Annals of Warsaw University of Life Sciences – SGGW
Forestry and Wood Technology No. 112, 2020: 54-59
(Ann. WULS–SGGW, For. and Wood Technol., 2020: 54-59)

Influence of the microstructure of tool coatings based on Ti and Al on the blunting process during chipboard processing

PAWEŁ CZARNIAK[1], KAROL SZYMANOWSKI[1], PETER PANJAN[2]

Department of Mechanical Processing of Wood, Warsaw University of Life Sciences – SGGW
Josef Stefan Institute, Ljubliana, Slovenia

Abstract: *Influence of the microstructure of tool coatings based on Ti and Al on the blunting process during chipboard processing.*This work concerns three different tool coatings containing Ti and Al. i.e. TiN, AlTiN, TiAlSiN applied to cutting tools used in the machining of wood materials. In the case of the AlTiN coating, a multilayer structure with alternately arranged AlTiN and TiN nano-layers was used. The above coatings were applied to standard replaceable knives used for CNC milling heads made of WC-Co cemented carbide. The deposition process was carried out using the RF Magnetron Sputtering method. During the measurement on a workshop microscope, the VBmax index measured on the clearance face was adopted as the wear criterion. The research proved a very good behaviour of the TiN/AlTiN multilayer coating, for which the longest average service life which was recorded exceeded the results obtained for the reference tool by about 30%. The addition of silicon, which was supposed to increase the abrasion resistance, only did not improve the durability of the blade, it actually worsened it by 6%. In addition, the coating, which has been widely used in the machine industry for a very long time, i.e. TiN, did not extend the tool life significantly (+ 7%).

Keywords: PVD, tool coatings, Al, Ti, Si, tool durability

INTRODUCTION

The technologies for applying tool coatings using plasma techniques have been known for a long time. In the initial stages of their development, single-layer coatings, such as TiN, were dominant. Over time, second-generation coatings, such as TiCN, AlN, CrN or DLC, appeared, extensively described by Vetter (2014). Recently, multi-layer and nanocomposite nanocoatings have also started to appear.

When analyzing the development of tool coatings, a very important breakthrough seems to be the introduction of additional elements in the form of Ti and Al to the market on a larger scale. Their market share began to increase rapidly from the end of the 90s, for example the share of TiAlN coatings reached even 40%. On the other hand, the share of the basic TiN coating decreased twice in the same period of time. A significant increase in the popularity of coatings containing the aforementioned elements results from their high hardness (about 25÷38 GPa), low hardness loss at high temperature (reduction by 30÷40% at 800 °) and resistance to oxidation (the same oxidation rate 15÷20 µg/cm2 at 800°C as for TiCN at 400 °C and for TiN at 550°C). Moreover, they show low heat conductivity (up to 30% lower relative heat indentation coefficient than for TiN) Werkzeug Technik (2003).

Due to such favourable mechanical properties, many scientists have carried out tests of tools covered with this type of coating during the milling of wood materials. Some researchers, e.g. Nouveau et al. (2007), proposed CrAlN coatings, which show 2.5 times longer durability in comparison to standard tools.

Others, such as Warcholiński et al. (2011), conducted durability tests under the Operational Programme Innovative Economy 2013 within a project titled "Hybrid technologies for woodworking tools modification" focusing on monolayer TiN, TiAlN and multilayer TiAlN/TiN. It was proved that the TiAlN coating shows higher oxidation resistance than TiN. Titanium nitride is oxidized at a temperature above 600°C, while the TiAlN exhibits an oxidation resistance up to 800°C. There were deposited seven bilayers TiAlN/TiN, each 400 nm thick. This value ensures the best mechanical properties, highest hardness, high Young modulus and the best adhesion. The thickness ratio of the bilayers was 1:1, together 3 μm on steel HS 6-5-2.

On the other hand, Panjan et al (2014) proposed and conducted strength tests of a multilayer TiN/AlTiN coating applied to drill bits made of HSS. The hardness of TiN/AlTiN coatings measured at different indentation loads was approximately 32 GPa, while their indentation modulus was about 340 GP. The results of scratch resistance tests were also very favourable. The photos show that the damage is not deep enough to cause delamination of the coating.

Also Si seems to be among other elements that could increase the abrasive wear resistance of the coating for milling chipboards. The basic properties of this type of coating were investigated by Miletec et al. (2014).

As can be seen from the information presented above, there is still a need to verify the durability of tool coatings that contain Al or Si dedicated to wood based materials machining.

MATERIAL AND METHODS

The work covers three types of coatings, i.e. single TiN, double TiAlSiN and multi-layer TiN/AlTiN nanocoating. The research used an industrial direct current (DC) magnetron sputtering system equipped with four targets placed in the corners of a chamber. The handle allowed the substrate to move in 2 directions ensuring a uniform coating thickness. The initial process was the ultrasonic cleaning and sputter-etching of knifes that was carried out in 45 min in mixed argon (flow rate 180 ml/min) and krypton (flow rate 50 ml/min) in an atmosphere under the pressure of 0.35 Pa. During the actual process, the tool table rotation for TiAlSiN was set to 3 RPM. Ti-Al targets were used during the modification process. The chamber had 48 cylindrical Al plugs that allow to obtain the coatings with approximately 1:2 atomic ratio of Ti:Al. The thickness of the individual TiN was depending on the total coatings thickness, the deposition time and the rotation speed of the turntable (3 rpm). It varied in range 5–10 nm.

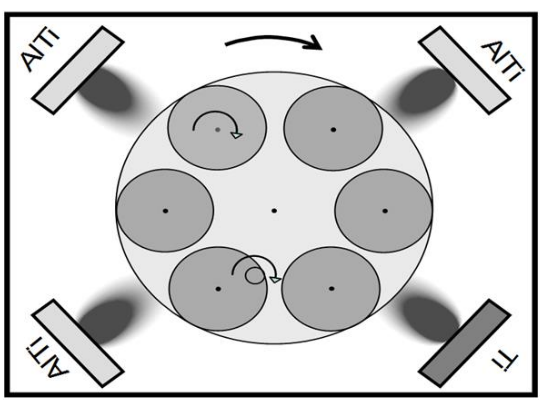

Figure 1. Configurations of the targets for the deposition of the nanomultilayer TiN/AlTiN (Panjan et al. 2014)

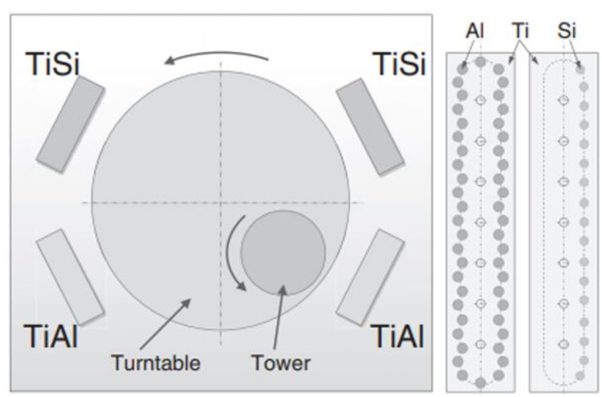

Figure 2. Configurations of the targets for the deposition of the nanolayer TiAlSiN (Miletec et al. 2014)

The physical and mechanical properties of the standard three layers chipboard 18 mm thick used in the tests were described in details in work of Czarniak et al. (2020).

Durability tests were carried out at WULS (Department of Mechanical Wood Processing) on a Busellato Jet 130 machining center (Italy 2004) using a modified FABA FTS-01 head with a diameter of 40 mm with replaceable knives, equipped with one WC-Co carbide cutting knife. The dimensions of the FABA knives with the trade designation N000808U were respectively: 29.5×mm×12 mm×1.5 mm. The head rotational speed was 18,000 RPM with a feed per tooth of 0.15 mm. The milling depth was 6 mm. The wear measurement procedure and the blunting diagram are shown in Figures 3 and 4.

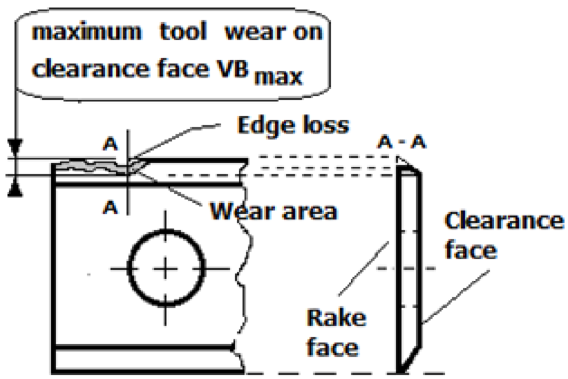

Figure 3. A view of tool wear indicator measurement

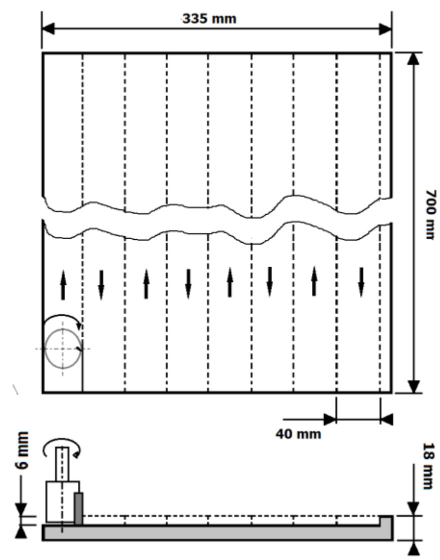

Figure 4. A view of tool blunting procedure.

The wear measurements were made on a bench microscope. The milling distance during each blunting cycle was 70 cm. Durability tests for a given blade were stopped after the tool wear index VB_{max} exceeded the value of 0.2 mm. Eight cutting blades were used in each variant. The cutting distance, after exceeding with the VB_{max} tool wear indicator 0,2 mm was calculated using the following equitation (Czarniak et al. 2020):

$$L_t = \frac{V_C \frac{L}{V_T}}{2} = \frac{\pi D n}{2} \cdot \frac{L}{V_T}$$

Equitation 1

where:
D- diameter of tool [m]
n- rotational spindle speed [1/min]
V_t – feed speed [m/min]
V_C – cutting speed [m/min]
L - feed distance [m]
L_t – cutting distance [m]

RESEARCH RESULTS

Table 1 shows the tool life (cutting distance) for each type of coating in relation to the unmodified tool.

Table 1. Average cutting distance for each type of coating and control tool

Reference [m]	*TiN/AlTiN [m]*	*TiN [m]*	*TiAlSiN[m]*
5458	7107	5825	5129

By analyzing the cutting distance shown in Table 1, an improvement in the durability of the multilayer TiN/AlTiN coating is visible in relation to a single TiN layer. The results obtained by Warcholiński et (2011) during industrial tests carried out for multilayer TiAlN / TiN or CrCN / CrN coatings also confirmed a significant improvement in functional properties when using a multilayer microstructure. The coating with the addition of silicon showed a particularly low resistance to cracking. In her case, a very large amount of chipping and chipping was observed, which is associated with the risk of CFM (catastrophic blade failure).

In addition, the wear curves of tools covered with the aforementioned coatings were analyzed and compared with the wear course of reference tools. The results are shown in Figures 5 ÷ 7.

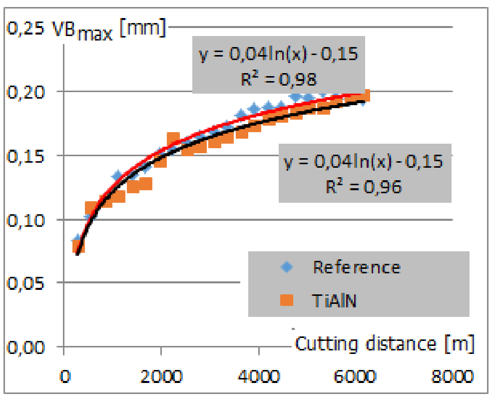

Figure 5. Wear curve for a single-layer TiAlN coating

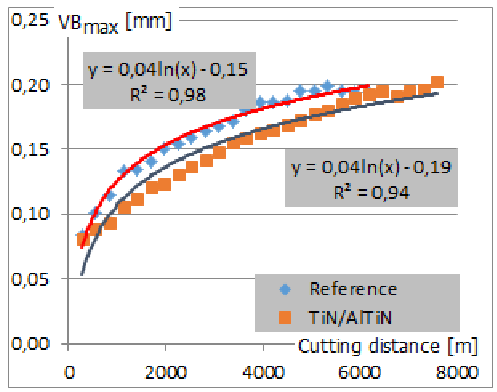

Figure 6. Wear curve for the multi-layer TiN / AlTiN coating

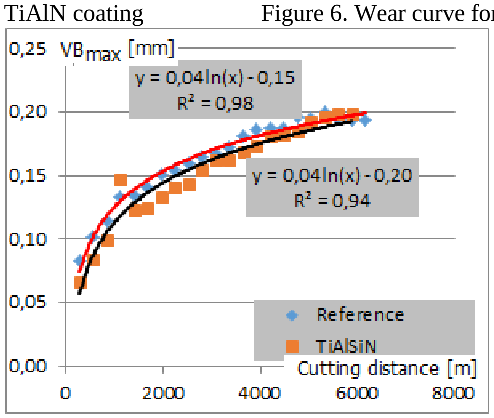

Figure 7. Wear curve for a single-layer TiAlSiN coating

When comparing three different examined in work coatings, it is clear that the wear behavior of a tool with a TiN coating is almost identical to that of an unmodified tool. In the case of a single-layer coating with the addition of Si, the scatter of results caused by very frequent chipping and the worst results in the average cutting path, make this type of modification ineffective. On the other hand, the curve showing the tool with multilayer TiN/AlTiN coating runs significantly below the curve observed for the variant with the unmodified tool.

The promising results obtained in this work with the multilayer TiN/AlTiN coating indicate that a change in the ratio between Al and Ti. in favor of Al is desirable. Increase in Al content. over 50% means that instead of TiAlN we have a touch with coating of the AlTiN type. The percentage of this element can reach up to 80%, thus significantly improving the properties of the coating such as adhesion, hardness and wear resistance (Werkzeug Technik 2003). So far, in the case of wood materials processing, single coatings of the TiAlN type or multi-layer TiN/TiAlN coatings have been analyzed (Warcholiński et al. 2010). In the literature, there are studies on similar coatings as those tested in this work (Panjan et al. 2014), but they were not subjected to durability tests during the processing of wood materials. In turn, the properties of the TiAlSiN coating were also the subject of research (Miletec et al. 2014). However, as was the case with the multilayer microstructure of TiN/AlTiN, no durability tests were performed.Based on the obtained results, it can be assumed that the Al and Ti based multilayer coatings should be further developed. They are used in the treatment of wood materials, but require further research in which other elements such as zirconium, vanadium, boron and hafnium would be added to the coating and the microstructure was improved.

CONCLUSIONS

From these results were obtained following conclusions:

- The multilayer TiN / AlTiN nanocoating turned out to be more durable compared to a single TiN coating, showing an increase in durability by about 30%.
- The coating commonly used in the machine industry, i.e. TiN, turned out not to be fully useful when processing wood materials. The average increase in blade life did not exceed 10%.
- The addition of Si in the single-layer TiAlSiN coating turned out to be disadvantageous, reducing the tool life compared to the uncoated tool.
- Despite the large dispersion of the results for the multilayer TiN/AlTiN coating, the favorable course of the wear curve compared to the reference tool supports further research on its improvement.

REFERENCES

1. BENLATRECHEA Y., NOUVEAU C., MARCHAL R., FERREIRA MARTINS J.P., AKNOUCHE H,. 2009: Applications of CrAlN ternary system in wood machining of medium density fibreboard (MDF), Wear 2009 (267): 1056–1061.
2. CZARNIAK P., SZYMANOWSKI K., PANJAN P., 2020: Characteristic of the wear of a tool coating based on amorphous carbon during chipboard milling, Annals of WULS - SGGW. Forestry and Wood Technology 2020 (111): 53-59
3. KOT M., RAKOWSKI W.A., MAJOR Ł., MAJOR R., MORGIEL, J. 2008: Effect of bilayer period on properties of Cr/CrN multilayer coatings produced by laser ablation, Surf. Coat.Technol. 2008 (202): 3501–3506.

4. MILETIĆ A., PANJAN P ŠKORIĆ B ČEKADA M DRAŽIČ G KOVAČ J. 2014: Microstructure and mechanical properties of nanostructured Ti–Al–Si–N coatings deposited by magnetron sputtering,. Surface and Coatings Technology. 2014 (241): 105–111.
5. NOUVEAU C., LABIDI C., FERREIRA MARTIN J.P., COLLET R., DJOUADI A. 2007: Application of CrAlN coatings on carbide substrates in routing of MDF, Wear 2007 (263): 1291-1299
6. PANJAN M., KLANJŠEK., GUNDE M., PANJAN P., ČEKADA M. 2014: Designing the color of AlTiN hard coating through interference effect. Surface and Coatings Technology. 2014 (254): 65–72.
7. VETTER J. 2014: 60 years of DLC coatings: Historical highlights and technical review of cathodic arc processes to synthesize various DLC types, and their evolution for industrial applications, Surface and Coatings Technology 2014: (257)
8. WARCHOLINSKI B., GILEWICZ A. 2011: Multilayer coatings on tools for woodworking, Wear 2011 (271): 2812–2820
9. Werkzeug Technik. Nanostructured Coatings for High Performance Tools. Die Deutsche Fachzeitschrift der Schneidwerkzeuge und Meßte No 77, 2003

Streszczenie: *Wpływ mikrostruktury powłok narzędziowych opartych na Ti oraz Al na proces tępienia podczas obróbki płyty wiórowej*. Praca dotyczy trzech różnych powłok narzędziowych zawierających Ti oraz Al. tj. TiN, AlTiN, TiAlSiN naniesionych na narzędzia skrawające używane podczas obróbki materiałów drzewnych. W przypadku powłoki TiN/AlTiN zastosowano strukturę wielowarstwową z naprzemiennie ułożonymi warstwami AlTiN oraz TiN. Powyższe powłoki zostały naniesione na standardowe wymienne noże stosowane do głowic frezarskich na maszynach CNC wykonane z węglika spiekanego WC-Co. Proces nanoszenia został zrealizowany przy użyciu metody RF Magnetron Sputtering. Podczas pomiaru na mikroskopie warsztatowym za kryterium zużycia przyjęto wskaźnik VB_{max} mierzony na powierzchni przyłożenia. Jako kryterium stępienia przyjęto wartość 0,2 mm. Badania dowiodły bardzo dobrego zachowania się powłoki wielowarstwowej AlTiN w przypadku której zanotowano najdłuższy średni okres trwałości przewyższający wyniki uzyskane dla narzędzia referencyjnego o ok 30%. Dodatek krzemu, który w założeniach miał zwiększyć odporność na ścieranie nie poprawił trwałości ostrza a wręcz ją pogorszył o ok 6%. Ponadto powłoka, która jest od bardzo dawna jest powszechnie stosowana w przemyśle maszynowym czyli TiN nie wydłużyła czasu pracy narzędzia w istotny sposób (+7%).

Corresponding author:

Paweł Czarniak
Warsaw University of Life Sciences – SGGW
Faculty of Wood Technology
159 Nowoursynowska St.
02-776 Warsaw, Poland
e-mail: pawel_czarniak@sggw.pl