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The influence of the type of coating on the cutting tool wear during turning of 316L austenitic stainless steel

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ABSTRACT

The paper presents the influence of coatings applied with the use of PVD method on cutting tools on the wear of the tool and compares it with an uncoated P25 cemented carbide plate. During the experiment, two types of TiAlN coatings were used, applied in various proportions, as well as TiN coating. During the tests, the average width of the wear band on the flank face in B VB_B zone and the width of *KB* crater were monitored. Moreover, the scanning analysis of the tool was conducted in order to determine the intensity of adhesive wear. The lowest values of selected tool wear indicators were found out with the use of TiAlN coating applied in eight layers in the proportions 33/67% - TiN/TiAlN. The scanning analysis proved the highest adhesive wear of the uncoated P25 cemented carbide plate, as well as increased abrasive wear of the flank face and the formation of a crater in comparison with coated plates.

KEY WORDS

Dry cutting
Tool wear
316L austenitic steel
SEM
TiN and TiAlN coatings

1. INTRODUCTION

Due to constant improvement of semi-finished product manufacturing technology, the development of tool materials and production machines, dry machining is becoming the most desired production method in terms of ecology and economy. The elimination of cutting fluids reduces the costs of manufacturing of parts and plays a very important role in the protection of the environment [1].Dry machining has a lot of advantages but also relative inconveniences. The advantages of dry machining include: dry and clean surfaces of parts being produced, reduction of costs related to the production and recycling of chipping (caused by the lack of oil contaminations). The cost connected with the application of dry machining in firms is investment expenditure connected with the commencement of its use [2].

However, savings occurring when using dry machining need a lot of research and scientific works in order to reduce excessive wear of tools [3–8]. In 2001, the National Nanotechnology Initiative was enacted in the United States, which concentrates on the provision of nanostructural coatings and materials, which may be successfully applied on cutting tools in dry machining. In 2006, US President, George W. Bush, allocated 497 million USD for that purpose to support research in nanoscale [9].

During machining, when tools are exposed to high wear mechanisms and extreme pressures, cemented tungsten carbide tools are used. During dry machining of C45 steel, temperature in the machining zone is from 600 to 1,200°C depending on the machining speed. In such a temperature the tool is particularly exposed to wear mechanism as a result of adhesion and diffusion, when temperature reaches 900°C (tungsten group carbides) and 1,000°C (tungsten titanium group carbides) [10]. Munz et al. [11] found out that during steel machining in the cutting tool above 800°C empty spaces begin to form between the substratum and the coating as a result of the diffusion of the workpiece. The authors proved that adding 1% of yttrium to coating material prevents this phenomenon and improves adhesion of the coating to the tool base material.

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On the other hand, Kupczyk [12] proposed a new method of producing tools from cemented carbides of nanocrystalline structure with Pulse Plasma Sintering (PPS) method developed at Warsaw University of Technology. The application of optimum sintering parameters (temperature 1,520 K and time 500 s) during the production with Pulse Plasma Sintering method enables to obtain tools in which cutting tools have greater hardness than in the case of tools made of carbides sintered with hot isostatic pressing method. Kupczyk and Komolka [13] proved that using tools of cemented carbides of nanocrystalline structure causes that the tool durability is 2.1 to 3.3 times higher in comparison with the tool made of ordinary cemented carbide. Kümmel et al. [14], in order to eliminate adhesive wear on cemented carbide plates, applied different shapes of textures on the rake face. Their research confirmed a change in the conditions of the occurrence of build-up and wear of cutting tools made of cemented carbides in dry machining. The authors found out that the application of various textures (recesses and channels) on the rake face enables a change in tendencies for the occurrence of build-up on the tool of the cutting tool.

Deeming et al. [15] investigated the effect of different types of coatings on delaying the oxidation process. For tin coating, wear due to oxidation begins above 500°C, for TiAlN coating above 700°C, and for a multi-layer coating above 950°C. The authors achieved the densest and strongest multi-layer coating on the substrate with the TiAlCrYN composition. During the tests, it was proved that the addition of Yttrium causes maximum coating wear at 600°C, and the smallest at 900°C. However, without the addition of Yttrium, the wear rate increases with temperature.

Thus, dry machining is becoming an important milestone in the production technology with a geometrically defined cutting tool, and the success of its application depends mainly on the workpiece and tools. The objective of the paper is to compare tools with TiN and TiAlN applied in various proportions on the tool wear during turning of 316L austenitic steel.

2. Experimental procedure

The test was carried out on a universal turning lathe CU502 with the use of a tool with SNUN120408-PF plate and CSRNR2525 holder. Cutting parameters were selected in compliance with the tool producer's recommendations: cutting speed v_c = 320 m/min, f = 0.1 mm/rev and a_p = 0.5 mm. During the test four cutting plates were used:

- uncoated plate made of P25 cemented carbide;
- titanium nitride TiN coating, 2 μm thick, applied with PVD method;
- with TiAlN coating, 3 μm thick, applied with PVD method. The coating was applied in the presence of nitrogen, argon and helium, and 4 layers of TiN and 4 layers of TiAlN were used in the proportions 50/50% for 125 minutes;
- with TiAlN coating, 3 μm thick, applied with PVD method. The coating was applied in the presence of nitrogen, argon and helium, and 4 layers of TiN and 8 layers of TiAlN were used in the proportions 33/67% for 110 minutes.

The workpiece was 316L austenitic steel with the following composition: Cmax – 0.03%; Smax – 0.015%; Nmax – 0.11%; Simax – 0.1%; Pmax – 0.045%; Mnmax – 2%; Cr – 16.5-18.5%; Mo – 2-2.5%; Ni – 10-13%.

To monitor the tool wear indicators, a universal microscope Dino-Lite AM7013MZT was used, and the measurement was taken every 4 minutes, until the value VB_B = 0.3 mm was obtained, in compliance with ISO PN-ISO 3685.

The scanning analysis was conducted with the use of JEOL JSM-5600LV microscope. It is an electron microscope, which in effect of coupling with an X-ray microanalyzer EDS enabled the assessment of the chemical composition of the studied tool surfaces.

3. Experimental procedure

3.1. Tool wear indicators

The use of tool wear during turning of 316L austenitic steel due to selected wear indicators is presented in Figure 1.

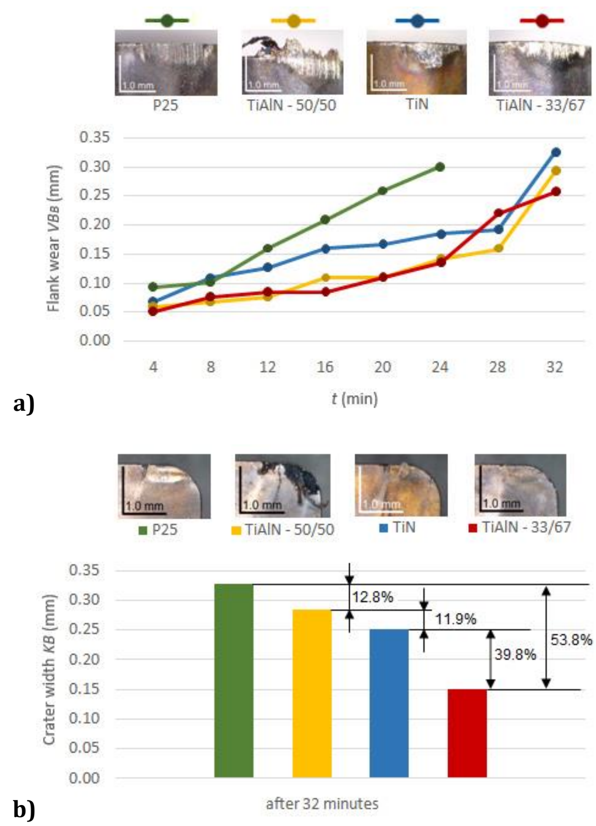

Fig. 1. The cutting tool wear during turning of 316L steel: a) average width of the wear band in B VB_B zone; b) width of KB groove

When analyzing the average wear band width on the flank face depending on the type of coating (Fig. 1a), it was found out that the lowest VB_B values are for TiAlN-33/67% coating, and the highest for the uncoated plate. The cutting tool wear of P25 cemented carbide is characterized by the wear similar to linear one, and the value of 0.3 mm was obtained as early as after 24 minutes of work. Up to the 24th minute of work of the tool for coated planes VB_B value does not exceed 0.19 mm (TiN coating), i.e. it is lower by about 36%, and in the case of TiAlN coatings by about 50%. In cutting tools with coatings there is a rapid increase in wear after approximately 28 minutes of work, when the coating becomes damaged and the plate base material becomes uncovered. A decrease of the cutting tool wear when using a cutting tool with TiAlN-33/67 coating in comparison with TiAlN-50/50 coating takes place as a result of a reduced relation between compressive stress and hardness of the discussed TiAlN-33/67 coating, as well as higher hardness of the coating, which, in turn, causes an increase in the tool's resistance to erosion processes and abrasive wear [11].

The highest values of the crater width after 32 minutes were also observed for the tool with TiAlN-33/67 coating. Increased resistance to abrasion of TiAlN-33/67 coating brought about a decrease in the KB value by as much as 53.8% in comparison with the uncoated plate, by 40% compared to TiAlN-50/50 coating and by about 39.8% compared to TiN coating.

3.2. Scanning analysis of the tool

The results of the conducted scanning analysis for individual cutting tools are presented in Figures 2–5.

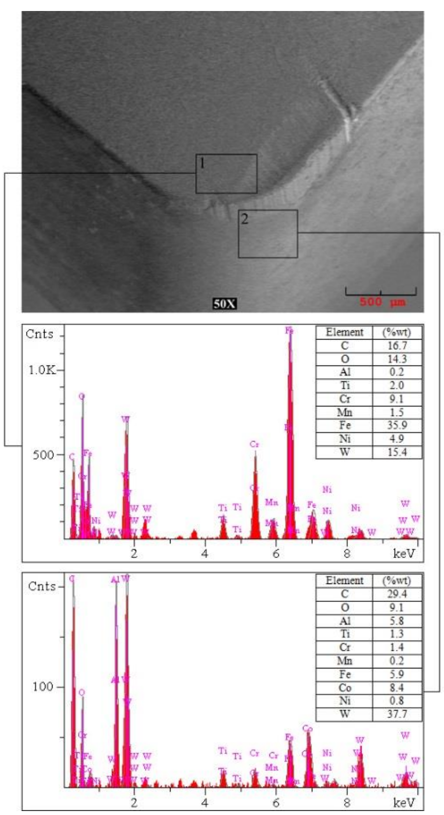

Fig. 2. X-ray microanalysis of a P25 cemented carbide cutting tool without coating after turning 316L steel

On the cutting tool without coating (Fig. 2), higher content of iron and chromium on the rake face was found, that is the main element of the workpiece, which proves an increased adhesive wear when compared with coated tools. On the tool withTiAlN-50/50 coating, a lower content of chromium (5.6%) and iron (20.3%) was found on the rake face. On TiAlN-50/50 plate, as a result of decreased hardness of the coating when compared with TiAlN-33/67, higher wear of the crater was found. The largest content of oxygen, both for the rake face and the flank face, was found for the plate with titanium nitride coating (Fig. 4). It can prove that the oxidation process occurred most intensely exactly in the case of the plate with TiN. The lowest content of oxygen was observed for the plate with TiAlN-33/67. An increase in the layers applied in the case of TiAl/N-33/67 to 8 brought about the growth of resistance to oxidation.

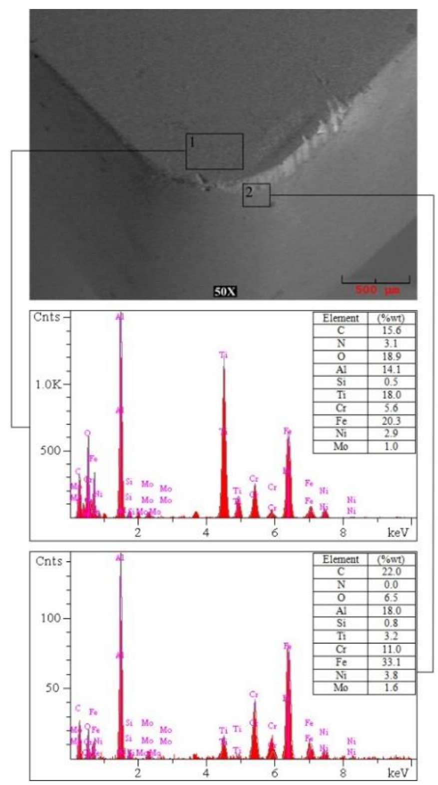

Fig. 3. X-ray microanalysis of the cutting tool with TiAlN-50/50 coating after turning 316L steel

Figure 6 presents visually the images of all the cutting edges participating in the test. The analysis of the tools was made at the end of the work of the cutting tool. It was observed that abrasion wear and notch wear are the greatest mechanisms of the tool wear, particularly concerning the rake and flank face. In the case of cutting edges without and with TiAlN-50/50 coating (Fig. 6 a, b), higher wear of the crater on the rake face was observed, indicating adhesive wear as one of the mechanisms of active wear, along with the abrasive wear mechanism.

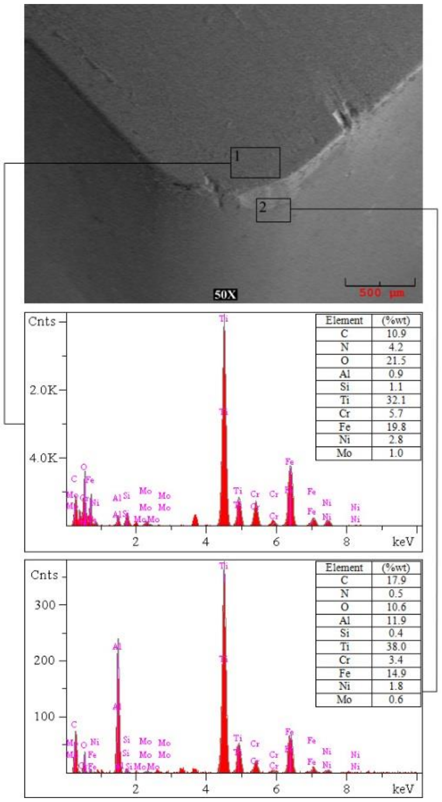

Fig. 4. X-ray microanalysis of the cutting tool with TiN coating after turning 316L steel

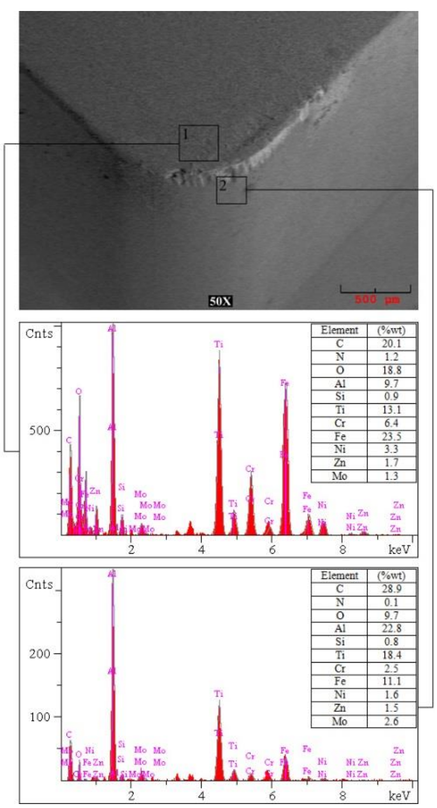

Fig. 5. X-ray microanalysis of the cutting tool with TiAlN-33/67 coating after turning 316L steel

On the surfaces of TiAlN-50/50 plate also the biggest amount of chipping on the substratum was observed, particularly on the main cutting edge, which formed as a result of the friction of hard particles of the workpiece with the tool surface. On the other hand, the longest chipping was observed for the uncoated plate (Fig. 6 a).

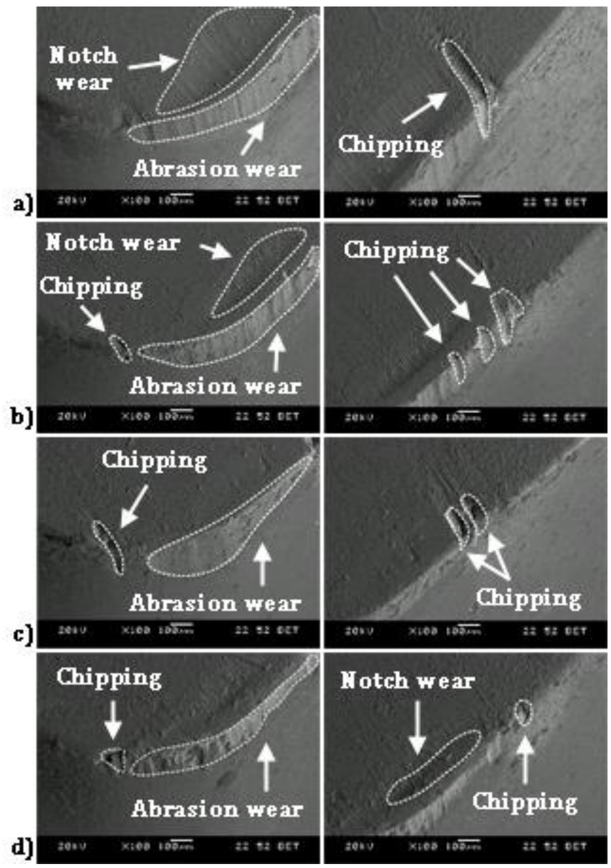

Fig. 6. Types of wear occurring on the tool after turning 316L steel: a) P25; b) TiAlN-50/50; c) TiN; d) TiAlN-33/67

4. CONCLUSIONS

During the experiment, tests were conducted aiming at the investigation of usability of the selected coatings in terms of the cutting tool wear when turning 316L steel, which is difficult to cut. The experiments were carried out with the use of P25 cemented carbide plate and plates with applied TiN, TiAlN-50/50 and TiAlN-33/67 coatings. On the basis of the conducted tests, the following conclusions were drawn:

- the lowest value of the average wear band in B zone was obtained for the plate with TiAlN-33/67 coating. Since this parameter is directly related to the abrasion of the flank face, it means that when turning 316L steel, the coating prevents the wear on this tool area to the greatest extent. The highest VB_Bvalues were observed for the uncoated plate and the plate with TiN coating;
- the measurements of the crater width confirmed greater durability of TiAlN-33/67 coating. In this case, the lowest *KB* values were found for this coating. Owing to its properties, the coating brought about a decrease in the intensity of the crater wear, and thus it protects the rake face.

The highest *KB* values for the plates with coatings were observed for TiAlN-50/50 coating;

- the cutting tool with TiAlN-33/67 coating during scanning analysis proved the smallest abrasive and notch wear. Lower tool wear was obtained owing to proportions between TiN and TiAlN applied to this coating, which caused the assurance of higher hardness with high ductility, enabling high resistance to the coating cracking for the main cutting edge, which usually occurs during turning of hard metal parts. The greatest adhesive wear was observed for the uncoated plate, which is proven by high iron content on the cutting tool.

To sum up, the implementation of the tests included in this paper provided a lot of important information about the discussed coatings. It was proven unambiguously that the application of coating on the cutting tool is tantamount to the prolongation of its durability, since to a greater or lesser extent it prevents the wear processes of varied nature. In spite of the fact that X-ray analysis did not prove a univocal advantage of a given coating, the measurements of the wear indicators suggest that by far greatest protection against wear during turning of 316L austenitic steel is provided by TiAlN-33/67 coating.

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