYSIS OF SINTERED CARBIDE INSERTS RESISTANCE AGAINST TEMPERATURE SHOCKS

Evaluation of resistivity of exchangeable sintered carbide cutting inserts against temperature shocks was performed by testing during front milling of a test machined piece with strongly interrupted cutting. The test was performed on the Kovosvit MAS - MCV 1270 POWER milling center with the Heidenhain iTCN 530 control system see **Fig. 2**. Sintered carbide exchangeable cutting plates with different content of cobalt and different sizes of grain were used for testing. 12 samples designated A to L were tested. [8]

Fig. 2 The Kovosvit MAS - MCV 1270 POWER milling center [8]

Table 1 Labeling and composition of sintered carbide inserts

Marking	Composition + WC	Cobalt content [%]	Grain size
A	+Cr_3C_2	7	0.6-1.2 μm
B	+Cr_3C_2	10	0.6-1.2 μm
C	+Cr_3C_2	13	0.6-1.2 μm
D	+TaNbC	8	1.2-2 μm
E	+TaNbC	10.2	1.2-2 μm
F	+TaNbC	12	1.2-2 μm
G	+ 19 hm% (Ti,Ta,Nb)C	8.6	1.6-3 μm
H	+12,5 hm% (Ti,Ta,Nb)C	8	1.6-3 μm
I	+12 hm% (Ti,Ta,Nb)C	11	1.6-3 μm
J	+20 hm% (Ti,Ta,Nb)C	9.6	1.6-2 μm
K	+Cr_3C_2	13	1.2-2μm
L	+TaNbC	9	1.6-3 μm

4.1 Cutting Parameters

Experimental milling of corrosion resistant steel represented by samples A-L was performed under preset cutting conditions:

- Tool diameter ØD = 100 mm
- Main cutting angle $\chi_r = 75°$
- Tooth count z = 1
- Cutting speed v_c = 420 m.min^{-1}
- Revolutions n = 1 319 min^{-1}
- Movement per tooth f_z = 0.1 mm
- Movement per revolution f = 0.1 mm
- Movement f_{min} = 132 mm.min^{-1}
- Cutting depth a_p = 2.5 mm
- Cutting width a_e = 50 mm
- Distance L = 300 mm

4.2 Measurement Process and Experimental Activity Analysis

Experimental part of sintered carbide tool resistance against temperature shocks analysis was focused on evaluation of crack lengths and determination of their frequency at the cutting tool edge. Measurement of individual crack lengths along the cutting tool edge corresponding to cutting depth was done on rasterizing electron microscope at the VSB-Technical University of Ostrava at the Faculty of Metallurgy and Material Engineering. The settings for back reflection of electrons (BES) and for topographic and material contrast were used for determination. The measured values were used to determine what chemical composition, cobalt content and grain size are suitable for production of exchangeable sintered carbide cutting plates.

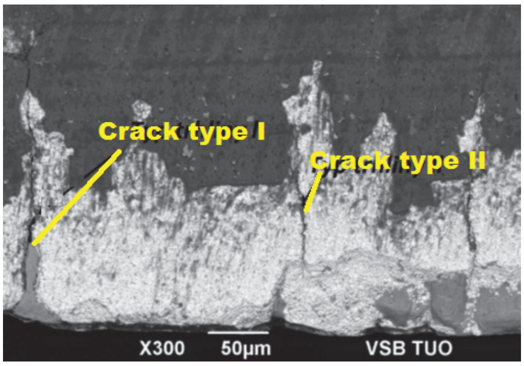

Fig. 3 The example of evaluated crack types

Two types of cracks were determined according to their character and location of origin based on observation - see **Fig. 3**:

- **Crack type I** - a crack starting at the cutting edge front,
- **Crack type II** - a crack occurring behind the cutting edge front.

4.3 Evaluation of Measured Cracks in Individual Samples

The first sample A had 13 cracks, 4 of type I and 9 of type II. It has composition of sintered carbide WC-Co+Cr_3C_2, the cobalt content 7 % and grain size 0.6 - 1.2 µm.

Table 2 Measured cracked lengths in the sample **A**

A	Crack lengths (µm)	Crack type	A	Crack lengths (µm)	Crack type
1	140.75	I	7	114.81	II
2	33.33	II	8	227.77	I
3	61.11	II	9	79.63	II
4	74.074	II	10	203.7	II
5	242.59	I	11	148.15	II
6	72.22	II	12	203.7	II
7	114.81	II	13	101.85	I

Sample D contains only one type I crack, which is, however, rather long. This sample composition is +TaNbC with the cobalt content of 8 % and the grain size of 1.2 - 2 µm.

Table 3 Measured crack lengths in sample **D**

D	Crack lengths (µm)	Crack type
1	303.7	I

Sample G contains only 3 cracks, all of them type I. The sample composition is +19 vol. % (Ti,Ta,Nb)C with the cobalt content of 8.6 % and the grain size of 1.6 - 3 µm.

Table 4 Measured crack lengths in sample **G**

G	Crack lengths (µm)	Crack type
1	301.85	I
2	316.66	I
3	277.77	I

Sample J contains only 2 cracks, both of them type I. The sample composition is +20 vol. % (Ti,Ta,Nb)C with the cobalt content of 9.6 % and the grain size of 1.6 - 2 μm.

Table 5 Measured crack lengths in sample **J**

J	Crack lengths (μm)	Crack type
1	296.29	I
2	307.41	I

This results show that the least number of cracks were in sample D, namely one crack with the length of 303.7 μm. In this sample a large part of its cutting edge front was broken off, the broken off part contained another crack that, however, was thus not possible to measure. Samples G and J show small number of cracks without large broken off parts of the edge. Both samples have comparatively long cracks, on the average about 300 μm long. The cobalt content is similar in both samples. Sample F has 5 cracks on the edge only, however, opposite to samples G and J these cracks measure about 200 μm on the average. The following three samples designated H, K and L that have 7 to 8 cracks and have their cracks shorter. In samples A, C and I we counted 12 to 13 shorter cracks with lengths about 131 to 135 μm. The last samples are sample E that has 16 cracks with average length of about 186 μm and sample B with 20 cracks of average length about 166 μm.

CONCLUSION

The main goal of this experiment was to determine numbers, types and lengths of individual cracks in order to propose suitable chemical composition and cobalt content of exchangeable sintered carbide inserts. The inserts were used in machining of corrosion resistant 1.4301 (X5CrNi18-10) steel, during which they were exposed to temperature shocks that caused occurrences of edge cracks at cutting tool edges and thus lowered durability of these tools.

The cracks in sintered carbide propagated along grain boundaries. In sintered carbides with fine-grained structure the cracks propagated faster and had tendency to have a linear shape. In samples with larger grains the cracks occurred after the temperature shock load and had tendency to propagate chaotically. Samples with the least number of occurring cracks were selected from a large amount of processed data. The best was sample D that has only one crack, however, a large amount of material was broken off at its cutting edge. Sample J contains two cracks, and together with sample G that contains three cracks, they have the same WC-Co+(Ti,Ta,Nb)C chemical composition and they came out best from the testing.

In order to determine crack types, samples were divided into three groups within the matrix, according to their chemical composition and cobalt content. The first group that contains samples A, B, C and K has the largest occurrence of type II cracks. The best out of this group is sample K with seven cracks and the cobalt content of 13 %. This sample has four type I and three type II cracks. The next group contains samples D, E, F and L, the best being sample F with three type I and two type II cracks. The last group of samples contains samples G, H, I, and J and has the least number of cracks. The best in this group is sample J with two type I cracks and the cobalt content of 9.6 % in the matrix. In order to evaluate crack lengths in dependency on cobalt content we have first determined average crack lengths that were later associated with corresponding contents of cobalt in the samples. Samples D, G and J have the longest average crack lengths; on the contrary the best are samples A and L with the smallest average crack length. Since, for this analysis, the most important was the number of occurring cracks, sample J appears the most suitable for production of exchangeable sintered carbide inserts.

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