IDENTIFICATION OF CHARACTER AND INTENSITY OF WEAR OF PVD COATED TWIST DRILLS IN DRILLING OF C 45 MATERIAL

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This article is aimed to investigation of four different PVD coatings of STATON company in order to determine a wear behavior on twist drills when drilling C45 material. A pearlite-ferrite structure of C45 material is common material for automotive industry and highly abrasive to cutting tools. Our comparative study is focused on flank wear of the cutting wedge of observed drills deposited at STATON. The article shows differences in chemical composition and their effects on wear behavior at the corner of the drill and along the cutting edge. We also demonstrate that chemical composition has significant influence on the temperature of a build-up edge during cutting.

KEYWORDS
Hard coatings, PVD technology, drills, flank wear, C45

1 INTRODUCTION

Cutting process is important step in production. Nowadays, it has been appealed to increase key factors in quality of products while maintaining a machining from economical point of view, production efficiency as well as reduction of process media and its impact to environment.

Various studies and surveys indicate that drilling is one of the most time-consuming metal cutting operations in the typical manufacturing. It is estimated that 36 % of all machine hours (40 % of CNC) is spent performing hole-making operations, as opposed to 25 % for turning and 26 % for milling, producing 60 % of chips [ASTAKHOV 2014].

Due to the frequent applications of engineering materials, which are characterized by degraded machinability and in order to maintain the above-mentioned aspects, it is necessary to pay increased attention to tribological issues in drilling technology. One of the alternatives to affecting these tribological issues to a greater or lesser extent, and to prolong the tool life and mitigate the degradation mechanisms of surfaces that interact with each other is the deposition of PVD hard coatings.

Correct identification of mechanism of tool wear is important and extremely complicated because cutting tool wear is a result of complicated physical, chemical, and thermomechanical phenomena. Because different simple mechanisms of wear (adhesion, abrasion, diffusion, oxidation, etc.) operate simultaneously with predominant influence of one or more of them in different situations, identification of the dominant mechanism is far from simple, and most interpretations are subject to controversy. Identification depends on the material of the tool, workpiece to be machined, chip cross-sectional area, type of coolant, tool geometry, and the condition of the machine tool and its rigidity, etc. The central problem are high contact temperatures at the tool–chip and tool–workpiece interfaces combined with high relative speeds over these interfaces [ASTAKHOV 2014] [EL-HOFY 2019].

PVD coatings are wear protective layers for cutting applications and in the last years have advanced significantly. Among them there are some of the most commonly used transition metal nitride based hard ceramic coatings.

TiN coatings have been widely used and investigated during the last decades due to their relatively high wear resistance, thermal and chemical stability. These essential properties have been the basis of investigations of more complex coatings in order to improve the performance of simple binary TiN films under more rigorous working conditions [TILMANN 2017].

However, the oxidation resistance of TiN coating is inferior to other coating compositions such as AlTiN or AlCrN. TiN coatings oxidize quickly at temperatures over 500 °C, with the creation of a brittle and loose TiO_2 layer [QIANXI 2021]. Incorporation of aluminum (Al) into TiN coating enhances hardness, wear resistance, Young´s modulus and especially oxidation resistance at high temperatures (to a maximum of 1000°C). However, coating properties of TiAlN strongly depend on the Ti:Al ratio. [PALDEY 2002] [QIANXI 2021]. The maximum solubility limit of Al in the $Ti_{1-x}Al_xN$ is x = 65.4 mol. % AlN before the wurzite-type h-AlN is formed [DING 2008]. Tonshoff et.al showed also that very important is a ratio of Al/Ti to structure, adhesive strength, hardness and wear behavior of (TiAl)N-based PVD coatings. Using dry machining, Tonshoff observed wear behavior on drills when machining material Ck45. The best ratio was at Al/Ti = 1.0. [TONSHOFF 1997].

The most common systems are based on TiAlN system. It is well-know that addition of certain elements from the group of transition metals (TM) can improve the cutting performance of a TiAlN coating. Besides these TM elements, there is also silicon (Si) that has shown further increase in hardness, cutting performance, wear resistance and lifetime of coated tools due to formation of nanocomposite (nc) structure where nanocrystalline grains are embedded in an amorphous matrix Si_xN_y [FLINK 2008].

The introduction of Si in TiN coating significantly improved the oxidation resistance of TiN coating. Nowadays, TiSiN coatings, with hardness around 40 GPa, are often used in lot of applications where high hardness, thermal and oxidation stability is needed. TiSiN coating exhibit also high compressive residual stress and adhere poorly to a substrate, if there is no proper adhesion layer or not sufficient ion etching [PALDEY 2002] [CHANG 2020].

TiSiN coatings consist of nanocrystalline TiN grains embedded in an amorphous Si_3N_4 matrix. The presented structure in these coatings provides an extremely high hardness to this ternary system and can prevent dislocation movements and micro-crackings, thereby improving its mechanical properties. [TILMANN 2017]

When drilling, the angular speed of the rotating drill is constant; however, the local linear cutting speed varies and depends on the distance from the axis. Accordingly, the cutting speed at the periphery of the drill is significantly higher than that at the center of the drilling edge, the “chisel”. If the drill is designed and manufactured properly, the drilling regime is optimized and the tool material of the drill is selected accordingly, and simultaneously if metalworking fluid (MWF) flow rate and its properties (particularly, concentration, pH, and purity), then the flank wear should be found at the distance that is equal from ⅔ to ¾ of the drill radius from the drill center. This applies in machining of a wide group of work materials as, for example, difficult-to-machine materials and aluminum alloys. This is because the maximum drill temperature is found in this region under optimized drilling conditions. Due to drill runout and lip height wide-open tolerances, the drill periphery normally has the greatest wear and, therefore, is often selected as the criterion of tool life in practice [ASTAKHOV 2014] [INSPEKTOR 2014].

In this work, four different PVD coatings producing in STATON company - TiSiN, AlTiSiN, AlTiCrN and TiAlSiN were deposited on cemented carbide twist drill by cathodic arc-evaporation technique. In order to identify a mechanism of wear, we studied and observed the flank wear at the outer corner area and ¾ area of drill radius from the drill center.

2 EXPERIMENTAL DETAILS

2.1. *Cutting tool and workpiece material*

The cutting tool was twist drill from solid carbide rod with diameter 8 mm (Fig. 1) The substrate grade of twist drill was a Ceratizit CTS20D with 10 % of cobalt content and submicron grain size in ranging 0.5 to 0.8 µm. More information about a substrate are available at the Ceratizit Group website [CERATIZIT GROUP 2021].

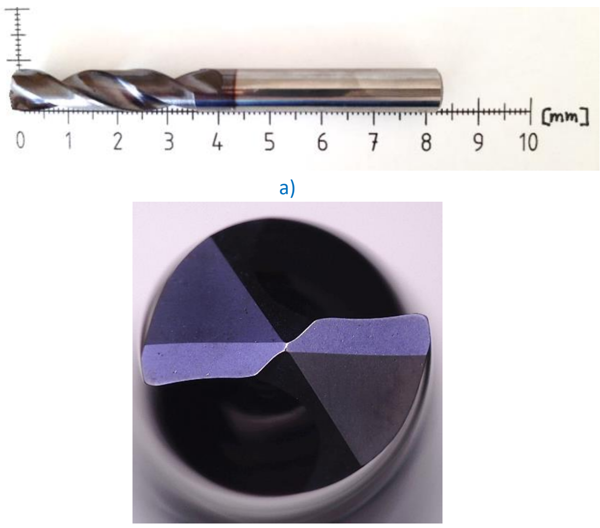

Figure 1. Twist drill a) view in P_f plane b) view in P_p plane

Geometry of the drills was the same in all cases. Cutting edge of the tools was treated by drag finishing process with a radius of r_n = 28 µm.

Each experimental coating was applied on 6 pcs. of drills. In this article, for observation of wear behavior, its character and intensity, we selected 4 types of produced PVD coatings by STATON company. Chemical composition these PVD coatings is mentioned in Tab. 1.

Content at. %	N	Al	Si	Ti	Cr	H [GPa]	E [GPa]	t [µm]
AlTiCrN	54.6	20.1	-	15.3	10	32.0 ± 2.0	450 ± 35	2.2
AlTiSiN	44.8	24.1	1.5	29.5	-	35. 5 ± 1.5	440 ± 35	1.9
TiSiN	53.9	6.2	4.1	35.6	-	36.5 ± 1.8	480 ± 40	1.8
TiAlSiN	53.7	17.2	2.1	26.9	-	34.1 ± 2.7	472 ± 30	2.1

Table 1. Chemical composition (EDX measurements 15 kV, at. %), mechanical properties and thickness of studied PVD coatings

All PVD coatings (Tab. 1) were deposited in a flowing pure nitrogen atmosphere at 4 Pa and 350 °C. To obtain different chemical composition, different cathodes were used. Bias voltage was the same in all PVD coatings, -80 V. Studied PVD coatings were deposited by Cathodic vacuum arc technology using STATON ARC300 coating unit. Workpiece material was C45 (1.1191), in the form of plate 450 x 500 mm with thickness of 15 mm. Detailed composition of machined material is listed in Tab. 2.

C	Mn	Si	Cr	Mo	Ni	P	S
0.42 - 0.50	0.50 - 0.80	max. 0.40	max. 0.4	0.10	max 0.40	max. 0.045	max. 0.045

Table 2. Chemical composition of workpiece material C45 (wt. %) [JKZ 2021] [ASTMSTEEL 2021]

2.2. *Experimental cutting conditions*

Before drilling process was carried out, nanoindentation measurements of hardness and Young's Modulus of as-deposited coatings was performed using Anton Paar NHT[2] device. 25 indents were made directly on the drills' shanks. Loading force was 10 mN.min^{-1}, loading and unloading rate was 30 mN.min^{-1}. The maximum depth was controlled and did not exceed 10 % of coating thickness, therefore a substrate effect could be neglected.

Drilling test (through hole) was performed on CNC milling machine Cincinnati Milacron. Cutting parameters were same for all drills, namely: v_f = 1100 mm.min^{-1}, v_c = 138 m.min^{-1}. The wear criterion was set at 3104 drilled holes. Behavior of flank wear was observed on each drill after 1940 drilled holes and after wear criterion at outer corner area (VB_{Cmax}) of drill and in ¾ area of drill radius from the drill center (VB_{Bmax}). These observation areas are shown in Fig. 2. From these measured values flank wears on each drill, an arithmetic mean value was made and the results were evaluated in the line graph.

Flank wear of cutting edge was assessed by using Keyence laser confocal microscope VKX-1050.

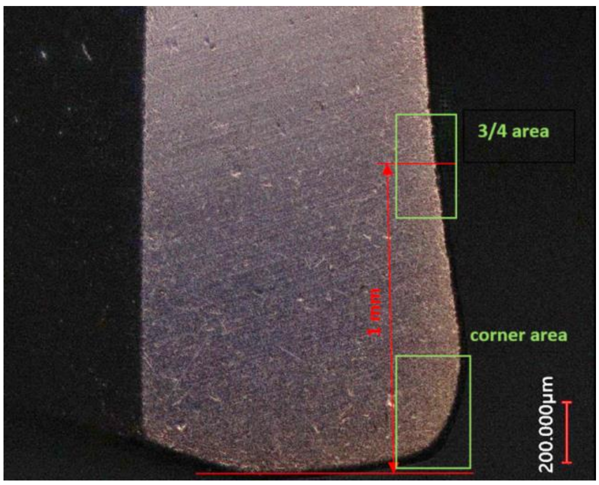

Figure 2. Observation areas on flank of drill, mag. x5.

3 RESULTS AND DISCUSSION

As mentioned in Chapter 2.2, behavior of the flank wear was observed after 1940 drilled holes and after criterion of wear (3104 drilled holes). The measured average value of VB_{Cmax} and VB_{Bmax} after 1940 and 3104 drilled holes are mentioned in Tab. 3.

Average value		AlTiCrN	AlTiSiN	TiSiN	TiAlSiN
VB_{Cmax} [µm]	After 1940 holes	246.72	148.28	90.37	93.98
	After 3104 holes	951.72	593.10	253.43	108.78
VB_{Bmax} [µm]	After 1940 holes	52.60	67.69	68.14	87.72
	After 3104 holes	59.78	69.58	82.74	106.22

Table 3. Maximal wear on flank of drills after 1940 and 3104 drilled holes

In Fig. 3 and Fig. 4 the course of average value of VB_{Cmax} and VB_{Bmax} on the flank with particular PVD coatings is depicted. The highest wear rate of VB_{Cmax} was noticed at AlTiCrN. On the other hand, drills with AlTiCrN coating had the smallest average value of VB_{Bmax} in ¾ area of drill radius from the drill center. In these graphs we can see a very interesting phenomenon and the fact that the course of VB_{Cmax} and VB_{Bmax} is opposite for individual PVD coatings.

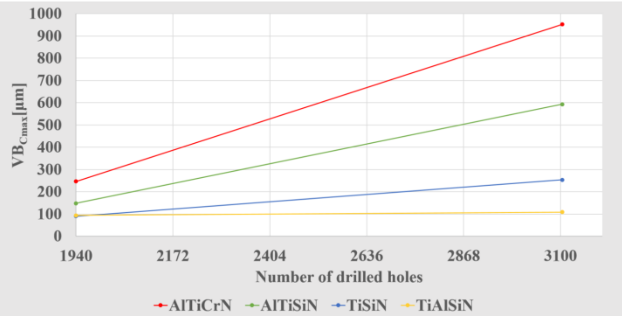

Figure 3. Line graph course of average VB_{Cmax} on flank of drill at different PVD coatings during drilling holes to C45 material

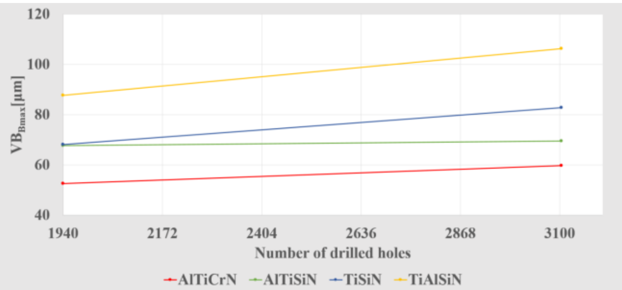

Figure 4. Line graph course of average VB_{Bmax} on flank of drill at different PVD coatings during drilling holes to C45 material

Drills with PVD coating AlTiCrN are presented in the line graph with red solid line. The increase in average VB_{Cmax} wear from the 1940 drilled holes to the wear criterion was most pronounced at this coating of all the tested coatings. The absolute increase was 705 micrometers, which is increase of approximately 290 %. The Fig. 5 shows the character of flank wear on drill with PVD coating AlTiCrN after 3104 drilled holes.

Along the whole cutting edge, the flank of drills exhibited a diffusive mechanism of wear with adhered material, characterized like built-up edge (BUE). The diffusive wear indicates that the tool material is diffusing into the chip as a result of very high temperatures on the tool-chip interface. Due to high temperature, pressure and friction on this interface, the layer of coating disrupted, and thus, a pure metal contact of the machined and cutting material occurs. Therefore, BUE was observed at the spots of diffusion wear (Fig. 6) and in this case, it can be considered as a consequence of the action of an adhesive mechanism of wear.

Figure 5. Flank wear of drill with AlTiCrN (No. 1) after 3104 drilled holes, mag. x5.

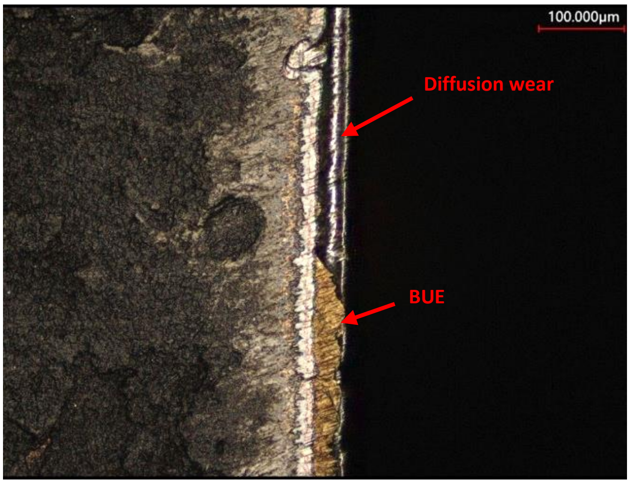

Figure 6. Detail of BUE and diffusive wear on the flank of drill with AlTiCrN (No. 2) after 3104 drilled holes, mag. x20.

The favorable process temperatures are 600-700 °C for the adhesive sticking weak layers to the cutting edge in combination with strong pressure [STAHL 2014]. In general, the thermal properties of ceramic PVD coatings for machining tools have a significant influence on the machining process. PVD coating are characterized by low thermal conductivity (units of $W.m^{-1}.K^{-1}$) and act as a thermal barrier for high speed processes, thus transferring more heat to the chip. On the other hand, a coating with high(-er) thermal conductivity enables the lateral transfer of heat on the surface.

Using a coating as a thermal barrier is also associated with some increase in temperature on the tool–chip interface. High speed machining processes also move the temperature upwards [MARTAN 2012]. These temperatures correspond to the color of the BUE, which is formed by the plasticized chip [STAHL 2014] [DUMKUM 2018] [CHAN 2021]. At high temperatures, different process parameters (e.g. force by material softening), friction conditions and tool deformation can take place, and also the coating itself can have different properties (e.g. oxidation rate, hardness, and thermal conductivity) [MARTAN 2012].

This high temperature and three-body abrasion with marks of plastic flow - observed at relief of drill (boundary outer corner and margin) during cutting also contributes to excessive flank wear because hardness of the machined surface has tendency to increase. Three-body abrasion occurs when a relatively hard contaminant (particle of BUE or wear debris) are squeezed between the two surfaces, which are in relative motion. This creates parallel furrows in the direction of motion [ASTAKHOV 2014] which we can observe relief of drill.

In the graph (Fig. 4), wear VB_{Bmax} measured at ¾ of drill radius from the drill center, we can see that the drills with PVD coating AlTiCrN had smallest width of the flank wear. Average value after 3104 drilled holes was 59.78 µm. The increase in wear, from 1940 to 3104 drilled holes in this area, was minimal (approximately 14 %) compared to the increase in wear in the outer corner area of drill, which was almost fourfold. As you can see in Fig. 7, the whole area is covered by BUE which substitutes the place of the original main cutting edge and to some extent also changes the geometry of the cutting edge.

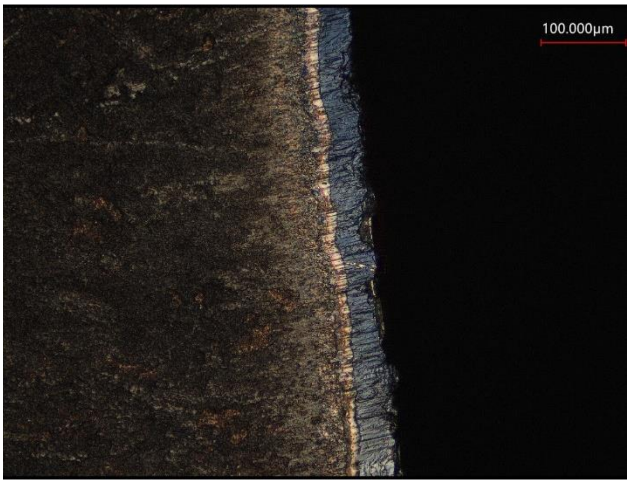

Figure 7. Detail of BUE on the flank of drill at 3/4 area. Coating AlTiCrN (No. 1) after 3104 drilled holes, mag. x20.

The color of the BUE in this whole area is dark purple, which indicates high process temperatures in this area and at its interfaces. Chan et al. stated that based on the color of BUE, the temperature is above 500 °C [CHAN 2021].

The change of color of the BUE on drilling tools with the AlTiCrN coating was detected approximately in middle area of the cutting edge (Fig. 8). Based on this, change in the process temperature can be expected in this area. Since the aim of this work was not to monitor the change in temperature along the cutting edge during drilling, we can only assume in which range of temperatures was moving. It is assumed that the yellow-colored chip and also the BUE have been affected by lower process temperatures. However, this cannot be said with certainty without a specifically focused experimental measurement. Based on these findings, we supposed that the change in process temperature along the main cutting edge of drills occurred, since the cutting parameters and cooling conditions were identical throughout the experiment.

Martan et. al. studied thermal conductivity of PVD coatings and showed how it changes in the case of several different coatings, i.e. ternary and columnar coatings of AlTiN, AlCrN vs nanocomposite (nc) coatings of TiAlSiN and CrAlSiN [MARTAN 2012]. It was shown that columnar coatings have almost two times higher thermal conductivity compared to nanocomposite coatings at room temperature, and 20 to 40 % higher thermal conductivity in the case of 500 °C.

Figure 8. Color change of BUE at middle area of flank on drill with AlTiCrN (No. 2) after 3104 drilled holes, mag. x10.

From the observation of tested drills, AlTiCrN coatings with no Si content do not offer enough protection against diffusive-adhesive wear during drilling of C45. It is more pronounced at the outer corner of the drill where the temperature during cutting reaches its maximum values. AlTiCrN coating is a typical representative of PVD coatings and it is characterized by rather larger columnar nitride grains (not shown here) than other studied coatings. Silicon addition leads to structural changes where pure crystalline structure is substituted by nanocomposite structure with nanocrystalline grains and amorphous matrix. This structure is responsible for increase in hardness, thermal stability and oxidation resistance [MUSIL 2012] because of presence of another element that produces stabile and protective oxides. In comparison to the other studied coatings (TiSiN, AlTiSiN and TiAlSiN), AlTiCrN coating was the only one as-deposited without silicon.

Fig. 9 illustrates the flank wear of the drill after 3104 drilled holes with PVD coating AlTiSiN that contains instead of Cr content low percentage of Si (1.51 at. %). It is obvious that the flank wear at the corner of drill is lower than the AlTiCrN coating, but the percentage increase of VB_{Cmax} from 1940 to 3104 drilled holes and wear at ¾ area is higher than AlTiCrN. Compared to the AlTiCrN coating, average value of VB_{Cmax} is smaller by 60 % and average VB_{Bmax} is higher by 16 % after criterion of wear. In this case, the absolute increase in VB_{Cmax} is 445 µm (from 1940 to 3104 drilled holes). Both coatings (AlTiCrN and AlTiSiN) exhibit diffusive wear that is observed along the main cutting edge with accumulated BUE. At the relief of the drill, marks after three-body abrasion were observed too. In cases where the BUE was still bonded/attached to the cutting edge, it was visible that the BUE exhibited a change of color closer to the corner of the drill compared to AlTiCrN (Fig. 10). As the diffusion rate increases exponentially with temperature [DADIC 2013], it can therefore be assumed that the course of the process temperatures at drilling was more favorable at the AlTiSiN coating than for the AlTiCrN coating. AlTiSiN with 1.5 % of Si showed lower tendency of BUE due to lower thermal conduction of the coating. More heat was then transferred to the chip and temperature at the interface tool-workipece was not high enough for BUE. This resulted into lower VB_{Cmax} compared to the AlTiCrN because of faster diffusion of the tool material into the chip.

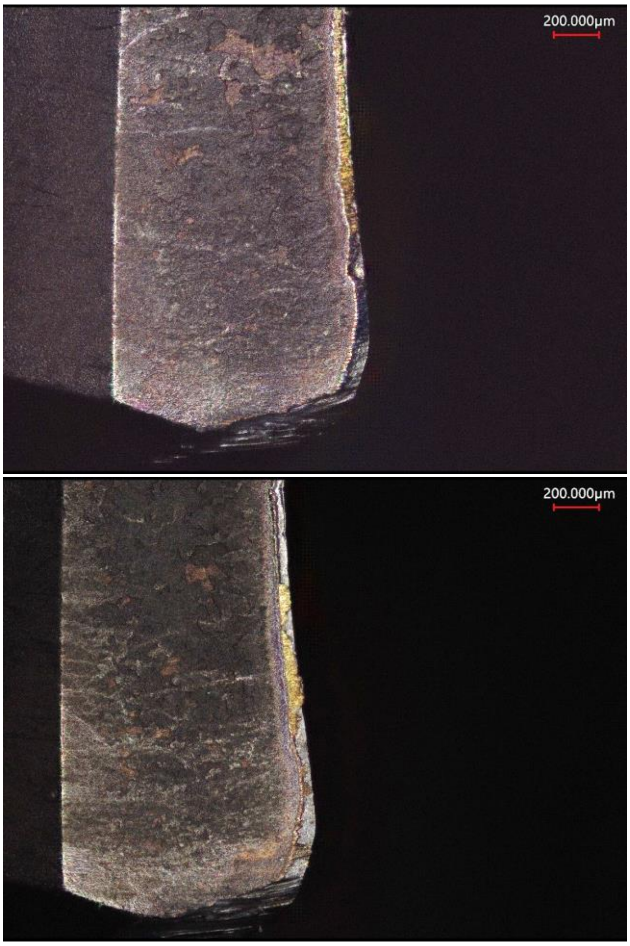

Figure 9. Flank wear of drill with PVD coating AlTiSiN (No. 1) after 3104 drilled holes, mag. x5.

Since the temperatures for the wear diffusion mechanism are around 800 °C and the favorable total temperature for the growth area of BUE is from 600 to 700 °C, there is no assumption the lowering the temperatures below these values. The coloration of a chip is also due to optical interference that depends on the thickness of oxide produced on the surfaces of the chip. This thickness depends on time at temperature, oxygen concentration as well as process temperature which make interpretation more difficult [STAHL 2014] [SHAW 2005]. We can also assume that coatings with lower thermal conductivity transfer more generated heat to the chip, then the lateral heat transfer is not so pronounced in coatings with higher Si content and proper Ti:Al ratio. Therefore, based on this, change of coloration of BUE could be observed closer to or farther from the corner of the drill. Martan et. al. stated in his work that thermal conductivity is influenced by Ti:Al ratio, as well as Si content [MARTAN 2012].

As it was mentioned earlier, the average wear VB_{Bmax} at this area was only around 10 µm wider, which we can consider an insignificant difference between these two PVD coatings (AlTiCrN vs. AlTiSiN). Detailed view of the ¾ of the drill radius area with AlTiSiN coating is in Fig. 11.

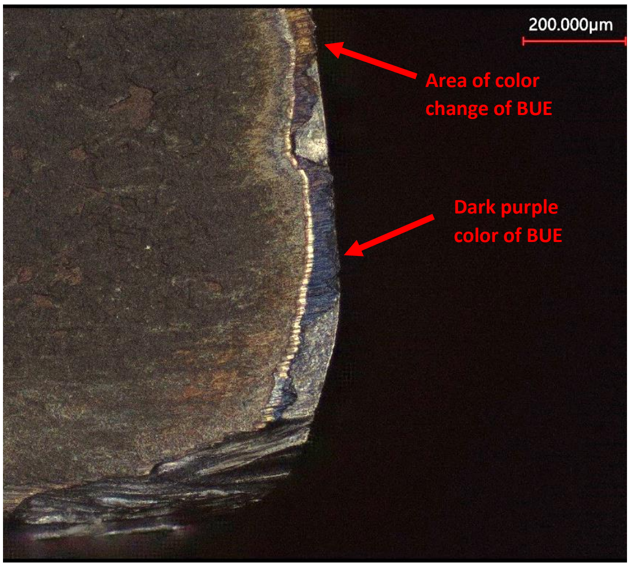

Figure 10. Detail of BUE color and diffusive wear on outer corner of flank. AlTiSiN coating (No. 1) after 3104 drilled holes, mag. x20

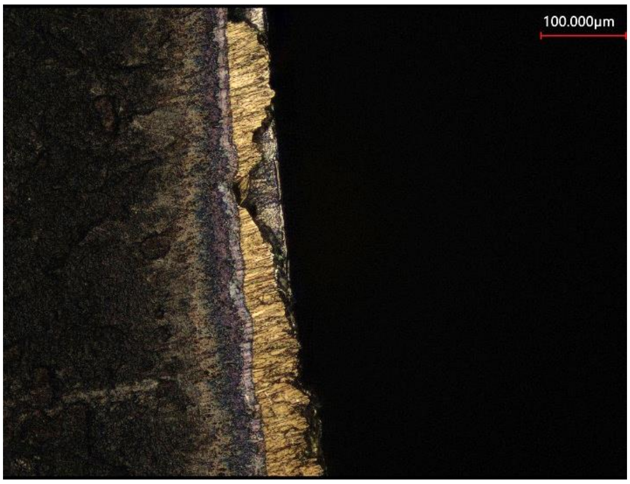

Figure 11. Detail of BUE on the flank of drill at 3/4 area. Coating AlTiSiN (No. 1) after 3104 drilled holes, mag. x20.

The VB_{Cmax} on the flank of drill with TiSiN coating (Fig. 12) was significantly lower than both observed AlTiCrN and AlTiSiN coatings after criterion of wear (almost 4 times smaller than AlTiCrN, and about 2 times smaller than AlTiSiN). The absolute increase in VB_{Cmax} from 1904 to 3104 drilled holes was 163 µm, which is a much less steep increase than was at AlTiCrN and AlTiSiN coatings. The dominant wear mechanism along the cutting edge is diffusive-adhesive mechanism again. The wear at outer corner of drill had also abrasive character with the range of diffusive wear substantially smaller on the corner of drill, what we can see in Fig. 13. At the corner of the drill with TiSiN coating, it was observed a low amount of yellow colored BUE. Deep purple color of BUE was not observed at any drills with TiSiN coating, and therefore, it can be assumed that the total temperature during drilling was again significantly reduced and lower than in the case of AlTiCrN and AlTiSiN coatings. With less occurrence of BUE, the process fluid penetrates into cutting area better due to lower contact pressure, what helps to reduce the temperature at the tool-chip interface.

The VB_{Bmax} wear was higher by 38 % than AlTiCrN and almost 19 % higher than AlTiSiN. The increase in the flank wear from 1940 to 3104 drilled holes was 21.4 % in this area. Fig. 14 shows the BUE exhibited a light yellow to white color in the ¾ area of drill radius from the drill center. As it was mentioned above, addition of silicon forms nanocomposite structure of TiSiN coatings, increases its hardness and thermal and oxidation stability, as well as lowers thermal conductivity [MUSIL 2012] [MARTAN 2012] [TRITREMMEL 2013].

TiSiN-based coatings offer a higher protection and a better wear resistance on the drill corner when drilling C45 material compared to AlTiCrN and AlTiSiN. Higher hardness of TiSiN improves abrasive resistance, but mainly higher amount of silicon enhances oxidation resistance and slow down a diffusion of substrate material to the chip.

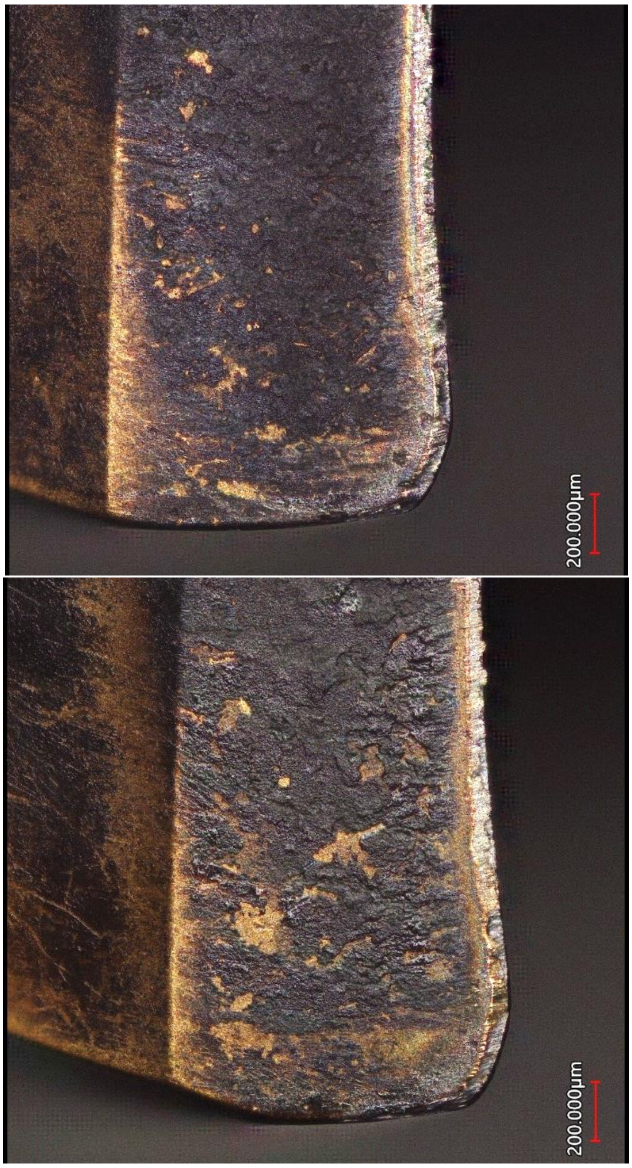

Figure 12. Flank wear of drill with PVD coating TiSiN (No. 1) after 3104 drilled holes, mag. x5

The smallest value of average VB_{Cmax} on the flank of drill was observed at TiAlSiN coating (Fig. 15). The flank wear of this coating was kept well below VB_{Cmax} 110 µm during the test. Increasing in average value of VB_{Cmax} from 1940 to 3104 drilled holes was only 15.7 %. It implies a good wear resistance of TiAlSiN coating at the outer corner of drill during the drilling test to C45 material.

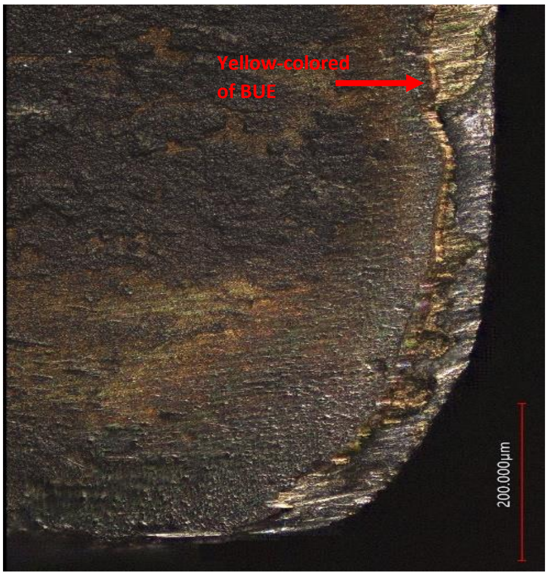

Figure 13. Detail of flank wear on the corner of the drill with PVD coating TiSiN (No. 2) after 3104 drilled holes, mag. x20

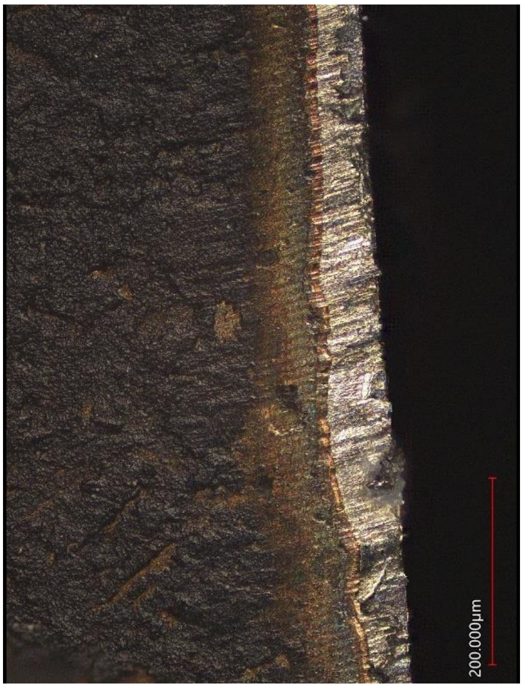

Figure 14. Detail of BUE on the flank of drill at ¾ area. Coating TiSiN (No. 1) after 3104 drilled holes, mag. x20.

The dominant wear mechanism of drill was diffusive-adhesive along the whole main cutting edge, but also an abrasive wear mechanism was observed especially at the corner of drill which disrupts the coating layer in this area. The BUE color was observed to be white on all coated drills with TiAlSiN coating, without color change. This indicates the best thermal conditions of the drilling process at the interfaces from the tested coatings in this article. Someone could expect that high performance TiSiN coatings should be the best option in machining process because its highest hardness, highest thermal stability and maximal operating temperature. But based on this experiment, hardness and max. operating temperature is not always the guarantee of success. It is worth noted that TiSiN coating is not pure TiSiN coating, but is doped with some portion of Al. Average Si content was around 4.1 at. %, aluminum was only 6.2 %. Apparently, Ti:Al:Si ratio in TiAlSiN coating offers the best combination of thermal conductivity, oxidation resistance along with hardness and resistance to diffusive wear.

The paradox for the TiAlSiN coating was that the area of the VB_{Bmax} showed the highest flank wear among the studied drills. Compared to AlTiCrN, average VB_{Bmax} wear is almost 78 % greater (Fig. 4). Both at the outer corner of the drill and at this area, the BUE color was white with variable height (Fig. 16).

Although the difference between the wear of the individual coatings in this area was much smaller than in the area at the outer corner of the drill, it is necessary to mention this interesting phenomenon. As mentioned by Astakhov, the maximum drill temperature is found in this region under optimized drilling conditions [ASTAKHOV 2014] and therefore this phenomenon of the opposite width of wear compared to the outer corner wear of the drill will be the subject of further research and testing in our company.

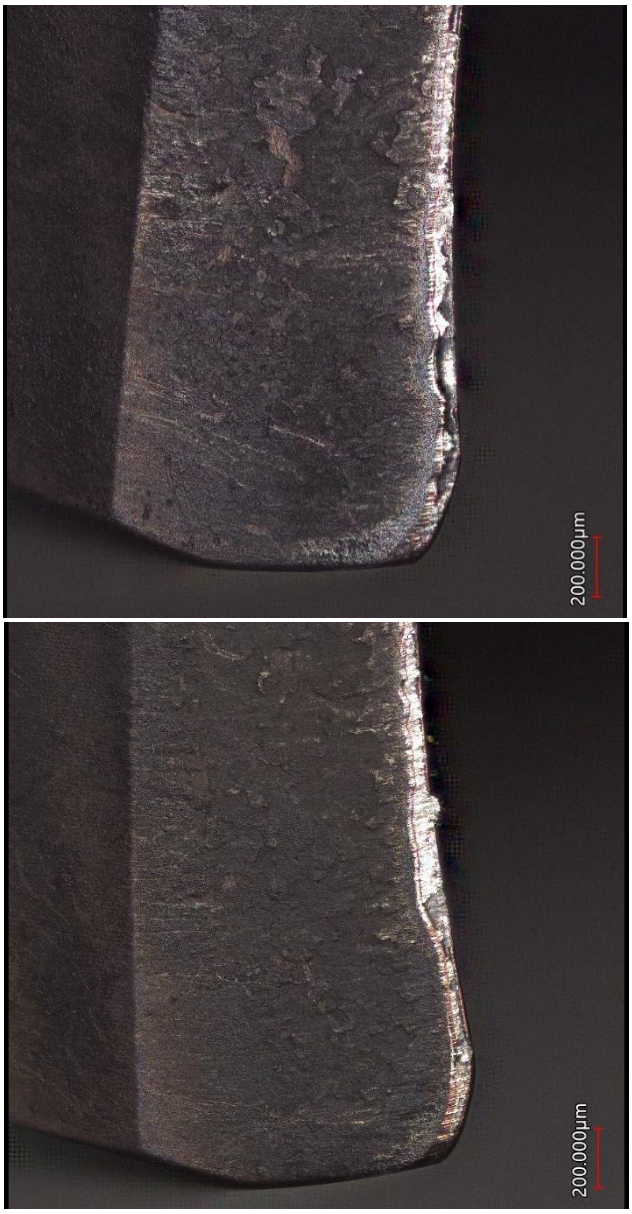

Figure 15. Flank wear of drill with PVD coating TiAlSiN (No. 1) after 3104 drilled holes, mag. x5

Since the area of dark purple color change of BUE shifted from the middle area of the main cutting edge in AlTiCrN to the corner area of the drill in AlTiSiN coating, and TiSiN and AlTiSiN coating did not show any area of dark purple color of BUE, we can state that the change in process temperature along the main cutting edge of drills occurred, while the cutting parameters and cooling conditions were identical throughout the experiment.

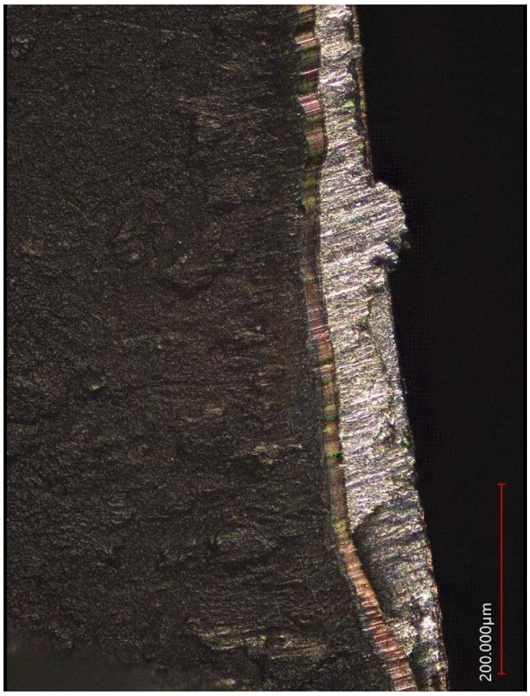

Figure 16. Detail of BUE on the flank of drill at ¾area. Coating AlTiSiN (No. 1) after 3104 drilled holes, mag. x20.

A possible explanation why the AlTiCrN coating has the minimal width of the flank wear in VB_{Bmax} area and the largest in the VB_{Cmax} area is that columnar structure with larger grains of AlTiCrN coating is more resistant against abrasive-diffusive wear. On the other hand, silicon in PVD coatings is responsible for precipitation of amorphous matrix Si_xN_y that enwraps nanocrystalline nitride grains. Excess of Si in the TiN crystal lattice leads to decreasing the grain size and growing of this amorphous phase. The more silicon, the more volume of amorphous phase. This could lead to more defects at the crystalline grain-amorphous matrix interface and could increase a wear rate on the cutting edge.

4 CONCLUSION

Since the main role in the growth process of BUE is played by the temperature on the tool surface and not the cutting speed, it is very important to reduce the temperature at the tool-chip and the tool-workpiece interfaces.

The BUE can cause 15-20 % fluctuations in cutting force and can lead to harmful oscillations. In addition to shortening the life of the cutting edge, the increase also leaves small volumes of removed material on the machined surface and therefore its quality deteriorates [KOVT 2021].

Effect of wear behavior of PVD coatings AlTiCrN, AlTiSiN, TiSiN and TiAlSiN with four different chemical compositions were studied in through-hole drilling test of C45 steel. All coatings were deposited by STATON company using PVD coating unit ARC300. VB_{max} as a decisive parameter was determined after

1940 and 3104 drilled holes. It was observed that the highest value of VB_{Cmax} was reached in the case of AlTiCrN coating, and the lowest value of VB_{Cmax} was measured in the case of TiAlSiN coating. Increased silicon content resulted in lowering the VB_{max} in general at the corner of the twist drill due to the fact that silicon offers lower thermal conductivity and then more heat can be transferred to the chip. Furthermore, coatings with Si enhances hardness, thermal and oxidation stability for drilling of C45 steel with worse machinability and supposed to decrease the process temperature, which was observed by shifting or removing the BUE color boundary. On the other hand, silicon itself is not only element that improved the resistance against diffusive wear. The more important is to have a proper ratio of elements Ti:Al:Si.

Based on the observation of the corner of the drill, it was found that the main wear mechanism is diffusive-adhesive wear, and TiAlSiN-based coating offered the best resistance against diffusive-adhesive wear. The maximal temperature was assumed on AlTiCrN coating and the minimal temperature was on TiAlSiN coating.

Despite the opposite effect of VB_{Cmax} and VB_{Bmax}, the decisive wear for determining the suitability of the tool for replacement resp. regrinding in the manufacturing is the total VB_{max} on the flank of the tool. The VB_{max} values in our experiment are met by VB_{Cmax} and therefore the TiAlSiN coating is the most suitable coating from this experiment for drilling C45 material.

As mentioned above, the subject of further research and testing in our company STATON will be the phenomenon of opposite wear of VBCmax and VBBmax on the main cutting edge when changing the composition of PVD coating. In the broader context of this research, in cooperation with Faculty of Materials science and technology in Trnava (STUBA), we have ongoing analyzes of the surface integrity of the drilled hole, tribological properties as well as EDX chemical analysis along the cutting edges with regard to wear, chemical maps of worn parts on the tool and surface of the drilled holes, etc. Continuation of our study will be a part of second article due to extensive amount of analysis and limited range for an article.

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