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Microscopic Wear Analysis of Indexable Inserts after Machining of 34CrNiMo6 Steel

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Machining is an important part of the manufacturing process in the engineering field. Turning is one of these areas. At present, almost exclusively exchangeable cutting inserts are used in production machining. The article describes the research in the field of their wear, where the electron microscopy was used to evaluate the results. Electron microscopy is a very important aid in research in many areas not only of human activity and also is the important aid in the field of mechanical engineering and manufacturing technologies. The results thus obtained can make in a given area it clearer and better document the resulting situation. Within the experiments, selected cutting inserts (WPP10S, WPP20S) were used and the given material was machined (34CrNiMo6 steel). The cutting speed was different depending on the type of insert (WPP10S 120 and 140 m·min^{-1}, WPP20S 80, 100 and 120 m·min^{-1}). The electron microscope Tescan Vega 3, which is available in the workplace where the experiment was conducted, was used to evaluate the resulting tool wear. As part of experiments was also realized the composition analyze of used cutting inserts. Analyzes of the machined material were also performed to confirm the declarations from the supplier.

Keywords: Turning, Cutting Insert, Tool Wear, Steel, Electron Microscopy

1 Introduction

Machining is one of the frequently used production technologies in the field of metal materials processing. In this machining, indexable inserts are currently almost exclusively used. So, durability of the tool and its resulting wear (form, location, shape, etc.) are important factors indicating the production process, its course and ultimately its suitability. Therefore, further analysis of the results obtained in this way is important and can bring further answers or questions. [1, 2, 3]

There is always an effort to make the cutting insert, like other production tools, predictable in the machining process both from the point of view of tool life and the machining results from the point of view of the resulting accuracy of the workpiece and the required surface integrity. A better reaction of VBD to the machined material and cutting conditions is ensured, apart from geometric adjustments, by their coating, of course. Coatings are applied to VBD by different methods and different types of coatings are used. This always depends on the specific VBD application. [4, 5, 6, 7]

Electron microscopy is one of the methods that can be used when evaluating the results of cutting insert life tests. Its use provides more detailed information, better display of selected places and expands the possibilities of interpretation and further confirmation of the results already obtained. Thus, SEM and EDS analyzes were used, among other things, to analyze the results of the durability tests of the insert. [8, 9, 10]

Recently, SEM (scanning electron microscope) is also often used to evaluate situations (structure, wear, layer, etc.) of various technical objects. The advantage of SEM over a classic optical microscope is a large depth of focus and the possibility of greater magnification, which is a great benefit when evaluating the tool wear of the cutting insert for example. [11, 12]

Analysis using SEM can be well complemented by EDS (energy dispersive spectrometer) analysis, when it is possible to obtain additional information about the elemental composition of the analyzed surface, which can provide additional interesting supplementary and complementary information when evaluating tool wear. [13, 14, 15]

2 Experiment

In the experiment was machined steel 34CrNiMo6 on CNC lathe DOOSAN Lynx 220L with control system FANUC. The Tescan Vega 3 electron microscope was used for image analysis. [16, 17] On the fig. 1 is presented work zone on the machine with workpiece and tool.

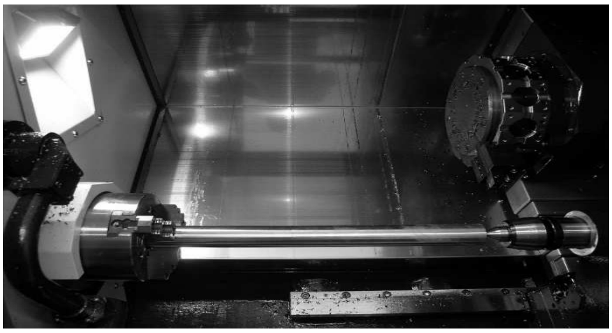

Fig. 1 *Work zone on the machine with workpiece*

2.1 Machined material

The machined material, after which the wear of the used inserts was evaluated, was chromium-nickel-molybdenum steel marked 34CrNiMo6 according to EN 10 027-1 (1.6582 according to EN 10 027-2), which was hardened to 40÷44 HRC. In the Tab. 1. the chemical compositions according to the standard of this material and the spectrometric analysis are summarized, where the composition declared by the supplier was verified by means of Q4 Tasman intrinsic spectrometer. Fig. 2 shows the structure of the material that has been examined to verify the material declaration, too. [18, 19]

Tab. 1 *Chemical composition of cutted material 34CrNiMo6 according of standard and analysis [18, 19]*

Material designation		Chemical composition in wt. %							
EN 10 027-1	EN 10 027-2	C	S	Mn	P	S	Cr	Mo	Ni
34CrNiMo6	1.6582	0.3÷0.38	max 0.4	0.5÷0.8	max 0.035	max 0,035	1.3÷1.7	0.15÷0.3	1.3÷1.7
Spectrometer Q4 Tasman		0.342	0.329	0.57	>0.005	>0.001	1.519	0.193	1.470

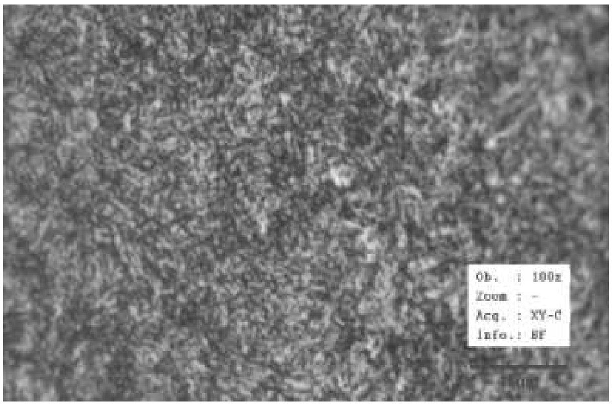

Fig. 2. *Microstucture 34CrNiMo6, mag. 1000x*

Initial sizes of workpieces were for diameter 60 mm and for length 350 mm.

2.2 Removable cutting inserts

Two removable inserts were used, namely CNMG 120408-MP3 WPP10S and CNMG 120408-MP3 WPP20S. WPP10S is mainly designed for machining steel. It is coated by chemical vapor deposition of TiCN and Al_2O_3. It shows good wear resistance, but lower toughness. It has a core consisting of a tungsten carbide and titanium carbide with a cobalt binder. WPP20S has chemical composition practically the same, there is only another architecture (thickness of applied coatings). As a result, this type exhibits higher toughness but less resistance to abrasive wear. It can therefore also be used for more difficult to machine materials. [20, 21, 22]

Fig. 3 shows cutting inser WPP10S, Fig. 4 shows an EDS analysis of this unused insert and Fig. 5 shows EDS anlysis fracture of this insert. The bottom coating of 11 μm thickness was formed by TiCN according to EDX analysis. The top coating consists of Al_2O_3 and is 8 μm thick. [23, 24]

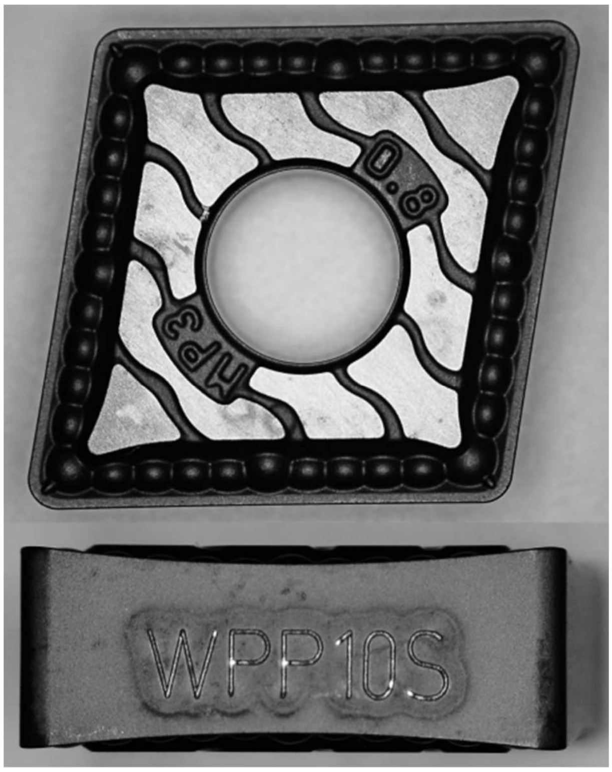

Fig. 3 *WPP10S insert*

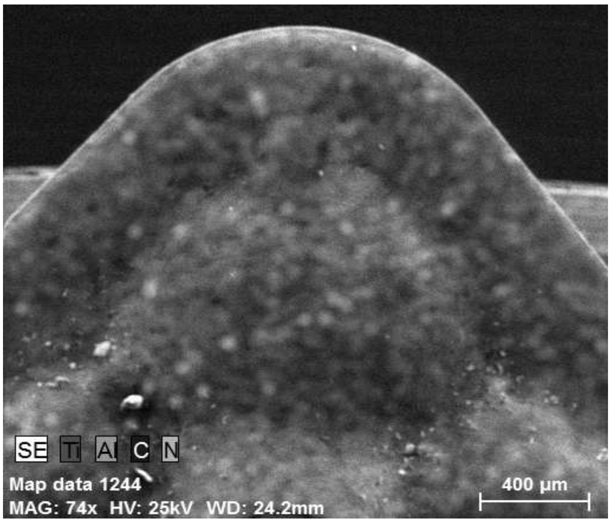

Fig. 4 *EDS analysis, unused WPP10S (front)*

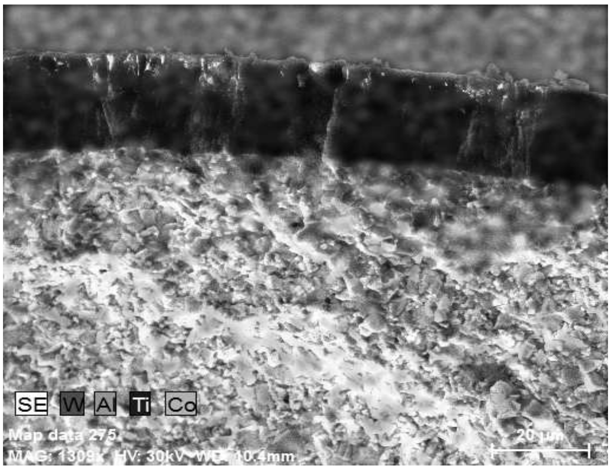

Fig. 5 *EDS analysis WPP10, fracture*

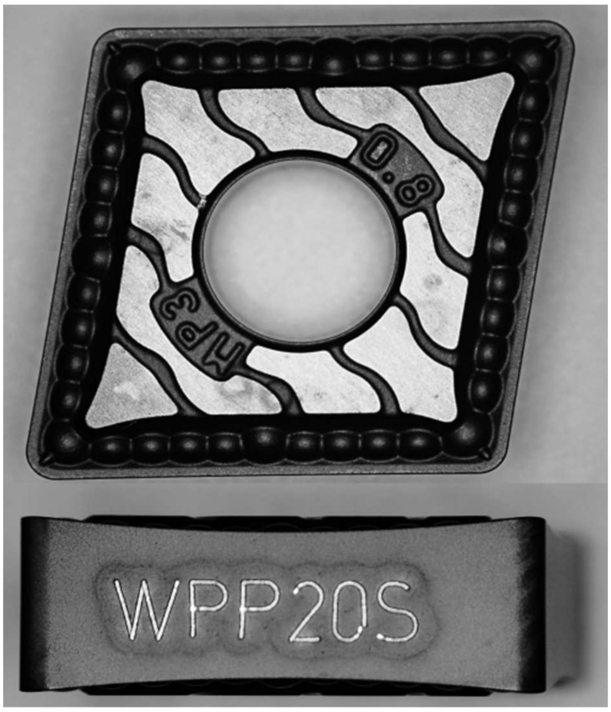

Fig. 6 *WPP10S insert*

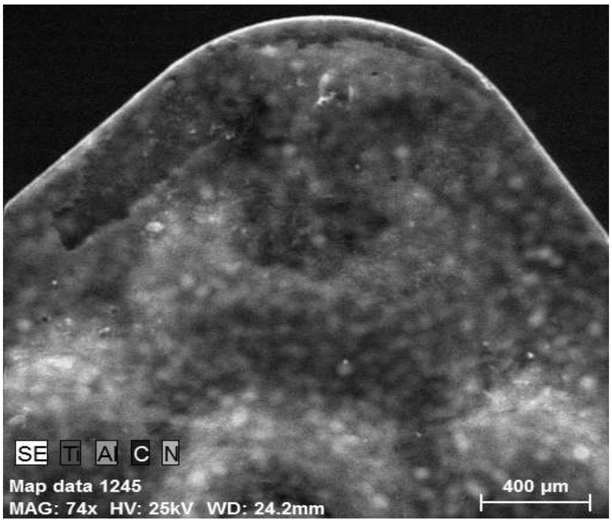

Fig. 7 *EDS analysis, unused WPP20S (front)*

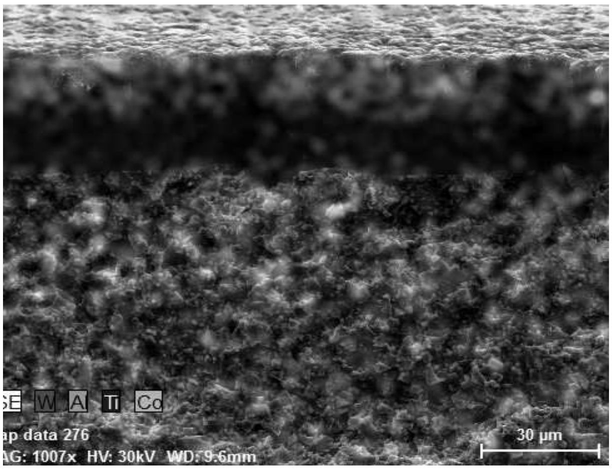

Fig. 8 *EDX analysis WPP20S, fracture*

Fig. 6 shows cutting inser WPP20S, Fig. 7 and 8 show EDS analyzes for this inser, again showing that the substrate is composed of tungsten carbides, titanium carbides, and cobalt binder. The bottom coating then has a thickness of 18 μm and is made up of TiCN. The topcoat from Al_2O_3 has a thickness of 15 μm.

2.3 Cutting conditions

The basic machining conditions for turning were:

- a_p = 1.5 mm,
- f = 0.3 mm·rot^{-1},
- workpiece supported in the tip,
- continuous cut.

The cutting speeds were different for each type of insert and were chosen based on previous experiments to ensure the stability of the cutting process due to the machined material and the machine used. They were in the range v_c = 80 to 140 m·min^{-1}. The cutting speed was different depending on the type of insert, see Tab. 2.

***Tab. 2** Velocity of cutting for machining of steel 34CrNiMo6*

Type of cutting insert	v_c [m·min^{-1}]
CNMG 120408-MP3 WPP10S	120
	140
CNMG 120408-MP3 WPP20S	80
	100
	120

3 Microscopic examination of the resulting wear

The cutting insert WPP10S was used at two cutting speeds, namely 120 m·min^{-1} and 140 m·min^{-1}. The cutting insert WPP20S was used at three cutting speeds, as a 80 m·min^{-1}, 100 m·min^{-1} and 120 m·min^{-1}. Fig. 9 and 10 show the resulting wear for WPP10S and Fig. 11, 12 and 13 the resulting wear for WPP20S. These images were taken with the stereomicroscope Olympus SZX103. The actual wear measurement of the inserts was realized on average at least every 2 minutes of machining.

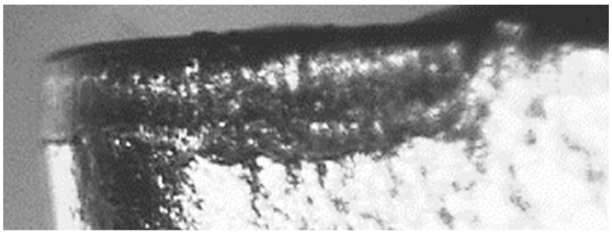

***Fig. 9** Final tool wear, WPP10S,120 m·min^{-1}*

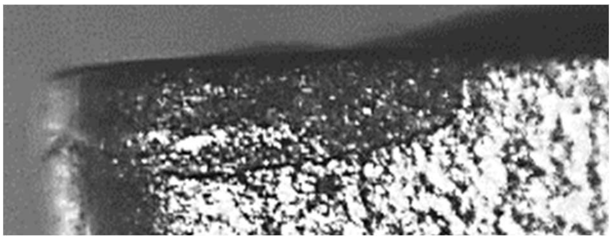

***Fig. 10** Final tool wear, WPP10S, 140 m·min^{-1}*

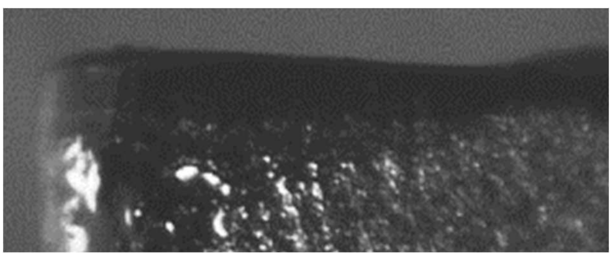

***Fig. 11** Final tool wear, WPP20S, 80 m·min^{-1}*

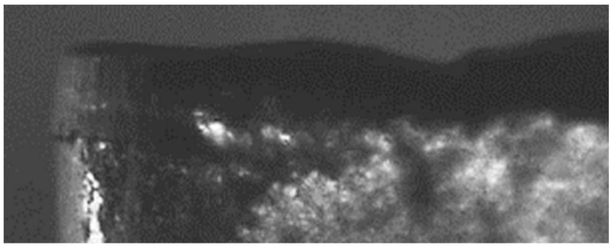

***Fig. 12** Final tool wear, WPP20S, 100 m·min^{-1}*

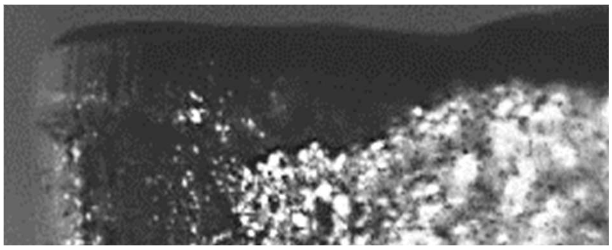

***Fig. 13** Final tool wear, WPP20S, 120 m·min^{-1}*

The surface roughness Rz of the obtained surface was also measured with each VB measurement (Hommel Tester T500 device, Rz according to the standard ČSN EN ISO 21920-2), as the development of this value may also indicate the tool condition, see fig. 14 and 15. The variance in the obtained roughnesses for all examined inserts was very small and it could be concluded that even after reaching the experimental tool wear value all inserts were still able to be reused, which was also confirmed by electron microscopy examination where no insert with the resultant wearing (VB_{max} = 0.3 mm) has not yet shown significant damage.

***Fig. 14** Measurement of Rz surface roughness with Hommel Tester T500*

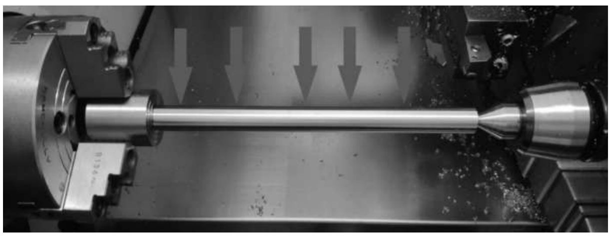

***Fig. 15** Places for measuring the roughness of the machined surface*

The resulting wear was, in addition to the usual procedures, also analyzed, as mentioned above, by electron microscopy.

3.1 Cutting insert WPP10S, v_c = 120 m·min^{-1}

For this speed, the tool life of the insert was 21.6 min, ie after this machining time the tool wear was VB_{max} = 0.3 mm, how it was determined by experiment (in according with standard ISO 3685).

As shown by SEM and EDS analysis (Fig. 16, 17), this insert showed signs of wear most likely to be abrasive in origin. Furthermore, it was apparent that both coating layers were broken in the tip region and the insert substrate was exposed. The main blade showed signs of abrasive wear. When looking at the main ridge, there was a "pothole" behind the depth of cut area, which could be caused by the erosive effect of flying chips, as there were traces of iron (Fe) at this place. All these inserts exhibited this kind of damage for all machining speeds used. In this area, the lower TiC coating was exposed.

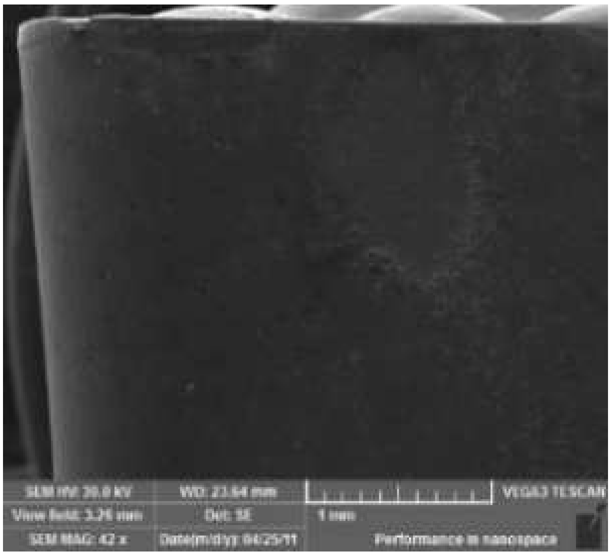

Fig. 16 *SEM main back WPP10S, 120 m·min^{-1}*

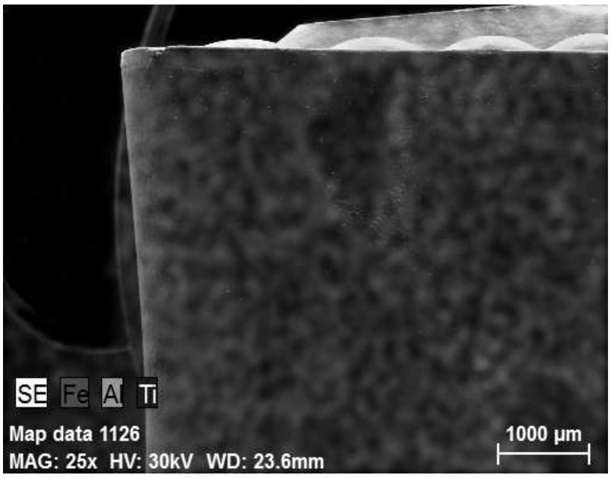

Fig. 17 *EDS main back WPP10S, 120 m·min^{-1}*

In the region of the minor blade, the most noticeable failure was apparent, in which not only the first coating layer but also the lower TiC coating layer was removed and at this point a substrate was revealed (it having a light gray color, Fig. 18 and 19).

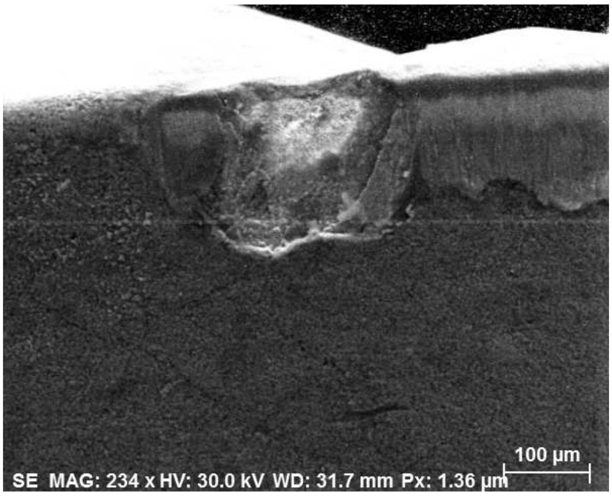

Fig. 18 *SEM minor blade WPP10S, 120 m·min^{-1}*

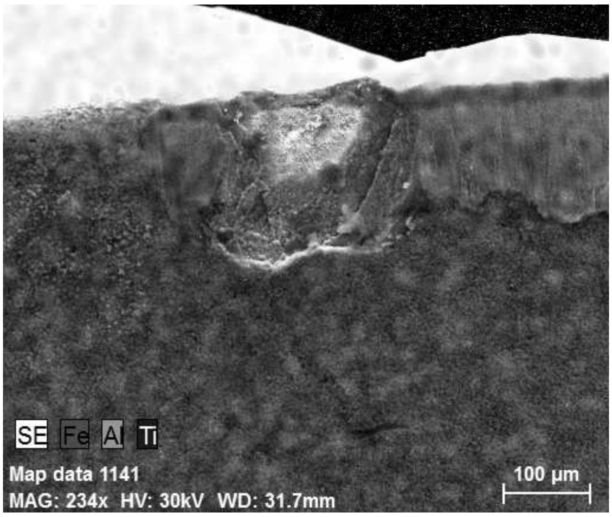

Fig. 19 *EDS minor blade, WPP10S, 120 m·min^{-1}*

The measured surface roughness Rz after machining ranged from 13.3 to 14.6 μm. The scattering in the obtained roughnesses was small and it was not possible to observe a change Rz depending on the amount of wear. The highest roughness was measured after 13.5 minutes of machining, after further machining the roughness decreased again.

3.2 Cutting insert WPP10S, v_c = 140 m·min^{-1}

For this speed, the tool life of the insert was 12.4 min, ie after this machining time the tool wear was VB_{max} = 0.3 mm, how it was determined by experiment. (Figs. 20, 21).

After this machining time, it was seen on the insert that the wear was moving at the interface between the upper and lower coating layers. The substrate was not detected. Furthermore, it was apparent that the material to be adhered to in the region of the cutting edge and the tool face, thus creating a build-up.

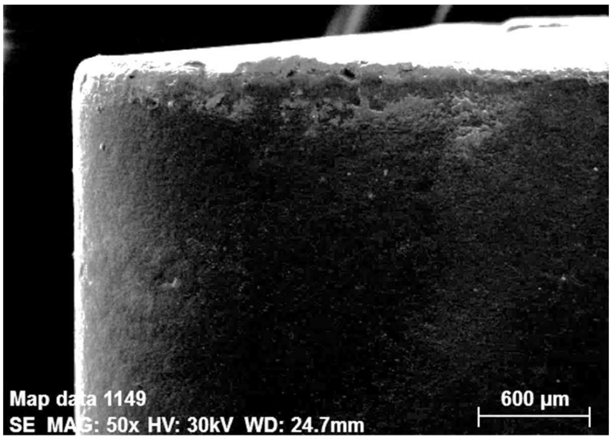

Fig. 20 *EDS minor blade, WPP10S, 140 m·min⁻¹*

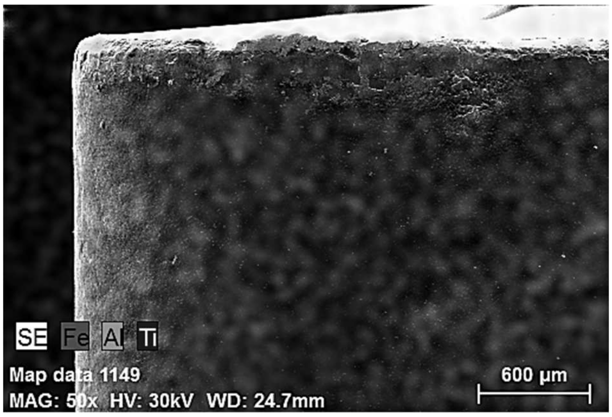

Fig. 21 *EDS minor blade, WPP10S, 140 m·min⁻¹*

The obtained surface roughness Rz after machining ranged from 12.2 to 20.5 µm. This variance in the obtained roughnesses can be considered as the largest in comparison with other measured surfaces for other v_c and inserts. But again there is no apparent dependence of Rz on the amount of wear. The highest roughness was measured after 2.5 minutes of machining, the lowest Rz size was measured after 5.5 minutes of machining. The considerable variation of Rz is likely to be attributed to the abovementioned build-up.

3.3 Cutting insert WPP20S, v_c = 80 m·min^{-1}

For this speed, the tool life of the insert was 20.5 min, ie after this machining time the tool wear was VB_{max} = 0.3 mm, how it was determined by experiment (Fig. 22, 23).

There was slight wear on the main edge of the insert, which was probably caused by abrasion (abrasive wear). This only extends into the topcoat layer, the bottom (second) layer of the coating being slightly exposed. Further, a formation that could be of erosive origin can be observed behind the cutting part of the head blade and in the wider area of the main back. In this area, however, only the lower (second) coating layer was exposed. This layer consists of TiCN. There are areas where the material (Fe) to be adhered is noticeable, but in this case we cannot speak about built-up. When looking at the main ridge (like Fig. 16 and 17), there was a "pothole" behind the depth of cut area, which could be caused by the erosive effect of flying chips, as there were traces of iron (Fe) at this place.

The obtained Rz after machining ranged from 14.7 to 16.9 µm. The variance in the obtained roughnesses is small. There is no apparent dependence of the size Rz on the amount of wear. The highest roughness was measured after 13 minutes of machining.

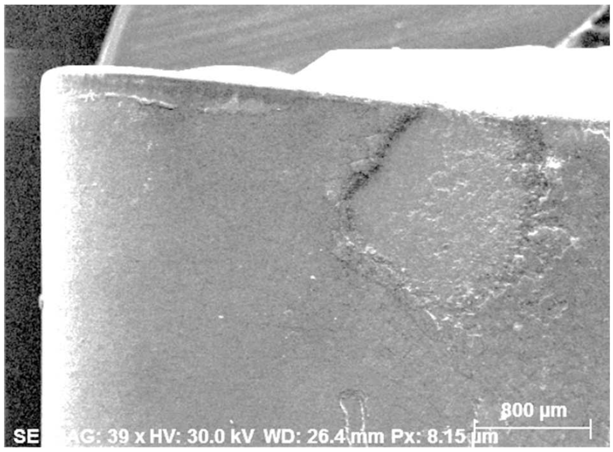

Fig. 22 *SEM main back WPP20S, 80 m·min⁻¹*

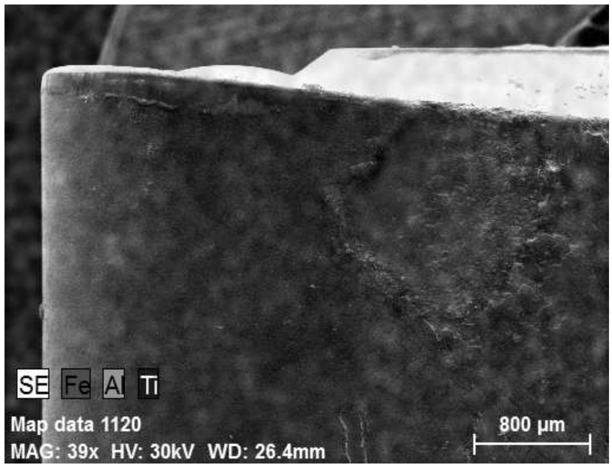

Fig. 23 *EDS main back WPP20S, 80 m·min⁻¹*

3.4 Cutting insert WPP20S, v_c = 100 m·min^{-1}

The cutting insert WPP20S at a cutting speed of 100 m·min^{-1} achieved wear VB_{max} = 0.3 mm after 10.7 minutes of machining. (Fig. 24, 25). The face of the insert is worn down to the depth of the lower coating layer at two points, on the main cutting edge near the tip and on the end of the cutting edge of the secondary cutting edge. The main blade bears signs of abrasive wear, which remains at the level of the first Al_2O_3 coating. On the main ridge was formed again to the depth of the lower TiCN coating, which appeared only behind the main blade (out of a_p). It is also possible to observe here area at the main ridge (like fig. 16 and 17 or 22 and 23), there was a "pothole" behind the depth of cut area, too, which could be caused by the erosive effect of flying chips, as in previous cases.

The obtained Rz after machining ranged from 14.5 to 17.7 µm. The variance in the roughnesses obtained is more pronounced. There is a slight increase in Rz towards the amount of tool wear. The highest roughness was measured at the end of machining after 12 minutes.

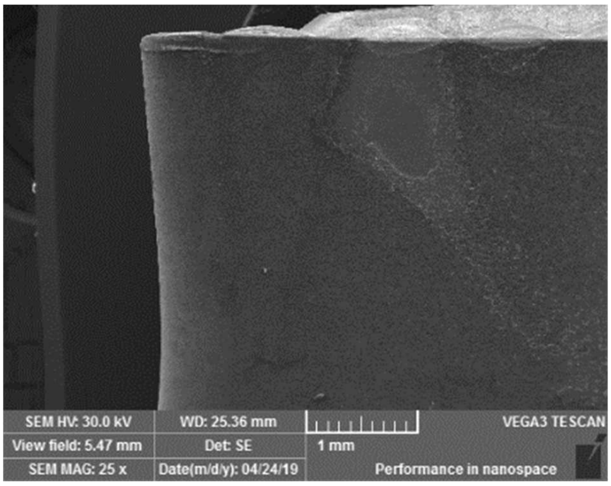

Fig. 24 *SEM main back WPPS20, 100 m·min⁻¹*

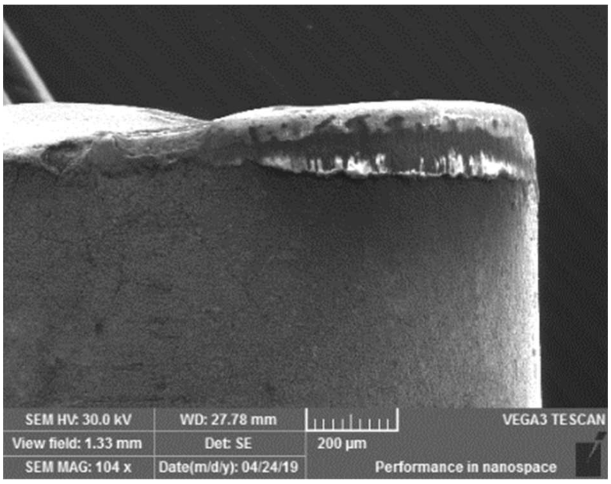

Fig. 25 *SEM secondary blade WPP20S, 100 m·min⁻¹*

3.5 Cutting insert WPP20S, v_c = 120 m·min^{-1}

The cutting insert WPP20S, which was used at a cutting speed of 120 m·.min-1, achieved wear VB_{max} = 0.3 mm after 8.2 minutes (Fig. 26, 27). This insert carries signs of relatively uniform wear, again likely to be abrasive. In some places the machined material to be adhered (traces of Fe) is visible. On the main back is again visible the formation, which could be caused by flying chips, traces of Fe are observed here (similar case like on the fig. 17 or 23).

The obtained Rz after machining ranged from 12.9 to 13.3 µm. The variance in the roughnesses obtained is very small. There is no apparent dependence of the size Rz on the amount of wear. The highest roughness was measured at the start of machining after 1 minute and the lowest Rz roughness was measured at the end of machining after 8.5 minutes.

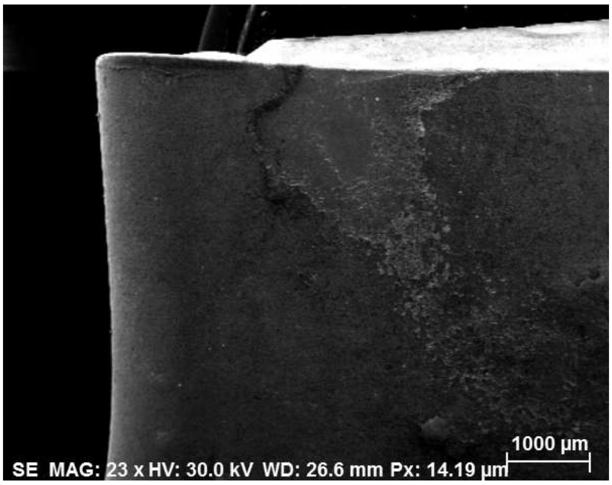

Fig. 26 *SEM main back WPP20, 120 m·min⁻¹*

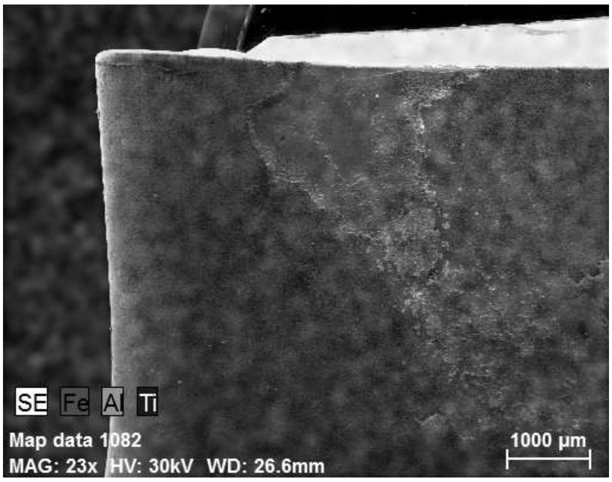

Fig. 27 *EDS main back WPP20, 120 m·min⁻¹*

4 Conclusion

The experimental cutting inserts were tested for their tool life. In these experiments, the resulting wear for various cutting speeds was analyzed also using electron microscopy (SEM and EDS methods). On this basis it was possible to state that even after the specified wear rate (VB_{max} = 0.3 mm, in according with standard ISO 3685) the inserts were still capable of machining, because the wear was relatively low and usually reached the level of the second (lower) coating. Basically, the damage never reached the insert substrate. Only on the side edge (secondary blade) of the WPP10S insert at a speed v_c = 120 m·min^{-1} at the end of the material-insert contact, a pothole formed and the substrate was exposed. On all inserts in the area beyond the main cutting edge it was possible to observe a "knocked out" area, which was probably caused by flying chips in this area, but this area was, as mentioned earlier, beyond the main cutting area, ie the machining process itself could have no effect, and the substrate was never exposed.

According to the performed analyzes, it could be stated that it would probably be possible to leave the analyzed inserts for some time in the process, because neither of them according to SEM and EDX showed marked damage. The evaluated size of the VB_{max} was chosen and was not limiting for the insert function. The Rz value obtained during the wear measurement except for one case (where it was not very significant) did not show any dependence on the wear level of the insert, which can be considered as one indication that the insert is still satisfactory. In one case, the values were relatively wavering, which was probably due to the build-up on the insert in this case.

The use of electron microscopy allows, among other things, to obtain a better picture of the final form of wear on a given insert. Using a light microscope it was possible to measure the wear VB_{max}, but the obtained images did not give a clear picture of the resulting situation. Using of SEM it gives images that are sharper and have a greater depth. EDS analysis provided information on where, when (each used machining speed) and whether the material being adhered to the inserts. With the help of EDS analysis, information was obtained on where and when (used machining speed) wear occurs and whether the material being adhered to the inserts, e.g. It is also possible to get an idea of how intense the resulting wear is in terms of the extent to which the individual layers of the coatings are exposed and whether the wear reaches the insert substrate or not. The information thus obtained provides a wider portfolio of knowledge that can be used, for example, to improve product quality.

The presented results are part of a larger research conducted at FME JEPU in Ústí nad Labem.

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