WEAR OF TURNING TOOL DURING MACHINING OF STEELS USED IN SURGICAL INSTRUMENTS

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Abstract. The paper presents an assessment of the wear rate of turning tool blades during machining of steels applied in medical industry. The subjects of the research were stainless steels X20Cr13 (1.4021) and X8CrNiS18-9 (1.4305) used in production of surgical instruments. An experiment was carried out to assess the wear of multi-edge turning inserts with CVD coatings (Pafana CNMG 12 04 08 ZSZ and Sandvik CNMA 12 04 12-KR 3205), and an uncoated turning insert (Sandvik CNGA 12 04 08 T0102 WG 650). The wear was measured by the direct wear indicator VB_C. On the basis of the results obtained for both X20Cr13 and X8CrNiS18-9, it was found that the Pafana CNMG 12 04 08 ZSZ turning insert had the best wear resistance during machining. The cutting path of Pafana CNMG 12 04 08 ZSZ was about 25 % longer than Sandvik CNMA 12 04 12-KR 3205 and about 300 % longer than Sandvik CNGA 12 04 08 T0102 WG 650. It was also found that each turning insert revealed a linear wear.

Keywords: tool blade durability, tool blade wear, turning, steel, surgical instruments.

Introduction

Surgical instruments are a group of medical devices. It covers a wide range of tools that differ in terms of functionality and geometricity. The materials from which surgical instruments are manufactured have to comply with stringent requirements. The expectations are defined in suitable usable features, high mechanical properties, corrosion resistance and extremely good biocompatibility [1-5]. New surgical robots use many types of instruments [6-9].

Widely used materials for surgical instruments are high-quality grades of stainless steel, especially austenitic and martensitic ones. These steel grades exhibit high resistance to air, moisture, and weak solutions of salts and acids. Corrosion resistance is endowed to a steel material by its feasibility to be passivated, which directly depends on the chemical composition. Passivation gives an oxide layer, which protects its substrate against ambient conditions and can replenish itself. In stainless steel, this effect is caused by chromium as an alloy additive, and only when its content is 10.5 % or higher. With the chromium content corrosion resistance grows [10].

Stainless steel grades vary in machinability. Ferritic and martensitic steels are relatively well machinable, while high-alloy austenitic grades exhibit a very poor machinability. Machinability of these steels depends first on high tendency to strain hardening, creating a build-up edge, low heat conductivity and capacity, accelerated cutting edge wear, and chip control problems. It is then critical to choose the correct machining parameters, materials and geometry of tools. CAD/CAM systems are recommended to use for modelling 3D virtual product and for generating a cutting path [11-15].

Cemented carbide tools are commonly used for machining of stainless steel workpieces. Additionally, they are protected with coatings to inhibit wear. Cutting tools made from cemented carbide with multi-layer coatings (with up to several dozen coating layers) have been increasingly popular. Another trend in cutting tools is their preservation with single-layer coatings of polycrystalline diamond (PCD) or common boron nitride (CBN). The protective coatings can be deposited to the working surfaces of cutting tools with two methods: CVD (Chemical Vapour Deposition) or PVD (Physical Vapour Deposition) [16-17].

The cutting ability and operation of cutting tools are largely affected by the protective coating material. Protective coatings increase the machining efficiency (which means higher technological parameters) and extend the cutting edge durability [18-19].

Stainless steel machining is recommended to be done with multi-edge tool inserts, the wear of which should be monitored. The wear of a cutting edge is determined by its loss of cutting ability properties over time. This process is very complex and defined by many factors. Wear occurs near the cutting edge over the flank face and/or the tool face. Several types of wear exist: abrasive, chemical, adhesive, thermal, and mechanical. During stainless steel machining, the following wear phenomena

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occur very often: focused cutting edge wear, VB_N; cutting edge plastic deformation; and relatively soon accelerated chase widening [20-23].

The cutting tool edge wear rate is determined with direct and indirect indicators. Indirect ratio defines changes in physical quantities caused by wear, including reduction in dimensional and shape accuracy, cutting force increase, reduction in surface quality (a lot of scientific papers focus on the study of surface roughness parameters), burr formation, cutting temperature increase, and growth in vibration and noise during machining [24-31]. The wear of machining tools is particularly important manufacturing elements with free-form surfaces [32-36] as well as in mould components production [37-42].

Materials and methods

The objective of this work was to assess the wear rate of turning tools during machining of stainless steel grades for medical instruments.

Experimental turning of the tested grades was done with a DMG MORI CTX450 turning centre with the Sinumeric 840D control system. The specimens were fabricated from X20Cr13 (1.4021) and X8CrNiS18-9 (1.4305) steel grades. X20Cr13 stainless steel has martensitic structure, while X8CrNiS18-9 is austenitic steel.

Turning was carried out with the following turning inserts:

- CNMG 12 04 08 ZSZ (multi-edge carbide insert of Pafana, coated with Ti(C,N) + Al2O3, CVD);
- CNMA 12 04 12-KR 3205 (multi-edge carbide insert of Sandvik, coated with Ti(C,N) + Al2O3 + TiN, CVD),
- CNGA 12 04 08 T0102 WG 650 (multi-edge ceramic insert of Sandvik, uncoated).

The specimens were fabricated into cylinders 12 mm in diameter. The specimens were fabricated by turning at a cutting length l = 150 mm and with fixed cutting parameters: cutting depth a_p = 1 mm, cutting speed v_c = 75 m/min, and feed f = 0.12 mm/rev. The machining program was developed in CAM NX 11.

The wear rate was analysed and defined as VB_C, the width of flank wear land in the corner area (according to PN-ISO 3685:1996, Tool-life testing with single-point turning tools). The conditions of the insert cutting edges were evaluated before machining and after each machining test under the Keyence VHX-5000 digital microscope. The turning insert wear was monitored after each tool pass. The testing was continued until catastrophic failure of the tested turning tool.

Results and discussion

Fig. 1 shows the images of the successive wear stages on the Pafana CNMG 12 04 08 ZSZ tool insert during machining of X8CrNiS18-9 stainless steel. Each image was captured after every 5th pass.

Number of passes	5	10	15	20	25	30	35
Cutting lenght L [mm]	750	1500	2250	3000	3750	4500	5250
							
Number of passes	40	45	50	55	60	65	70
Cutting lenght L [mm]	6000	6750	7500	8250	9000	9750	10500
							

Fig. 1. **Images of successive wear stages on Pafana CNMG 12 04 08 ZSZ tool tip during machining of X8CrNiS18-9 stainless steel (each image was captured after every fifth pass)**

Given a very high number of test results, the direct wear ratio VB_C was presented for every fifth turning tool pass. Fig. 2 shows the trend of VB_C as a function of the cutting path length L during machining of X20Cr13 stainless steel with the following turning inserts: CNMG 12 04 08 ZSZ, CNMA 12 04 12-KR 3205, and CNGA 12 04 08 T0102 WG 650.

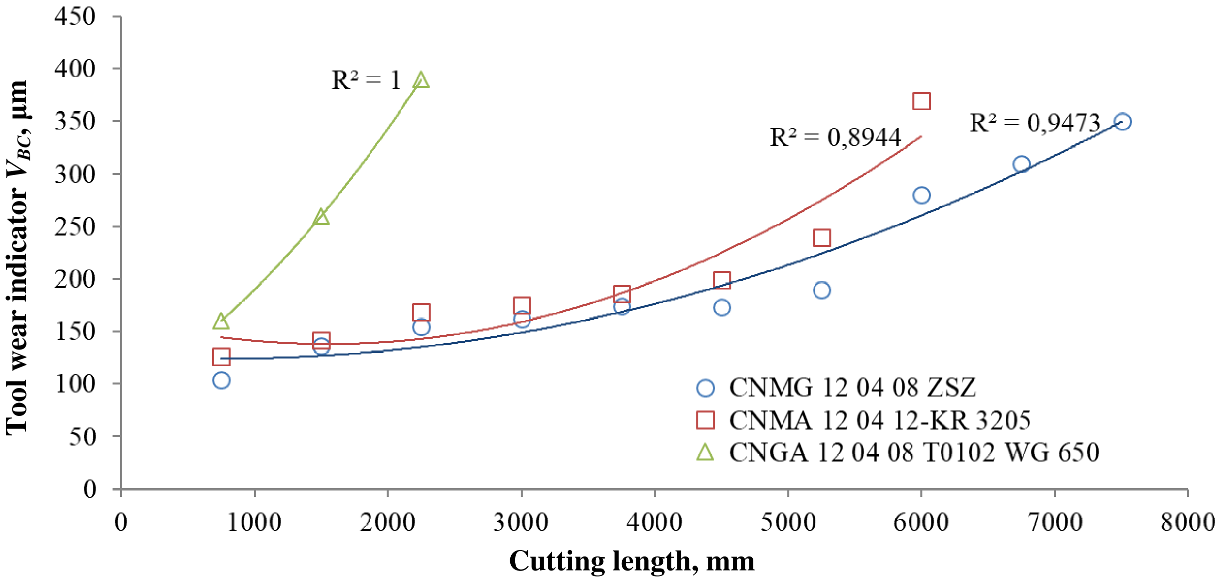

Fig. 2. **Trend of tool wear indicator V_{BC} as function of cutting path length L during machining of X20Cr13 stainless steel**

The test results for the width of the flank wear land VB_C during machining of X20Cr13 stainless steel grade were approximated with a second-degree polynomial function. Equation (1) shows the trend of VB_C for the Pafana CNMG 12 04 08 ZSZ tool insert. Equation (2) presents the trend of VB_C for the Sandvik CNMA 12 04 12-KR 3205 tool insert. Equation (3) shows the trend of VB_C for the Sandvik CNGA 12 04 08 T0102 WG 650 tool insert.

$$VB_c = 5 \cdot 10^{-6} L^2 k_2 - 0.0075 L k_1 + 126.82 k_0 \tag{1}$$

$$VB_c = 10^{-5} L^2 k_2 - 0.031 L k_1 + 162.09 k_0 \tag{2}$$

$$VB_c = 3 \cdot 10^{-5} L^2 k_2 - 0.733 L k_1 + 90 k_0 \tag{3}$$

where k_i are the polynomial unit factors being the unit ordinals: $k_2 = 1$ μm·mm², $k_1 = 1$ μm·mm, $k_0 = 1$ μm.

The trend of VB_C as a function of the cutting path length L during machining of X8CrNiS18-9 stainless steel with the CNMG 12 04 08 ZSZ, CNMA 12 04 12-KR 3205 and CNGA 12 04 08 T0102 WG 650 tool inserts is shown in Fig. 3.

The test results for the width of the flank wear land VB_C during machining of X8CrNiS18-9 stainless steel grade were approximated with a second-degree polynomial function. Equation (4) shows the trend of VB_C for the Pafana CNMG 12 04 08 ZSZ tool insert. Equation (5) presents the trend of VB_C for the Sandvik CNMA 12 04 12-KR 3205 tool insert. Equation (6) shows the trend of VB_C for the Sandvik CNGA 12 04 08 T0102 WG 650 tool insert.

$$VB_c = -3 \cdot 10^{-6} L^2 k_2 + 0.072 L k_1 + 114 k_0 \tag{4}$$

$$VB_c = 2 \cdot 10^{-6} L^2 k_2 - 0.0018 L k_1 + 130.43 k_0 \tag{5}$$

$$VB_c = 10^{-6} L^2 k_2 - 0.0107 L k_1 + 101.85 k_0 \tag{6}$$

where k_i are the polynomial unit factors being the unit ordinals: $k_2 = 1$ μm·mm², $k_1 = 1$ μm·mm, $k_0 = 1$ μm.

The analysis of the direct wear ratio VB_C revealed that each tool insert had wear progression approximate to linear. The fastest wear was found in the CNGA 12 04 08 T0102 WG 650 turning insert, which due to its material was not insensitive to vibrations of the machine tool/holder/workpiece/tool system.

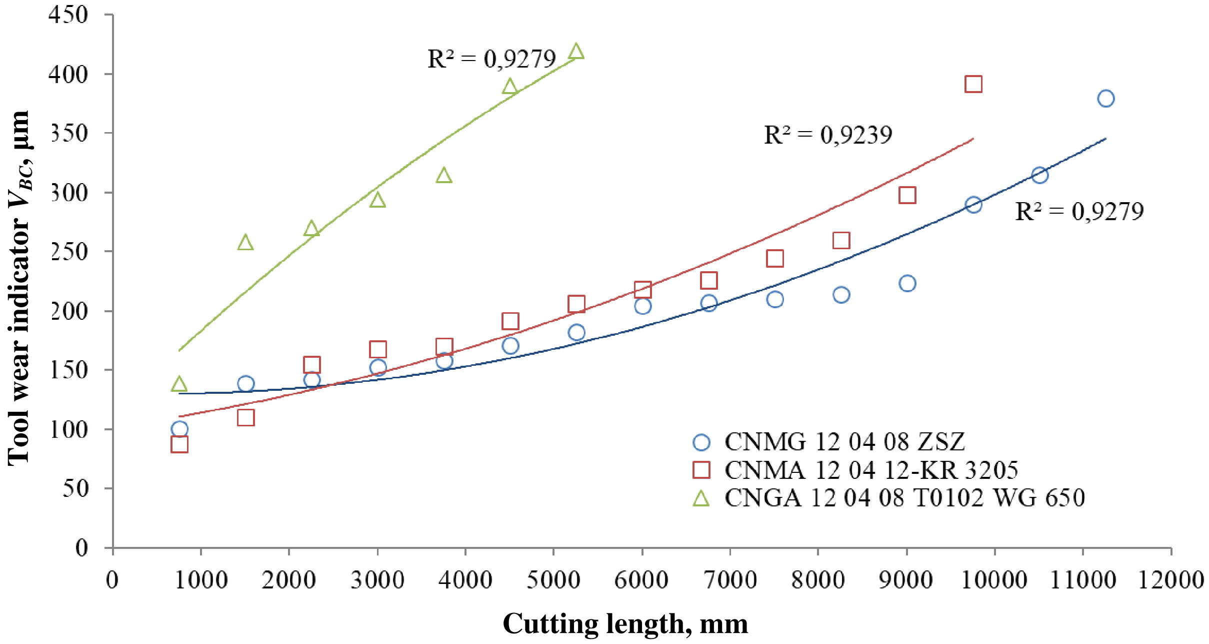

Fig. 3. **Trend of tool wear indicator V_{BC} as function of cutting path length L during machining of X8CrNiS18-9 stainless steel**

Conclusions

The experimental test results allowed the following conclusions:

1. X8CrNiS18-9 stainless steel grade had better machinability than X20Cr13. While the former was austenitic, its sulphur content favoured better machinability. This was confirmed with a relatively longer cutting path when machining X8CrNiS18-9. Depending on the tested tool insert, the overall cutting path until the catastrophic failure of the tool insert was longer between 45 % and 175 % than the overall cutting path when machining X20Cr13.
2. In both stainless steel grades tested herein, the cutting path of Pafana CNMG 12 04 08 ZSZ was about 25 % longer than of Sandvik CNMA 12 04 12-KR 3205 and about 300 % longer than Sandvik CNGA 12 04 08 T0102 WG 650.
3. Considering the durability of replaceable multi-edge tool inserts, it is recommended to machine the tested stainless steel grades with Pafana CNMG 12 04 08 ZSZ.

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