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Characteristic of the wear of a tool coating based on amorphous carbon during chipboard milling

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Abstract: Characteristic of the wear of a tool coating based on amorphous carbon during chipboard milling. The study verified the durability and the course of wear during the durability tests of the TiAlN / a-C:N double tool coating. The aforementioned coating consisted of a bottom layer of TiAlN and a top layer based on nitrogen-enriched amorphous carbon. Standard replaceable cutters for milling heads made of WC-Co sintered carbide were subjected to the modification process. The coating was applied using plasma by RF Magnetron Sputtering. During the tests, the blade wear was measured using a workshop microscope. The VB_{max} indicator measured on the clearance face was adopted as the blunting criterion and its maximum value was set on 0,2 mm. The results show that the additional coating of amorphous carbon contributed to the increase of the tool durability determined with cutting distance. The use of only a single layer based on TiAlN shortened the durability by about 3%. On the other hand, applying both the bottom and top layers (TiAlN /a-C:N) extended the cutting distance by about 24%. The research showed a clear advantage in terms of the durability of the blades modified with a multi-layer coating in relation to a single-layer. Moreover, the positive effect of the top layer containing amorphous carbon on tool durability has been demonstrated.

Keywords: PVD, tool coatings, a-C:N, tool durability

INTRODUCTION

Due to the dynamic development of plasma techniques known as PVD (physical vapor deposition), nowadays a wide range of companies specializing in this field, such as PLATIT-AG that can be found on the market. Their offer includes both first-generation single-layer coatings, such as TiN, and multilayer coatings based on TiAlN or CrCN / CrN. A special role in machining is played by DLC (diamond like carbon) coatings that thanks to the presence of amorphous carbon, significantly reduce the coefficient of tool-material friction. Moreover, if the proportion of sp^3 bonds between carbon atoms exceeds 50%, the tetra hydrate form of carbon (ta-C) is formed.

The micro hardness of such a material in relation to the material in which sp^2 bonds predominate can reach very high values (Vetter 2014). This type of coverage is described as a super hard coating (Ratajski et al. 2009, Pancielejko et al. 2012, 2013). Information about DLC coatings can also be found in another work (Endler et al. 1999). Taking into account the dominant role of the abrasive wear mechanism of the blades in the processing of wood materials and its dynamic nature, the interest in DLC coatings is understandable. An anti-wear coating of this type may constitute the top layer (Faga and Settineri 2006). The authors have successfully tested the above coatings on two types of tool material, i.e., high speed steel HSS 18 and alloy steel AS 90CMV8

In the case of tools for wood materials processing, a multi-layer CrCN / CrN coating can be also applied (Gilewicz et al. 2013). The additional top ta-C layer brought a further increase in the durability of the blade by 15% when milling wet pine timber. As mentioned before, the amorphous form of carbon a-C, which does not show such high hardness, has however very good tribological properties. Moreover, it can be relatively easily enriched with various elements, both metals and non-metals, therefore, it improves its functional properties. This prompted some scientists to conduct tests with this type of coating applied to work tool steel AISI D2, powder metallurgy tool steels (CPM-3V) and cemented carbide (Panjan et al. 2011).

In addition, a TiAlN coating was used as the bottom layer which due to the presence of Al is characterized by high hardness. The microhardness of the surface layer based on amorphous carbon enriched with nitrogen and the bottom layer TiAlN were 950 HV and 3300 HV, respectively. The scratch resistance tests also showed promising results of the scratch pattern analysis. The images showing the condition of the blade surface after the test prove that the bottom layer adheres well to the substrate and has not been damaged.

Due to the different mechanism of wear of the tools used in the furniture industry, the aim of the study is to verify its usefulness for processing wood composites.

MATERIAL AND METHODS

The coating application process was carried out at the Joseph Stefan Institute in Ljubljana using the RF Magnetron sputtering method. The device is equipped with 4 targets located in the corners of the chamber. The tools were placed in handles that allow to move in two directions. Consequently, it ensured a uniform thickness of the coating. In the first phase, the tools were ultrasonically cleaned and sputter-etched. The current of 650 V was used with the mixture of argon (flow rate 180 ml/min) and krypton (flow rate 50 ml / min) in which the tools stayed for 45 min under the pressure of 0.35 Pa.

The pressure that was maintained during the actual coating procedure was 0.6 Pa at 450 ° C with the flow rates of nitrogen, argon and krypton of 100, 160 and 110 ml/min, respectively.

Three TiAl targets were used for the application of the first layer with the Ti to Al ratio being approximately 1:1 and for the application of the second layer one pyrolytic graphite target (purity 99.8%). The total thickness of the a-C:N/TiAlN coating was 3.9 μm with the thickness ratio of TiAlN to a-C:N was 6:1.

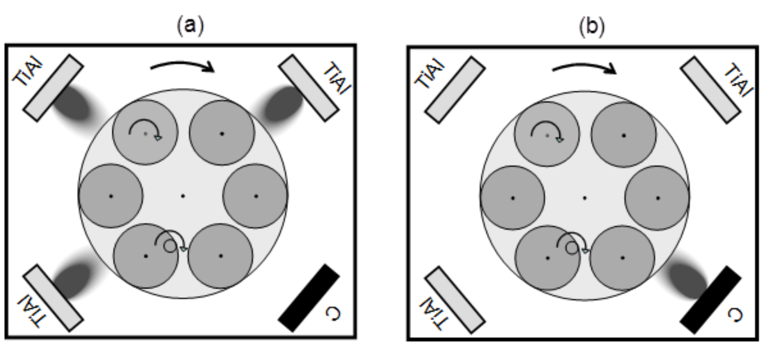

Figure 1. Configurations of the targets for the deposition of the TiAlN/a-CN double layer coating: (a) deposition of bottom TiAlN layer (b) deposition of top a-CN layer.

The physical and mechanical properties of three layers chipboard commercially made and used in the durability tests were determined in accordance with standards. (PN-EN 310, EN 323, EN 1534, PN-EN 320, PN-EN 319, PN-EN 317, PN-D-04234, PN-D-04213, PN-D-04213, ISO 3340) and are presented in Table 1.

Table 1. Physical and mechanical properties of commercially made, three layers chipboard

PROPERTY	VALUE
Density [kg/m^3]	650
Flexural strength [N/mm^2]	13.1
Elastic modulus [N/mm^2]	3200
Strength in pull out of screws test [N/mm]	70.9
Hardness in Brinnel scale [HB]	2.61
Mineral contamination [%]	0.18
Swelling 24h [%]	25.6
Tensile strength [N/mm^2]	0.37
Impregnability 24h [%]	86.5

Durability tests were carried out at WULS (Department of Mechanical Processing of Wood) on a Busellato Jet 130 machining center (Italy 2004) using the manufacturer's modified FABA FTS-01 head with a diameter of 40 mm equipped with 1 replaceable cutting knife. The dimensions of the FABA knives with the trade designation N000808U were 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 procedure of blunting shows Fig. 3. In each variant, 8 cutting edges were tested. The milling distance during each blunting cycle was 70 cm.

The wear measurements were made on a bench microscope. As a direct indicator of the blade wear, the maximum wear on the clearance face VB_{max} including both the loss of the cutting edge and the wear on the surface was used. The schema of measurement procedure shows Fig 4. The durability test was discontinued after the VB_{max} value of 0.2 mm was exceeded. The cutting distance recorded at this moment indicated the durability of the tool.

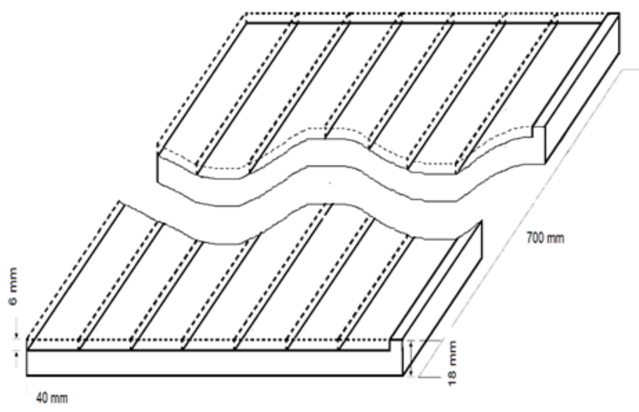

Figure 3. Schema of blunting procedure

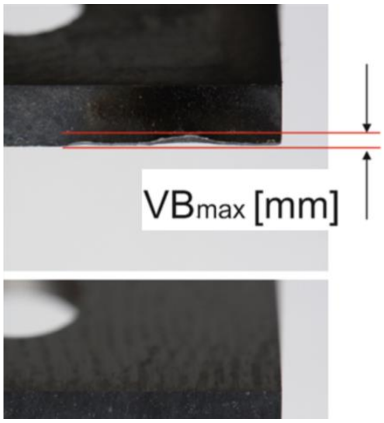

Figure 4 Tool wear indicator VB_{max}

The cutting distance was calculated according to the following equitation (1).

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

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

Figure 5 shows the durability of reference tools and those coated with a single TiAlN and double TiAlN / a-C:N coating compared to the reference tool.

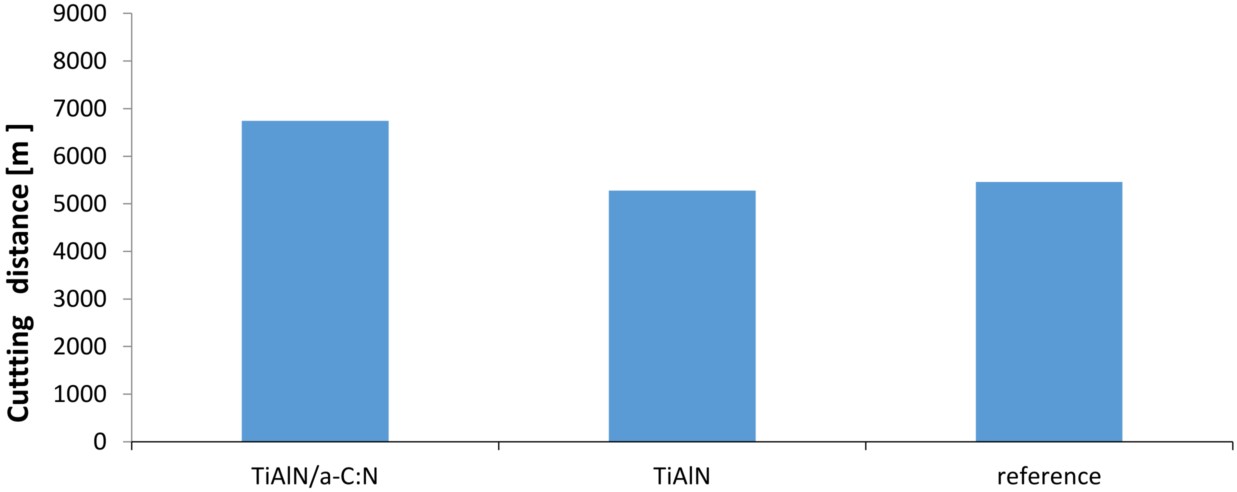

Figure 5. Durability comparison of a single-layer TiAlN coating and a double TiAlN / a-C: N coating in relation to the unmodified tool.

The graph shows that the tool coated with a double layer of TiAlN / a-C:N turned out to be the best tool in terms of durability. On the other hand, a single TiAlN coating did not extend the tool durability. The shortening of the average cutting distance of the tool was even observed, in comparison to the reference tool. Moreover, the study shows the course of the wear curve in relation to uncoated knives. The results are shown in Figures 6 and 7.

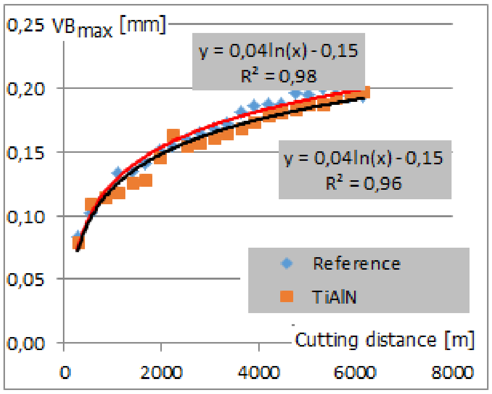

Figure 6. The wear curve for a single-layer TiAlN coating

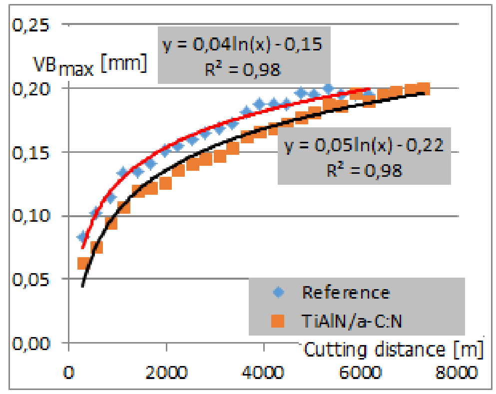

Fig. 7. Wear curve for the double TiAlN / a-C:N coating

The study also shows the trend lines of the wear curve for both the single-layer TiAlN and the double TiAlN / a-C:N coatings. The course of the curve showing the behavior of a single TiAlN coating that practically coincides with the curve observed for the reference tool. On the other hand, the tool covered with a double TiAlN / a-C:N coating shows a lower degree of wear throughout the entire service time in comparison to the unmodified tool. This demonstrates the beneficial effect of a softer outer layer based on a properly nitrogen enriched amorphous a-C:N carbon.

The results presented above are difficult to relate directly to the works concerning DLC (diamond like carbon) tool coatings (Faga and Settineri 2006, Pancielejko et al. 2012, 2013). It results in the fact that the microstructure of the coatings proposed by the authors mentioned above is completely different. The former authors subjected modification to DLC coatings of HSS tools which had been pretreated with nitriding and next coated with Cr compounds. In the case of the latter ones, chromium compounds were used as the bottom layer. At the same time, the study shows that the DLC layer was not enriched with another element. On the other hand, other researchers focused on tetra hydrate form of carbon with completely different mechanical properties than the amorphous form used in this study (Gilewicz et al. 2013). According to literature, a single TiAlN coating applied to HSS substrate turned out to be about 50% more durable in comparison to uncoated tool (Warcholiński et al. 2011). This result was probably achieved by the Ti-based interlayer with the thickness of 0.1μm. On the other hand, work in which an analogous coating was testified, did not include durability tests in the field of wood material processing (Panjan et al. 2011).

On the basis of the research results, it can be concluded that the further development of tool coatings has to be based on the use of a multilayer structure increasing the adhesion of individual layers to the substrate.

CONCLUSIONS

Based on the results obtained, the following conclusions can be drawn:

- Double TiAlN / a-C:N coating with nitrogen-enriched amorphous carbon as the top layer turned out to be more durable than a single TiAlN coating.
- The coating commonly used in the engineering industry, i.e., TiAlN deposited on WC-Co carbide, turned out to be ineffective in the machining of standard chipboard.

- In the entire service time of the tool modified with the double TiAlN / a-C:N coating, a lower value of the wear index VB_{max} was observed compared to the reference tool.

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Streszczenie: *Charakterystyka zużywania się powłoki narzędziowej opartej na węglu amorficznym podczas frezowania płyty wiórowej*. W pracy zweryfikowano trwałość oraz przebieg zużywania się podczas prób trwałościowych podwójnej powłoki narzędziowej TiAlN/a-C:N. Na wspomnianą powlokę składa się spodnia warstwa TiAlN oraz wierzchnia oparta na węglu amorficznym wzbogaconym azotem. Procesowi modyfikacji poddano standardowe wymienne noże do głowic frezarskich wykonane z węglika spiekanego WC-Co. Powłoka została naniesiona przy użyciu plazmy metodą RF Magnetron Sputtering. W trakcie badań wykonywano pomiary zużycia ostrzy przy pomocy mikroskopu warsztatowego. Jako kryterium stępienia przyjęto wskaźnik VB_{max} wynoszący 0.2 mm, mierzony na powierzchni przyłożenia. Rezultaty wskazują, iż dodatkowa powłoka z amorficznego węgla, przyczyniła się do podniesienia trwałości ostrza wyrażonego drogą skrawania. Zastosowanie jedynie pojedynczej warstwy opartej na TiAlN obniżyło trwałość narzędzia o ok 3 %. Natomiast zastosowanie zarówno spodniej jak i wierzchniej warstwy (TiAlN/a-C:N) wydłużyło drogę skrawania o ok 24%. Praca wykazała wyraźną przewagę ostrza modyfikowanego powłoką wielowarstwową pod kątem trwałości w stosunku do powłoki jednowarstwowej. Ponadto, został wykazany pozytywny wpływ wierzchniej warstwy zawierającej węgiel amorficznego na trwałość narzędzia.

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