

## Using of the Electron Microscope to Evaluate the Tool Wear for a Selected Cutting Insert

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Using of cutting inserts is currently a normal part of the manufacturing process. The article deals with analysis of tool wear after machining at one selected cutting insert. Evaluation of this insert was made by electron microscopy. There was used SEM and EDS analysis. For this purpose was used scanning electron microscope Tescan Vega 3 and EDS analyzer Bruker 16 which is part of this microscope. These analysis can provide a good picture of the structure and construction of inserts, their composition and for situation on the insert after machining. This may assist in finding suitable cutting conditions. As experimental material the hardened steel class 16MnCr5 according to EN 10027-1 has been machining. SEM images of final tool wear of the cutting insert were recorded. The reason was to map the tool wear state after machining using electron microscopy to give a better view of the situation. These analyzes were performed in other experiments performed at the Faculty of Mechanical Engineering at Jan Evangelista Purkyně University in Ústí nad Labem.

**Keywords:** Cutting Insert, SEM, EDS, Tool Wear

### 1 Introduction

At the Faculty of Mechanical Engineering, which is part Jan Evangelista Purkyně Univerzity in Ústí nad Labem are carried out several research projects. One of them is research in area of tool life of cutting inserts. As part of this research were also carried out various analyzes. One was analyses of final tool wear of experimental inserts after machining and the methods, which are used at FME JEPÚ, are SEM and EDS analyses. For this purpose, in experiments at FME JEPÚ, there is used electron microscopy. [1, 2, 3]

The abbreviation SEM means a scanning electron microscope. This microscope is working with a narrow electron beam. To the formation image are used primary and secondary electrons backscattered from the sample surface. These electrons formed by the interaction of atoms of the sample with electrons of the electron beam. Detector receives and processes the electrons so as to obtain a sharp image of the sample surface. Rather than a traditional optical microscope is its advantage a large depth of focus and the ability to get more magnification. [2, 4, 5]

EDS analysis is an analysis using an energy dispersive spectrometer. This spectrometer is used as an auxiliary device for a scanning electron microscope and used to perform the spectral analysis of the sample. The principle is to capture of X-ray radiation generated during the bombardment of samples by primary electrons. The output of EDS analysis is the frequency range of X-ray signal in the energy windows. The resulting characteristic peaks that correspond to the elements in a given location. The height of the peaks is proportional to the concentration of the element in the sample. [6, 7, 8]

One of the important information about the machining process is also the final wear of the tool after machining. Modern analytical methods allow us to take more information about this tool wear in present. This is, for

example, electron microscopy, where the image obtained can provide more information about the particular state of the tool (in our case cutting inserts). Also, using EDS analysis helps us evaluate the tool's final wear, when it is possible to detect, for example, how the machining material is inclined to adhere to the tool under the given cutting conditions, or how durable the insert coating is under the cutting conditions. This information can then be used to improve the cutting process itself. Therefore, the tool wear in frame of the experiments performed at the FME JEPÚ was also evaluated by these methods. [9]

### 2 Experiment

Experiments were carried out on the basis of cooperation with industrial companies, which take place at FME JEPÚ. The experimental material was supplied by the contracting authority and it was a steel 16MnCr5 according to EN 10027-1 (steel class 14 220 according to ČSN 41 0002, 1.7131 according to EN 10027-2). It is a noble structural steel that is alloyed with Mn and Cr. It is mainly used for cementing, nitriding and nitro-cementing. Steel is heat-forming well. It shows good machinability and weldability. It also has good wear resistance after cement hardening and high surface hardness at core toughness. In Tab. 1 shows the chemical composition of the machined material according to the standards.

By spectral analysis it was found that the mass content of the elements contained in the material corresponds to the weight amounts given in the standards (Tab. 2).

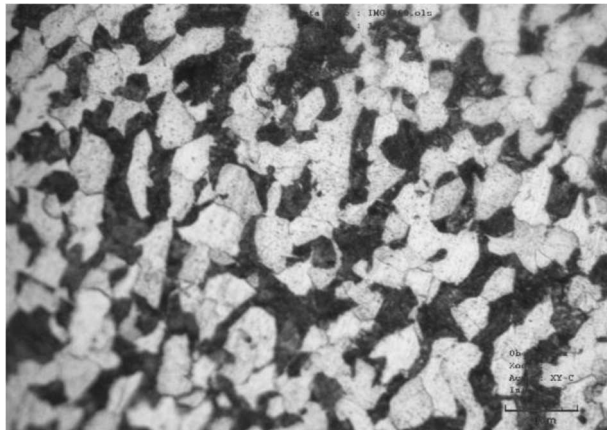
To verify the structure of the experimental material was made a microscopic analysis using a confocal laser microscope LEXT OLS 3100. From the microstructure images it was clear that the experimental material was in line with its declaration (Fig. 1). The structure of the material was ferritic-perlite. [3]

**Tab. 1** Chemical composition of experimental material

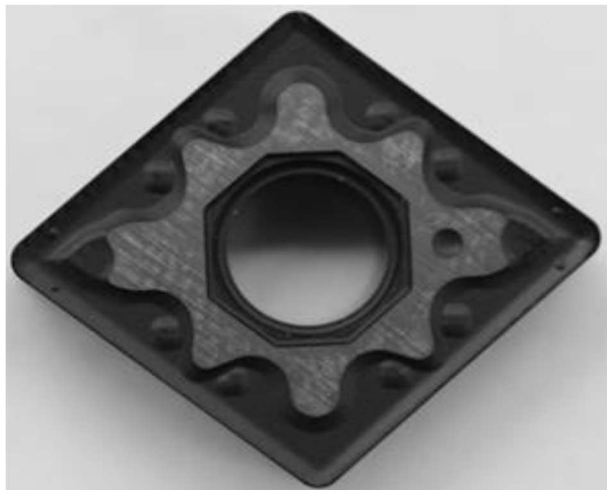
Chemical composition according to ČSN 41 4220 [wt. %]					
C	Mn	Si	Cr	P	S
0.14-0.19	1.10-1.40	0.17-0.37	0.80-1.10	max. 0.035	max. 0.035
Chemical composition according to EN 10027-2 [wt. %]					
C	Mn	Si	Cr	P	S
0.14–0.19	1.00–1.30	max 0.40	0.80–1.10	max 0.035	max 0.035

**Tab. 1** Chemical composition of experimental material according to measurements in wt. %

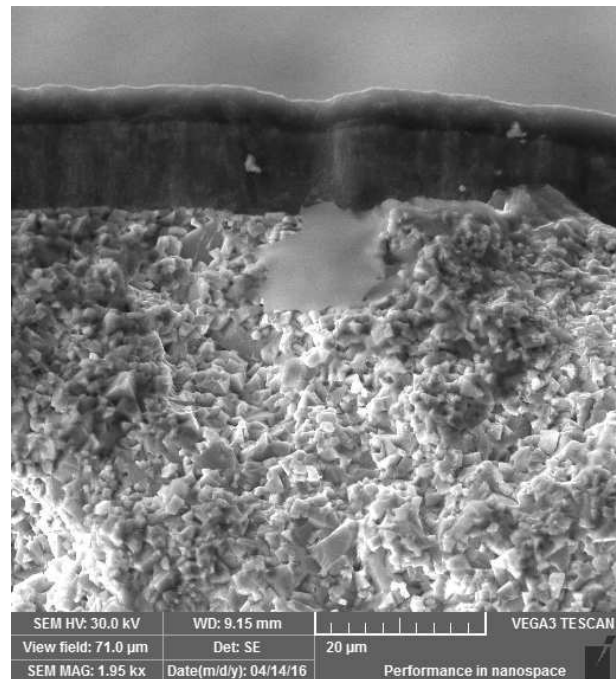
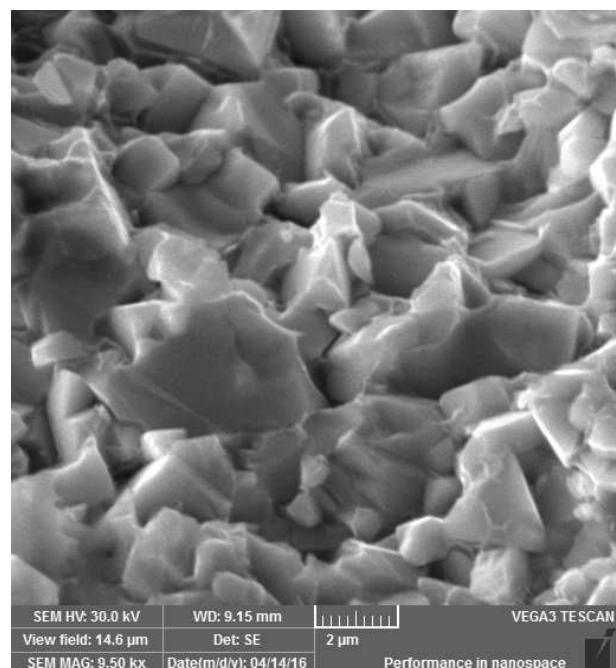
C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al	W	Fe
0.168	0.333	1.183	0.015	0.011	1.055	0.014	0.076	1.139	0.029	0.016	96.79

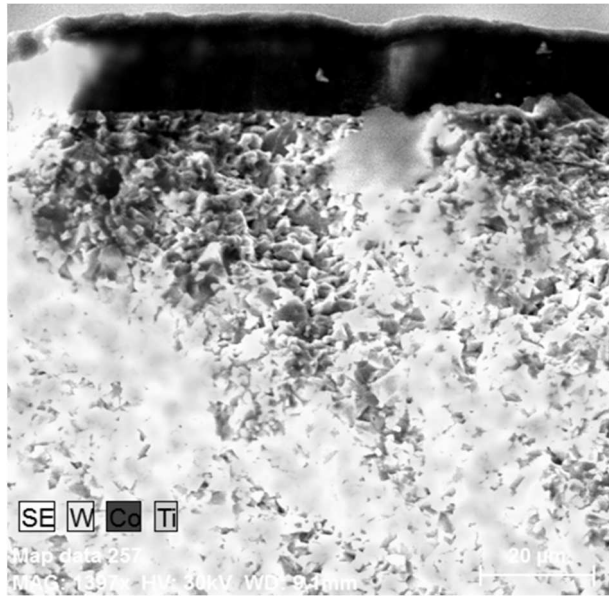
**Fig. 1** Microstructure of experimental material (mag. 500x)

The two-sided replaceable cutting insert CNMG 120408-M KT-CTP25 suitable for ferrous materials (Fig. 2) was used for the experiment. For presented insert was declared, that it was from cemented carbide and with double coat. [10]

**Fig. 2** Cutting insert CNMG 120408-M KT-CTP25

On the Fig. 3 is a cross-sectional view of experimental insert and on the Fig. 4 is a illustration of this plate substrate. Both pictures were taken using a scanning electron microscope Tescan Vega 3. On the Fig. 5 is a picture of the EDS analysis showing the composition of the used cutting insert. This picture was taken with the EDS analyzer Bruker 16, which is part of the electrone microscope Tescan Vega 3.

**Fig. 3** SEM of cross section of insert CNMG 120408-M KT-CTP25**Fig. 4** SEM of substrate of insert CNMG 120408-M KT-CTP25



**Fig. 5** EDS of insert CNMG 120408-M KT-CTP25

Based on the analyzes performed on this plate we can say that this plate was composed of substrate and double-coat. The substrate was formed by EDS analysis carbides of tungsten, titanium, tantalum and niobium with a cobalt binder. The lower coat with thickness of 15  $\mu\text{m}$  was formed by titanium carbide and top coating with thickness 3  $\mu\text{m}$  by  $\text{Al}_2\text{O}_3$ . From the EDS analysis but it was also shown the presence of elements such as calcium, copper or iron. These elements are found more often in inserts from cutting ceramics. [10, 11]

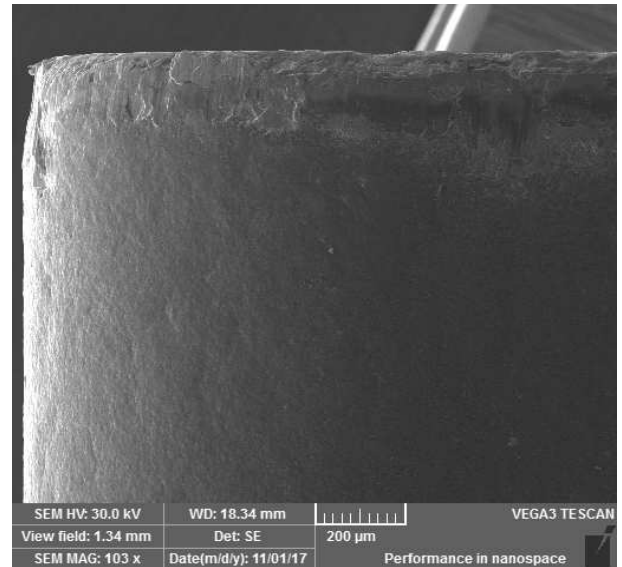
The machining experiment was carried out on the three axis CNC lathe DOOSAN Lynx 220L with the control system FANUC. The depth of clearance was set to  $a_p = 1.5 \text{ mm}$ , the feed rate was determined as  $f = 0.2 \text{ mm}$  and the cutting speed values were set as  $v_1 = 230 \text{ m min}^{-1}$ ,  $v_2 = 250 \text{ m min}^{-1}$  and  $v_3 = 270 \text{ m min}^{-1}$ . The tool holder PCLNR 2020 K12 was used. The value  $V_{Bmax} = 0.3 \text{ mm}$  was chosen as the criterion for evaluating the tool wear of the insert after machining. Once this wear has been achieved, the experiment was terminated.

The final tool wear evaluation of the experimental insert after turning the experimental material was performed on an electron microscope and SEM and EDS analysis were performed. The SEM abbreviation refers to a scanning electron microscope, for experiment was using the electron microscope Tescan Vega 3, which is available at FME laboratories. Unlike a conventional optical microscope, its advantage is high sharpness and greater magnification of acquired images. EDS is used as an additional device for a scanning electron microscope and is used to perform spectral analysis. For this purpose, the Bruker 16 EDS analyzer is available at FME UJEP, which is part of the electron microscope Tescan Vega 3. [12, 13, 14, 15]

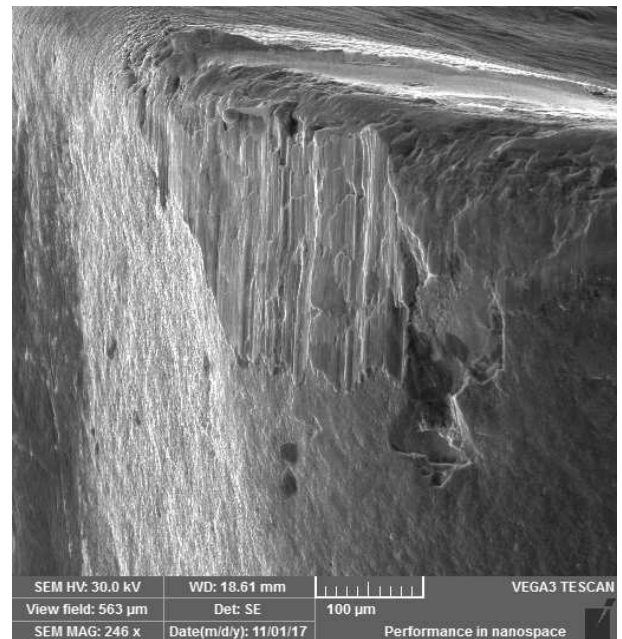
### 3 Evaluation of tool wear

The first insert was analyzed after machining at  $v_c = 230 \text{ m min}^{-1}$ . In Fig. 6 and 7, the SEM images of the resulting tool wear of the plate are for this rate. This wear

was achieved after 35 minutes of machining. Figures 8 and 9 are images taken with an EDS analysis showing the occurrence of individual elements within a replaceable cutting insert after machining.

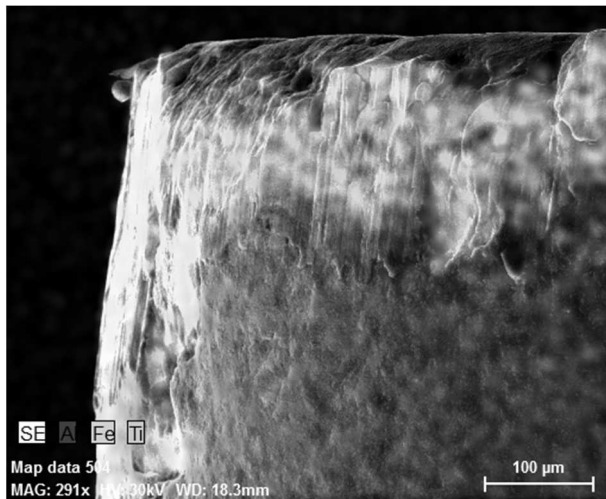


**Fig. 6** SEM for insert after machining by  $v_c = 230 \text{ m min}^{-1}$

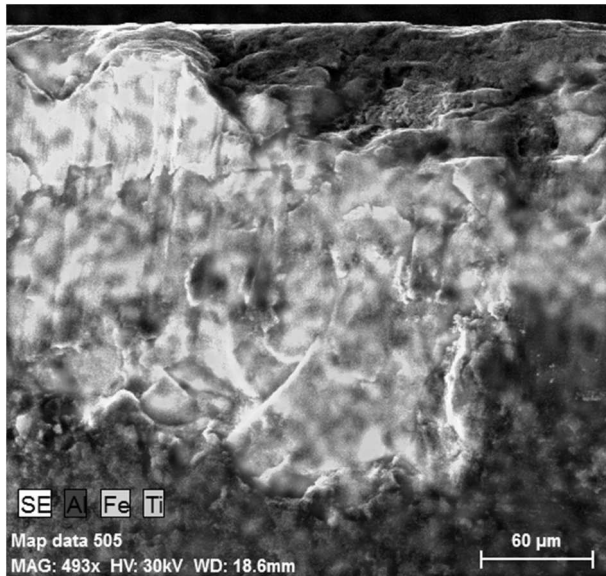


**Fig. 7** SEM for insert after machining by  $v_c = 230 \text{ m min}^{-1}$ , greater magnification

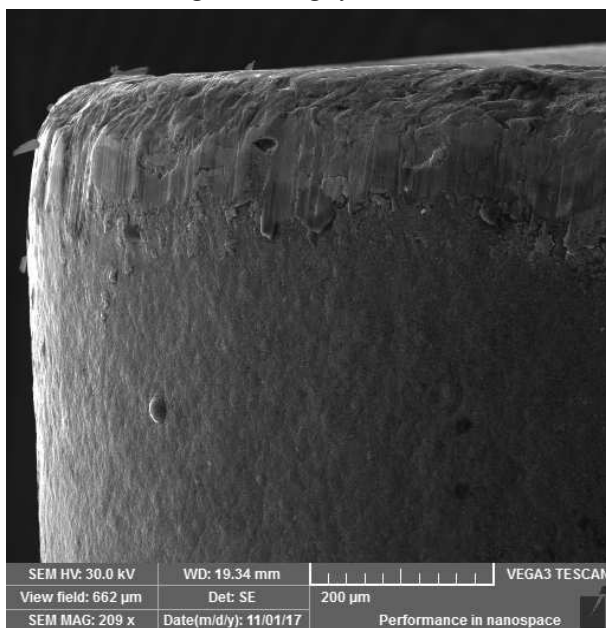
SEM analysis showed that the resultant tool wear for cutting speed  $v_c = 230 \text{ m min}^{-1}$  showed the usual traits, and there were no anomalies visible on the plate after this machining. Additionally, EDS analysis was carried out. It can be seen from these figures that, after the machining, the substrate of the plate was not detected (revealed), which is made of tungsten carbide and niobium and cobalt binder. The tool wear revealed the lower coating, which is made of titanium carbide. The top coat of  $\text{Al}_2\text{O}_3$  has been damaged in the machining area, essentially in the entire area of machining (contacting the insert with the material). There is also a visible presence of iron that comes from the machined material.



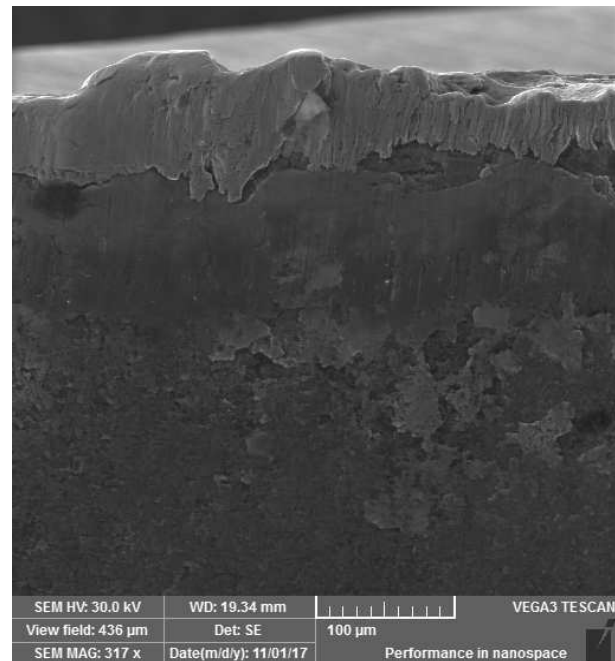
**Fig. 8** EDS for insert after machining by  $v_c=230 \text{ m} \cdot \text{min}^{-1}$



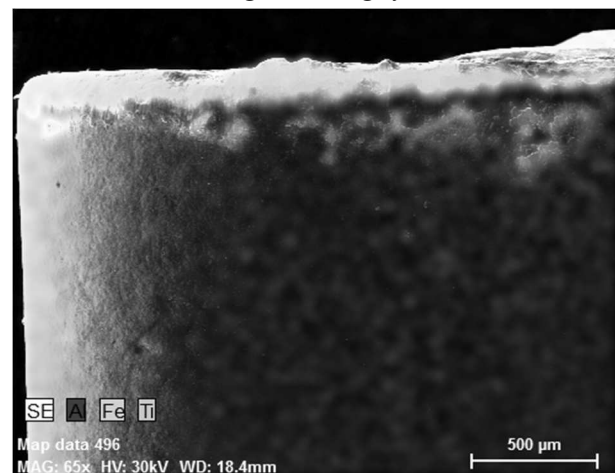
**Fig. 9** EDS for insert after machining by  $v_c=230 \text{ m} \cdot \text{min}^{-1}$ , greater magnification



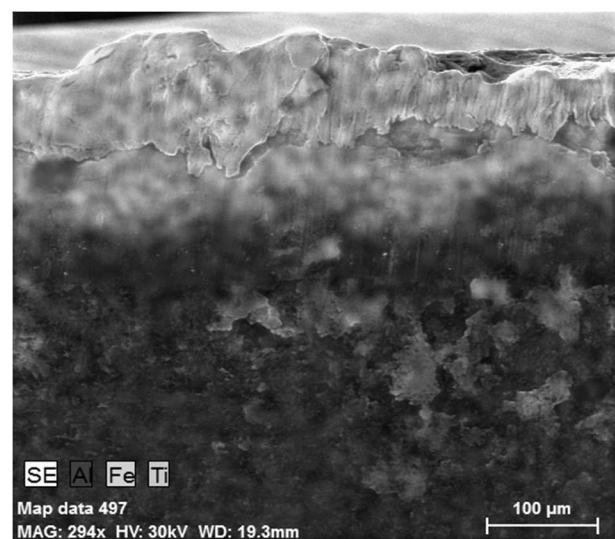
**Fig. 10** SEM for insert after machining by  $v_c=250 \text{ m} \cdot \text{min}^{-1}$



**Fig. 11** SEM for insert after machining by  $v_c=250 \text{ m} \cdot \text{min}^{-1}$ , greater magnification



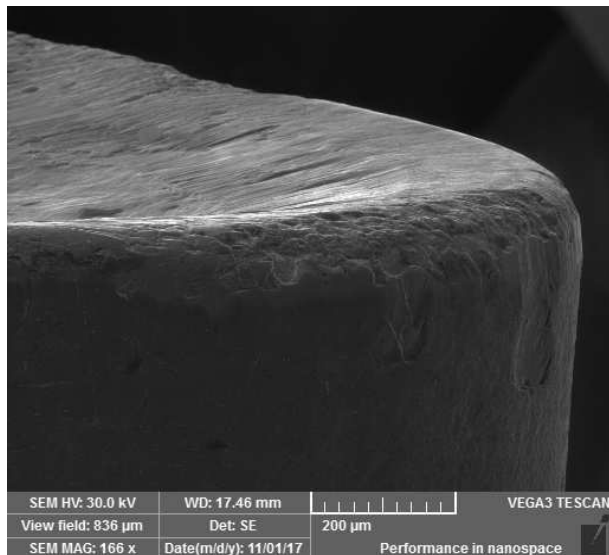
**Fig. 12** EDS for insert after machining by  $v_c=250 \text{ m} \cdot \text{min}^{-1}$



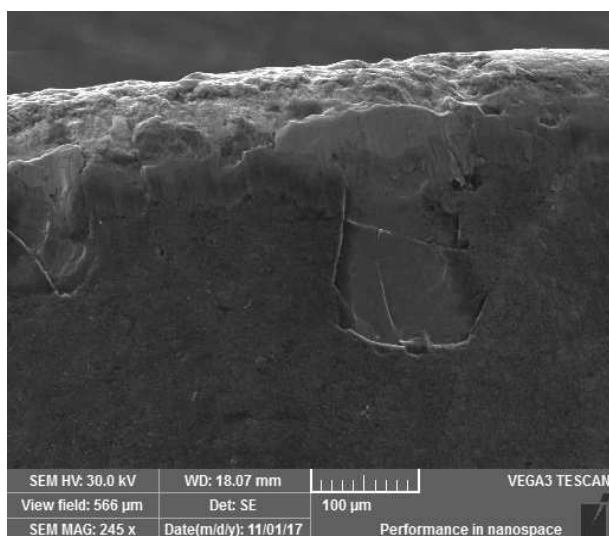
**Fig. 13** EDS for insert after machining by  $v_c=250 \text{ m} \cdot \text{min}^{-1}$ , greater magnification

Next, the plate was analyzed after machining at a rate of  $v_c = 250 \text{ m} \cdot \text{min}^{-1}$ . This tool wear was achieved after 32 minutes of machining. In Fig. 10 and 11, the SEM images of the resulting tool wear of the plate are for this rate. Fig. 12 and 13 are images taken with an EDS analysis showing the occurrence of individual elements within a replaceable cutting insert after machining.

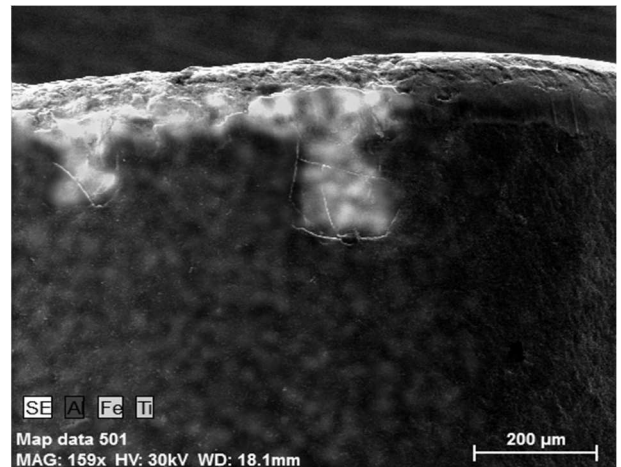
SEM analysis showed that the resultant tool wear for cutting speed  $v_c = 250 \text{ m} \cdot \text{min}^{-1}$  showed the usual traits, and there were no anomalies visible on the plate after this machining. There is no significant difference between wear for  $v_c = 230 \text{ m} \cdot \text{min}^{-1}$  and for  $v_c = 250 \text{ m} \cdot \text{min}^{-1}$ . Additionally, EDS analysis was carried out. It can be seen from these figures that even with this machining speed after machining, the substrate of the plate was not detected. Here, the wear revealed the lower coating, which is made of titanium carbide, too. The topcoat formed by  $\text{Al}_2\text{O}_3$  has been damaged in the machining area, again in substantially the whole machining area (contacting the insert with the material). There is again the presence of iron that comes from the machined material.



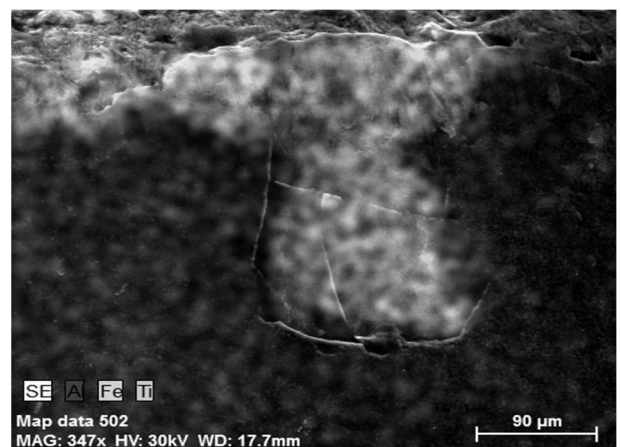
**Fig. 14** SEM for insert after machining by  $v_c = 270 \text{ m} \cdot \text{min}^{-1}$



**Fig. 15** SEM for insert after machining by  $v_c = 270 \text{ m} \cdot \text{min}^{-1}$ , greater magnification



**Fig. 16** EDS for insert after machining by  $v_c = 270 \text{ m} \cdot \text{min}^{-1}$



**Fig. 17** EDS for insert after machining by  $v_c = 270 \text{ m} \cdot \text{min}^{-1}$ , greater magnification

Next, the plate was analyzed after machining at a rate of  $v_c = 270 \text{ m} \cdot \text{min}^{-1}$ . In Fig. 14 and 15, the SEM images of the resulting tool wear of the plate are for this rate. This tool wear was achieved after 27 minutes of machining. Fig. 16 and 17 are images taken with an EDS analysis showing the occurrence of individual elements within a replaceable cutting insert after machining.

SEM analysis showed that the resultant tool wear for cutting speed  $v_c = 270 \text{ m} \cdot \text{min}^{-1}$  showed the usual traits, and there were no anomalies visible on the plate after this machining. Against the previous  $v_c$ , there are two small grooves visible on the edge. Here, EDS analysis was also carried out. It can be seen from these figures that even with this machining speed after machining, the plate substrate was not detected. Here, the tool wear revealed the lower coating, which is made of titanium carbide, too. The top coat of  $\text{Al}_2\text{O}_3$  has been damaged in the machining area, again substantially throughout the machining area. There is again the presence of iron that comes from the machined material. For this rate, the presence of iron from the machined material was the smallest.

#### 4 Conclusion

The cutting insert CNMG 120408-M KT-CTP25 was used for machining of experimental material 16MnCr5 according to EN 10027-1 by given cutting conditions.



Among other things, the plates due to their final tool wear after machining were evaluated by the electron microscope Tescan Vega 3 and EDS analyzer Bruker 16 which is part of this microscope. SEM and EDS images were taken.

For experimental insert there was possible to state that, according to SEM analyses tool wear in place did not show any extra features. In the EDS analysis, it was apparent that the experimental machined material more adhered to machining speeds  $v_c=230 \text{ m}\cdot\text{min}^{-1}$  and  $v_c=250 \text{ m}\cdot\text{min}^{-1}$  on the plate, compared with machining speed  $v_c=270 \text{ m}\cdot\text{min}^{-1}$ .

For each cutting speed, it was true that in the area of the cut the tool wear reached the bottom layer of the coating, but the substrate of the cutting plate was never revealed.

The use of electron microscopy can help in obtaining more detailed information even in such cases. This information can better approximate the examined process also in the field of machining and therefore it has been applied at FME JEPU.

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