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CrCN/CrN+ta-C multilayer coating for applications in wood processing

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ABSTRACT

The paper presents mechanical and tribological properties of CrCN/CrN and CrCN/CrN+ta-C multilayer coatings. Tetrahedral carbon (ta-C) layer formed using the pulse cathodic arc evaporation method are characterised by high hardness –45 GPa, very low friction coefficient—below 0.1 and a low wear rate -1.3×10^{-17} $m^3N^{-1}m^{-1}$ providing promising application perspectives.

Three sets of tools—planer knives for cutterheads were tested: uncoated (as reference), tools with a CrCN/CrN coating and tools with CrCN/CrN coating with additional friction-reducing tetrahedral carbon (ta-C) layer. The results of investigations indicate that the "tool life" depends on the type of coating and machining conditions. The blades covered with CrCN/CrN multilayer coating after machining of dry, seasoned pine timber showed a twofold increase of durability, and knives covered with CrCN/CrN+ta-C multilayer coating were characterised further by about 15% higher durability. Durability of knives tested in the course of rounding of wet pine timber, despite relatively high depth of machining was improved and for cutters with a CrCN/CrN coating increased more than twice, while the use of the additional ta-C layer on the multilayer coating improved durability by almost 5 times.

1. Introduction

Current market requirements in relation to tools include: possibility of increasing the speed of processing, processing of novel materials (including hard to machining materials) and work of tools in automatic processing centres associated with requirements to increase their durability and reliability. These requirements can be met by three groups of modifications. The first group comprises tools themselves, i.e. introduction of new materials for the construction or modification of properties of the existing materials (e.g. by thermo-chemical treatment [1,2]) as well as choice of appropriate geometry of working parts of the applied tools. The second group is associated with the application of suitable cooling and lubricating agents. Finally, the third group of modifications is connected with the choice of a proper substrate-coating system and possibilities of surface properties modification from the point of view of improvement of tool durability.

Improved durability of high-speed steel tools applied for wood processing can be increased by cover them with thin, hard wear-resistant coatings of nitrides and/or carbides of metals having high melting point (Ti, Cr, W, V, Mo, Ta, Zr, Nb, Hf) obtained using PVD and CVD methods. So modified tools have successfully been used for over twenty years in industrial processing of metals where their application led to a breakthrough in the increase of both production possibilities and product quality. However, a simple transfer of the above-mentioned experience into the field of processing of timber and wood-based materials is not always possible.

Coatings used on tools for the processing of timber and wood-based materials can be sorted into one of the following three groups based on: TiN [3,4], CrN [5–14] and DLC [11–13]. Additional elements, for example aluminium, improve significantly physical and mechanical properties of such coatings [3–16].

Faga and Settineri [13] investigated the effect of the application of mono- and multilayer CrN-containing coatings as well as DLC coatings deposited onto various steel substrates. Machine cutting tests of spruce wood were conducted on a bottom-spindle shaper with cutting speed of 1740 m/min and feed speed of 3000 mm/min. Presented results indicate that the coated tools were characterised by higher machining effectiveness when compared with the uncoated tools. CrN-containing multilayer coatings exhibited better anti-wear properties when compared with monolayer coatings but it was dependent on the type of coating material and the thermo-chemical treatment of the substrate. Analysis of surface morphology of knives showed that the cutting edge was damaged in uncoated tools, whereas tools with CrN and DLC coatings were characterised by a constant wear.

Similar results for CrN-containing mono- and multilayer coatings were presented in other studies [14–17]. In this case, the

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reference coating was titanium nitride (TiN). Tests were carried out during peeling (for the production of veneer and plywood) of birch, Douglas fir and beech wood. The above-mentioned researchers confirmed that also in this kind of processing as well as different processed materials, the smallest tool wear was observed in case of tools with the CrN coating. The reference TiN coating only reduced slightly the cutting tool wear.

Addition of carbon to CrN structure reduces coefficient of friction and wear rate. High temperature tests conducted by Polcar et al. [18,19] indicate that CrCN coating shows excellent properties, especially at higher temperature up to 400 °C. This indicates that these coatings may be a good candidate for applications in the woodworking tools. In such machining liquid coolants and lubricants are not applied. It causes an increase in the temperature in the friction contact. The papers of Polcar inspired to form a CrCN/CrN multilayer coating [5] the more that multilayer coatings have a higher wear resistance of single-layer coatings [20].

This article presents research results of semi-industrial tests of durability of tools with CrCN/CrN and CrCN/CrN + ta-C multilayer coatings used for wood processing.

2. Deposition and characterisation methods

2.1. Technology

CrCN/CrN and CrCN/CrN with 1 μm thick layer of tetrahedral carbon (ta-C) multilayer coatings were deposited onto experimental tools ($40\times30\times4$ mm^3 planer knives for cutterheads, made from HS18-0-1 steel). The chemical composition of HS18-0-1 (1.3355) steel is (wt%): C–0.8, W–18.0, Mn–0.4, V–1.1, Cr–4.2, Si–0.45 and Fe balanced.

Steel substrates were mirror polished and cleaned with alcaline in an ultrasonic bath, dried in warm air and then mounted on a rotating table (2 min^{-1}) at a distance 180 mm from the arc source.

CrCN/CrN coatings were deposited in the conventional multi-arc PVD system. Chromium targets (100 mm in diameter) with a purity of 99.8%, were used as cathodes for the deposition of the CrN and CrCN layers of multilayer coatings. To obtain CrCN layer acetylene was added at a flow rate of 10 sccm, controlled by an MKS 100 mass flow controller.

Prior to deposition, the chamber was pumped down to a pressure lower than 1×10^{-3} Pa. For further cleaning the substrates were sputter etched using chromium Cr^+ and argon Ar^+ ion bombardment with a bias voltage of −600 V for 20 min at the gas pressure of 0.5 Pa. Before deposition the proper coating a chromium adhesion sub-layer of about 0.1 μm was at first deposited onto the substrates. Arc current, nitrogen pressure, substrate bias and substrate temperature were 80 A, 1.8 Pa, −70 V and 300 °C, respectively.

A PVD device C55 (produced by INOVAP Dresden) with pulsed arc sources was used to tetrahedral carbon (ta-C) layer deposition. The solid graphite cathodes with 99.99% purity with 70 mm diameter were used as a carbon sources. Distance cathode-substrate was 150 mm and the substrate temperature was below 200 °C. The pulsed arc process works without any additional reactive gases at the pressure of about 5×10^{-3} Pa. DC-arc current of 50 A was used. The pulsed arc current reached 1600 A on pulse maximum with 300 μs duration at 100 Hz pulse frequency [21].

The structure of deposited coatings is presented in Table 1.The other details of coating deposition technology are presented in Ref. [6] and [21,22] respectively.

Table 1
The structure of deposited coatings.

	CrCN/CrN	CrCN/CrN + ta-C
Number of CrCN/CrN bilayers	6	6
Thickness ratio of CrCN and CrN l ayers in bilayer	1:1	1:1
Bilayer thickness [μm]	~0.4	~0.4
Cr sub-layer thickness [μm]	~0.1	~0.1
ta-C top layer thickness [μm]	–	~1
Total coating's thickness [μm]	~2.5	~3.5

2.2. Characterisation of the coatings

Sample surface morphology was observed in a JEOL (JSM 5500 LV, U — 15,000 V) Scanning Electron Microscope (SEM) and a NIKON Eclipse MK200 optic microscope. Thickness of coatings was determined using the Calo-test method.

Chemical composition was determined using EDS (Oxford Link ISIS 300) and WDS (Noran Instruments IBEX) methods.

Hardness of CrN coatings was evaluated with the assistance of a Fischerscope® HM2000 nanoindenter, a computer-controlled measuring system for micro hardness testing and determination of material parameters as hardness, elastic modulus etc. This system is equipped for hardness measurements using Berkovich indenter. The FISCHERSCOPE® HM2000 hardness tester with software WIN-HCU® allows determination of hardness in two modes: with a constant load or at constant depth of indentation. Here the measurements were realized with fixed at approximately 0.3 μm depth of the indentation. This value was close to 1/10th of the coat thickness and, in view of the absence of influence of the soft substrate, it allowed on a correct measurement of the hardness. Each value was average of at least of seven measurements.

The adhesion of the tested coatings to the substrate was assessed using the Rockwell method and the scratch method (CSEM Revetest® Scratch-Tester). The type C Rockwell indenter moved with the velocity of 10 mm/min and, simultaneously, the load was linearly increased at the rate of 200 N/min.

The critical load (a function of coating-substrate adhesion) was determined from the friction load–normal load plot. At a certain load the coating will start to fail and it was very precisely detected using an acoustic sensor attached to the load arm but can also be confirmed with observations from optical microscope. The critical load Lc1 is associated with the first cracks of the coating, whereas the critical load Lc2 is connected with the total delamination of the coating from the substrate. These loads were determined on the basis of at least 3 measurements. In the Rockwell test, the adhesion was determined examining the response of the coating to the indentation of the indenter loaded with the force of about 1500 N.

A stress occurring in the coating in relation to the silicon substrate ($30\times3\times0.5$ mm^3) was determined using the Stoney method equation. The silicon curvature before and after deposition was measured using Hommelwerke T8000 profilometer.

Friction of investigated coatings deposited on steel substrates was assessed using the ball-on-disc method. In Table 2 are collected the parameters of these tests. In case of fiction of wood pin-on disc method was used. The beechwood pin with 6 mm diameter was oriented in a cross direction as a counterpart, the sliding speed 1.2 m/s and the loads 30, 40, 50 N were used. The moisture of wood was not higher than 8%. The measurements were conducted in room air of a relative humidity of about 50% at 20 °C.

Surface roughness and wear profiles were measured with the assistance of a calibrated Hommelwerke T8000 stylus profilometer. The wear rate was determined as the volume of the material