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WEAR MECHANISM OF CEMENTED CARBIDE CUTTING TOOL IN THE TURNING OF 316L STAINLESS STEEL

S. Saketi[1,2], U. Bexell[1] and M. Olsson[1,2]
Dalarna University, Material Science, Sweden
[1] ssi@du.se, ubx@du.se, mol@du.se
[2] Uppsala University, Material Science, Sweden.

ABSTRACT:

Austenitic stainless steels are regarded as difficult to machine materials due to the high work hardening tendency, low heat conductivity and especially the strong bonding against the tool rake face which leads to transfer and formation of build-up layers during the machining process. The formation and subsequent detachment of build-up layers may result in adhesive wear and involve tribochemical reactions.
In the present work, the mechanisms behind the crater wear of uncoated cemented carbide inserts in the turning of 316L stainless steel is characterized using high resolution scanning electron microscopy (SEM) and Auger electron spectroscopy (AES). The influence of (Ta, Nb)C on the wear resistance and worn surface morphology is also investigated. The results show that the wear behind crater formation involve both tribochemical and mechanical wear mechanisms.

Keywords: Cemented carbide; stainless steel 316 L; turning; SEM; AES.

INTRODUCTION

The continuous development of WC-Co cemented carbides used for metal cutting tools has led to materials that have high resistance to different wear mechanisms. Increasing the WC fraction and/or decreasing the WC grain size will increase the hardness, and in many cases the wear resistance, while increasing the Co content and/or increasing the WC grain size will increase the fracture toughness. In some grades, complex carbides such as TaC, TiC and NbC are added to the microstructure to further improve the wear resistance.

Tool wear resulting in the formation of a crater on the rake face of a cemented carbide inserts during turning has been the subject of a number of investigations. Adhesive wear [1], diffusion and dissolution wear [2, 3] are commonly cited as the major wear mechanisms of cemented carbide tools. In order to understand the mechanisms behind crater formation of cemented carbide inserts it is vitally important to evaluate the chip/tool rake face interface and the formation of adhering build-up layers. During the turning of stainless steel, small chip fragments are welded against the rake face surface. Due to the high contact pressure in combination with deformation and frictional heat, the development of a crater on the rake face will occur. Although there are many papers focusing on understanding the mechanisms behind the crater wear of uncoated cemented carbide inserts in the machining of stainless steel no studies of the chip/tool rake face using Auger electron spectroscopy have been reported. The objective of the present paper is to evaluate the mechanisms behind crater wear of uncoated cemented carbide inserts in the turning of 316L by using scanning electron microscopy and Auger electron spectroscopy (AES).

MATERIALS AND METHODS

Orthogonal turning tests, using a work material of SANMAC 316L (chemical composition in wt%; <0.009 C, 0.005 Al, ≤0.31 Si, ≤0.031 P, ≤0.023 S, 0.003 Ca, 0.048 V, 16.86 Cr, 1.71 Mn, 10.25 Ni, 2.04 Mo, bal Fe), were performed on a surface-machined workpiece. The cutting velocity, v_c, was 240 m/min, the depth of cut, a_p, was 2 mm, and the radial feed rate, f_n, was 0.2 mm/rev. The cutting tests were run for different cutting times ranging from 3 sec to 50 sec.

Sandvik Coromant inserts, TCMW 16T304, without geometry were used in turning tests. The inserts were made from cemented carbide (89.6 wt% WC, 1.6 wt% (Ta,Nb)C, 8.8 wt% Co, mean WC grain size 1 µm).

The worn rake face of the inserts was characterized using a Zeiss Ultra 55 FEG-SEM equipped an energy dispersive X-ray spectroscopy (EDS) system (Oxford Instruments Inca). AES analysis using a Ulvac-PHI 700Xi Scanning Auger Nanoprobe was performed at an acceleration voltage of 10 kV and a beam current of 10 nA. AES depth profiling was performed using 1.0 kV Ar+ ion sputtering. The sputter rate was 4 nm/min as measured on a Ta_2O_5 reference sample with known thickness (30 nm). Computer software from PHI-Matlab was used to evaluate the Auger depth profile data.

In order to remove the adhered work material and expose the worn rake face surface, some of the worn inserts were etched in an acidic solution consisting of 75 vol% concentrated hydrochloric acid and 25 vol% concentrated nitric acid for 15 minutes at room temperature. Cross-sections, parallel with the chip sliding direction, of the worn inserts, aimed for SEM and EDS analysis, were prepared by cutting followed by conventional metallographic grinding and polishing techniques using 1 µm diamond in the last step.

RESULTS AND DISCUSSION

After the cutting tests, all cutting inserts show extensive transfer of work material to the rake face and the flank covering most part of the worn areas. Etching of inserts show that a crater was formed on the rake face of the insert already after some seconds. Figure 1 shows the worn cemented carbide morphology within the crater after a cutting time of 12 seconds. As can be seen, the worn cemented carbide surface is relatively smooth but reveals a large number of fine ridges parallel with the chip flow direction. The height of these ridges was found to be 1-2 µm and EDS analysis show that the ridges always originate due to the protrusion of complex carbides in the crater, i.e. the higher wear resistance of the complex carbides make these to protrude from the surface and protect the material behind (with respect to the chip sliding direction) from wear. The protection effect will last for a distance of 20-30 µm and result in the observed ridges. The cross-section in Figure 2 illustrates the ridge formation mechanisms where a complex carbide protrudes from the surface and protects the WC/Co microstructure behind it from wear. The higher wear resistance of complex carbides in the machining of steel is usually explained by a lower solubility in iron as compared with WC, see e.g. ref. [4].

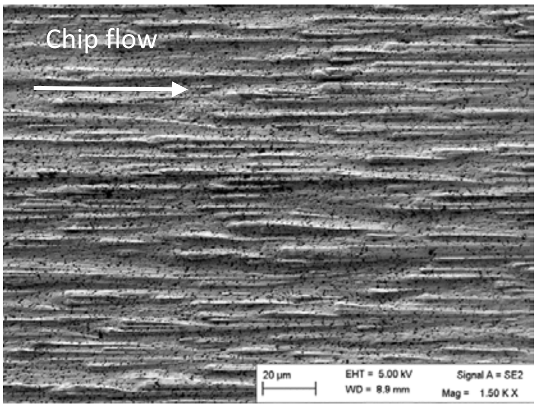

Figure 1. Wear characteristics of worn cemented carbide within the crater on the insert rake face. Note the formation of ridges parallel with the chip flow direction. Cutting time 12 seconds.

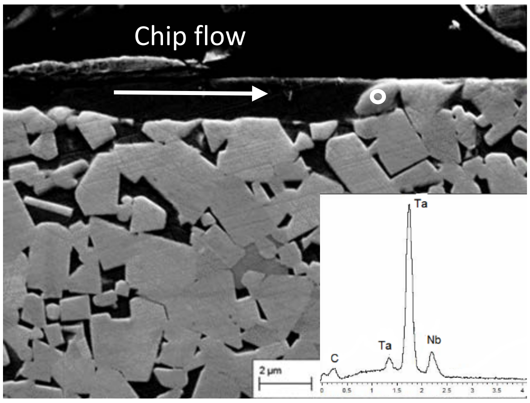

Figure 2. Cross section cemented carbide after 12 seconds turning at cutting speed of 240 mm/min and feed rate of 0.2 mm/rev.

At a higher magnification, see Figure 3a, it can be seen that the WC grains in the crater region display two different surface morphologies. While some WC grains show a smooth surface, some WC grains show a slightly rougher fine crystalline surface morphology. AES analysis of these types of surface reveal that the smooth WC grains show the expected WC composition, see Figure 3b. In contrast, the WC grains with a fine crystalline surface morphology show the presence of a thin layer with significant amounts of O, Cr and Fe which decreases with increasing sputtering depth, which indicates the presence of a tribochemical (diffusion) wear mechanism. Complex layer of Fe, O, W and C on the WC grain surface with fine crystalline morphology while the smooth one is pure WC.

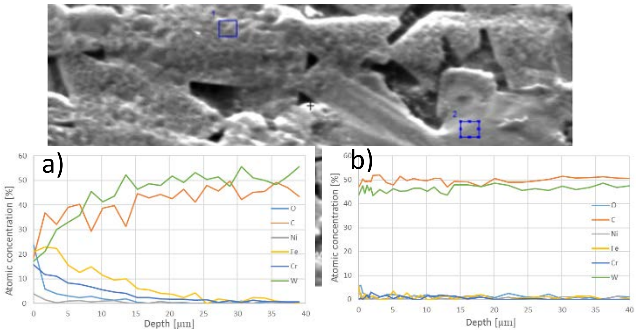

Figure 3. AES depth profiles showing the element composition of the two types of WC grain surface morphologies found in the crater region. Cutting data; v_c: 240 m/min, cutting time 12 seconds.

CONCLUSIONS

- The crater formed on the rake face is due to the action of both tribochemical and mechanical wear mechanisms. However, at high cutting speeds (high temperatures) tribochemical wear (diffusion) is the dominant wear mechanism.
- Due to the lower solubility of (Ta,Nb)C in iron at high temperature, as compared with WC, protruding (Ta,Nb)C grains will initiate ridge formation in the formed crater.

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