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POSSIBILITY OF INCREASING THE LIFETIME OF THE CHOPPING KNIFE BY APPLICATION OF PVD COATING EVALUATED IN LABORATORY CONDITIONS

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Abstract

A wood is a heterogeneous material and its elements adversely affect the process of its processing. This also significantly affects the service life of tools during its processing. The aim of the contribution was, based on laboratory tests, to assess the suitability of the application of the selected coating on the chopping knife. After the basic analysis of the chopping knife, the CROSAL+ (AlCrN) coating was designed, which is an improved variant of the successfully used first generation CROSAL coating. In the experiment, samples from two knives made of tool steel X48CrMoV8-1-1 were analyzed. One sample was uncoated and the other coated. Based on the results of laboratory analyzes and tests, namely basic macroscopic and microscopic analysis of samples from tools, with semi-quantitative EDX analysis to determine the presence and content of individual chemical elements on the base material - substrate. Furthermore, the samples were tested for resistance to abrasive wear according to GOST 23.208-79. Relative resistance to abrasive wear ψabr was assessed. and hardness coefficient KT. HV and HRC hardness measurements were also carried out to determine the difference in hardness between uncoated and coated knife samples. In conclusion, it can be concluded that from the analysis and results of the measurements, the given coating for the process of processing wood by chopping can ensure the extension of the life of the tool and ensure the sufficient quality of the produced chips.

Keywords:

X48CrMoV8-1-1 steel, AlCrN coating, abrasive wear, hardness, chopping wood

1 INTRODUCTION

Currently, the emphasis is on renewable resources. Biomass is a huge source of renewable raw materials and energy that can be used for many purposes in special industrial, technical and energy sectors. Currently, it covers 14% of global energy consumption [Latushkina 2016]. Devices for processing biomass and wood chips are called chippers, in which chopping knives made of tool steel are stored. Their task is to chop the material to the required size and of sufficient quality. This is necessary in cases where wood chips are used as primary raw material, e.g. for the production of pellets. Chopping knives are affected by several factors in the chopping process that enter the chopping process and have a negative effect on tool wear. An effective method of reducing tool wear is its modification with a thin hard coating produced by the PVD - Physical Vapor Deposition or CVD - Chemical Vapor Deposition method [Kucharska, 2022, Warcholinski 2022, Schalk 2022, Majerik 2018]. The coating on the tool serves, among other things, to reduce the consumption of the cutting edges, which should increase their service life. For a long time, coated tools have been used with success for chip machining or metal forming. Several authors [Rudak 2015, Cho 2015, Kazlauskas 2022] confirmed the importance of using this surface treatment technology on tools. Coating tools also for wood chipping in secondary production (eg drills, knives for peeling and cutting veneers) is also becoming a common practice and brings many benefits. The advantages of this modification for increasing the life of the tool, as well as the quality of the final product, have been published in many works [Warcholinski 2022, Nadolny 2020, Kalincová 2018, Sadilek 2013]. However, for primary woodworking tools (e.g. splitting knives and planing) the surface treatment method is not as common and therefore not well described in the literature. Compared to metals, wood does not have homogeneous structural properties. Its structure is the elements that during its processing affect the rapid wear of the cutting parts of the tool [Čunderlík 2009, Heidari 2013, Cep 2011].

2 MATERIALS AND METHODS

A knife made of tool steel X48CrMoV8-1-1 (Wr. Nr. 1.2360) from the manufacturer PILANA Group a.s., Hulín, Czech Republic (Fig. 1) was used for the experiment. It is a tool alloy steel for cold and hot work. It is intended for e.g. for dies for forging presses, die inserts, punching tools, tools with good compressive strength and especially with high abrasion resistance.

Fig. 1: Chopping knife

The chemical composition of steel according to the material sheet [Lexicon of Metals 2019] is shown in Table 1.

Table 1. Chemical composition of tool steel X48CrMoV8-1-1 (Lexicon of Metals 2019)

Element	C	Si	Mn	P	S	Mo	Cr	V	Fe
Wh %	0.45–0.5	0.7–0.9	0.35–.45	0.02	0.005	1.3–1,5	7.3–7.8	1.3–1.5	Balance

The dimensions of the knife are 248 mm×115 mm×13 mm, edge 25°/35°, 3×14 mm groove. From the point of view of the mechanical properties of steel, in the hardened and tempered state, the limit of the strength of steel is Rm = 1,270–2,100 MPa. The achievable hardness in the quenched and tempered state is in the range of 40.3–56.8 HRC from a value of 60 HRC after quenching. Annealing temperature is 550-700°C.

The second chopping knife (Fig. 2) was coated with CROSAL+ coating at Voestalpine High Performance Metals Division, s.r.o., Martin, Slovakia. It is a new generation coating based on AlCrN (Aluminum Chromium Nitridate). It is an advanced development of the older, but practically proven, proven CROSAL coating. It is characterized by high resistance to oxidation, abrasive and adhesive wear, excellent adhesion with a low coefficient of friction. The coating is suitable for materials with a tendency to stick. Its basic applications are e.g. for metalworking and forming tools, used for high-performance cutting. The AlCrN-based coating presented by [Souza 2020] has a lower coefficient of friction and a lower wear rate than the TiAlN (Titanium Aluminum Nitridate) coating.

Fig. 2: Chopping knife coated with CROSAL + coating

The basic mechanical properties and technological parameters of the coating The basic properties and technological parameters of the coating are: hardness 61HRC, coefficient of friction μ=0.45(-), coating thickness t=2-5μm, max. working temperature T=1,100°C, coating temperature T_c=400°C, colour slate grey.

An exact data and information about the coating process as well as specific values of individual parameters used in coating the chopping knife are the know-how of company Voestalpine High Performance Metals Division, s.r.o., Martin, Slovakia.

In order to assess the suitability of the application of the PVD coating on the chopping knife, in order to increase its service life, the quality of both knives was sampled. Tests and analyses were performed on them, namely:

- hardness measurement HV0.5 (uncoated knife only) and HRC,
- macroscopic analysis of tools and light and scanning electron microscopy to determine the state of the microstructure (uncoated knife only),
- tests of resistance to abrasive wear.

Vickers hardness HV 0.5 was performed according to ISO 6507-1:2018 by Vickers hardness tester 432SVD, load duration t=15s, load force F=98.07N.

Rockwell hardness was performed in accordance with ISO 6508-1:2016. A Rockwell hardness tester, type UH250 with a load force F of 1,471 N was used to determine the hardness.

Microscopic analysis was performed using an Olympus CX71 inverted metallographic microscope with an Olympus DP12 camera. A Jeol JSM 7000F scanning electron microscope with an Oxford Instruments EDX analysis unit was used for local chemical elemental analyses. Standardless ZAF analysis was used for the analysis of EDX spectra, the results of which were semi-quantitative with an accuracy of 2% of the calculated element concentration.

The test of resistance to abrasive wear was performed according to the Russian standard GOST 23.208-79. The method consists in comparing the weight loss of the tested material with the weight loss of the standard material under the same test conditions. The test was carried out on a Tester T-07, ITC PIB, with a BT-16 controller. Each sample was prepared using abrasive water jet cutting technology, milled and ground on a magnetic plane grinder to dimensions of 30 mm × 30 mm × 10 mm with a surface roughness Ra of 0.4 μm. OTTAWA silica sand with a grain size of 0.1 mm with 54 HRC was used as an abrasive. The weight of the samples was measured on a Kern ABS analytical balance. Experiments on the samples were carried out in the laboratories of the Faculty of Technology of the TU in Zvolen, the Institute of Materials Research of the Academy of Sciences in Košice and the laboratories of the Technical Faculty of CZU in Prague.

3 RESULTS AND DISCUSSION

3.1 Hardness measurement by the HV and HRC method

Vickers hardness was measured from the surface to a distance of 9.3 mm on a sample of the base material, taken from an uncoated knife (Fig. 3). The average value from the measured values is 631 HV0.5.

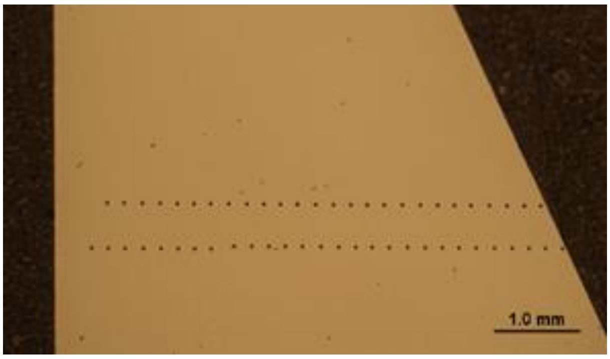

Fig. 3: Measurement of hardness HV0.5

To determine the difference in HRC hardness of the uncoated and coated knife, the samples were measured five times and the average value was calculated from them.

3.2 Macroscopic analysis of tools and light and scanning electron microscopy

In order to determine the state of the microstructure, samples were taken from the clamping part of the uncoated knife for analysis of the knife surface and determining the direction of the fibres by deep etching in 15% HCl at a temperature of 60°C for 30 minutes. The direction of the fibres was parallel to the cutting edge of the chopping knife. The surface of the knife was ground. Grinding marks are captured in pictures 4a. – macroscopy and 4b. grinding marks, captured on a scanning electron microscope (SEM).

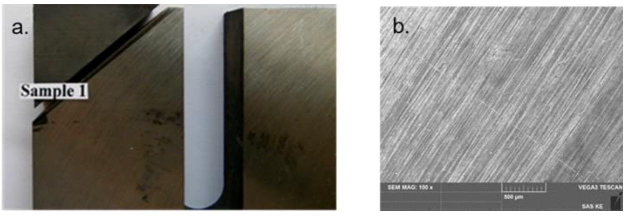

Fig. 4: Macroscopy of the ground surface of the knife sample (a.); tool surface grinding marks (SEM) (b.)

Detection of the condition of the macro and microstructure of the chopping knife was carried out using light microscopy (LM). Inclusions were isolated in the microstructure of the chopping knife material (Fig. 5a). The microstructure of the material was sorbitic with fine, mostly globulitic carbides excluded in sorbitic blocks and along the boundaries of these blocks (Fig. 5b).

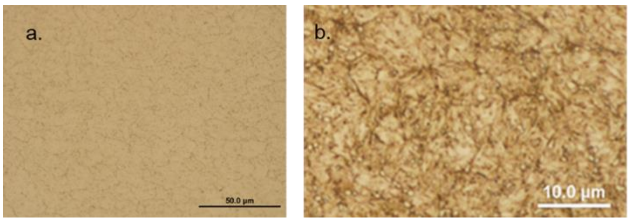

Fig. 5: Structure of chopping knife without etching (LM) (a.); microstructure of the chopping knife after etching (LM) (b.)

In Fig. 6, the sample is observed with a scanning electron microscope. It confirms the microstructure detected by LM. Along the boundaries of the sorbitic blocks and in the sorbitic blocks, mainly fine globulitic carbides based on iron and chromium were excluded (Fig. 7). The chromium content was detected by chemical spectral analysis at a value of 8.16% by weight. This also confirms the value given in the material sheet of steel X48CrMoV8-1-1 (Tab.1).

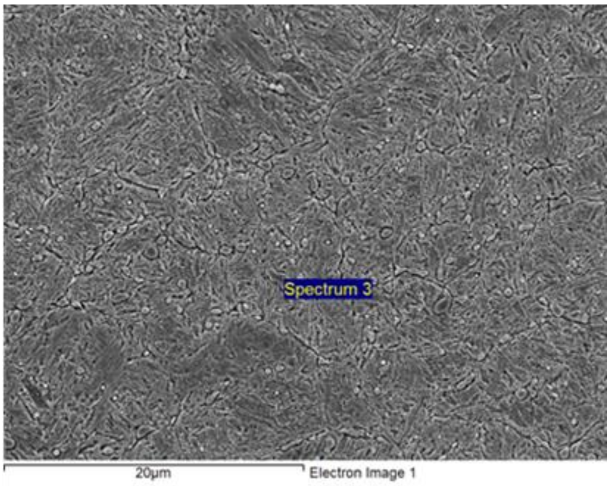

Fig. 6: Microstructure of the knife sample (SEM)

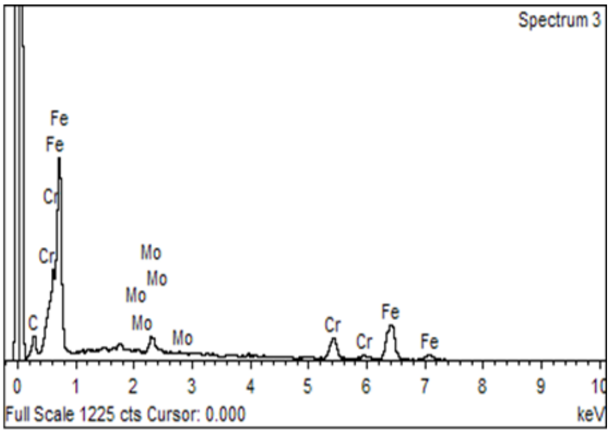

Fig. 7: Semiquantitative EDX microanalysis

3.3 Abrasive wear resistance test

The relative resistance to abrasive wear $\Psi_{abr.}$ was calculated according to the formula (1):

$$\Psi_{abr.} = \frac{W_{hR}}{W_{hC}} [-] \tag{1}$$

$$\Psi_{abr.} = \frac{0.0030}{0.0028} = 1.07$$

W_{hR} - weight loss of uncoated sample (g),

W_{hC} - weight loss of the coated sample (g).

The K_T hardness coefficient was calculated to determine how much the material resists abrasion conditions in terms of hardness. The K_T hardness coefficient of the uncoated HR sample was calculated according to formula (2):

$$K_T = \frac{H_R}{H_a} [-] \tag{2}$$

$$K_T = \frac{57}{54} = 1.06$$

The hardness coefficient K_T of the coated H_C sample was calculated from formula (3):

$$K_T = \frac{H_c}{H_a}[-] \quad (3)$$

$$K_T = \frac{61}{54} = 1.13$$

H_R – hardness of uncoated sample (HRC),

H_a – abrasive hardness (HRC),

H_c – hardness of the coated sample (HRC).

Table 2 shows the summary results of the measurements. There is also a comparison with the values documented by the knife manufacturer after hardening and tempering with the data given after coating the surfaces with CROSAL+ coating. In the case of a un coated knife, the manufacturer indicates a greater difference in hardness, which is determined by the choice of tempering temperature. In the hardened state, the value is 60HRC. This is the basic value for obtaining the required hardness after subsequent tempering. Next, the table shows the results of the test of resistance to abrasive wear.

Tab. 2: Results of HRC hardness measurement and abrasive wear resistance test

Knife sample	HRC	Average weight loss w_h [g]	Relative resistance to abrasive wear $\Psi_{abr.}$ [-]	Coefficient of hardness K_T [-]
Uncoated	57	0.0030	1.0	1.06
Coated	61	0.0028	1.07	1.13

As stated by the authors of scientific papers focused on the coating of tools used for wood processing [Faga 2006, Ratajski 2009, Šramhauser 2022] currently, TiN coatings are the most recommended, TiAlN and CrN - CrCN applied by the PVD method. The use of coating on woodworking tools has been researched for a long time [Kucharska 2022]. It is generally known that wood does not have homogeneous structural properties compared to metals. Its structure contains elements that accelerate the wear of the cutting wedge during its processing. One of the factors is the organic acids contained in the wood fibers, as well as the changing humidity and density of the wood [Čunderlík 2009, Csanády 2013, Krilek 2023]. This also results in the choice of the type of coating and its chemical composition. The thickness of the coating, its hardness and cohesive properties are decisive factors for obtaining the resistance of the coated surface of the tool against wear and the obtained quality of the machined surface [Schindlerová 2017, Czarniak 2020, Faga 2006, Ratajski 2009].

The values of 57HRC and 631HV0.5 are correlated according to the conversion tables of hardness measurements. As the authors [Kalincová 2018, Ratajski 2009] state, hardness is not always an absolute indicator of the abrasive resistance of materials. The structure of the material is also important [Wu 2023] as well as suitable surface treatment methods [Souza, 2020, Warcholinski 2022]. Due to the tempering temperature of the material (550-700°C), this coating is suitable for application to the material, as the coating temperature is only 400°C. Microscopic analysis of a sample of an uncoated knife confirmed the sorbitic structure, typical for tool steels used for tools working in abrasive and adhesive environments.

Based on the mentioned results of the experiment, we can conclude that the sample with the applied CROSAL + coating based on AlCrN achieved better results on the knife samples tested in laboratory conditions. This created a certain assumption that a knife modified in this way will better withstand the conditions of abrasion in operation, that is, when chopping wood. The sample with CROSAL+ coating achieved a relative resistance to abrasive wear $\Psi_{abr.}$ better by 7% and the K_T hardness coefficient better by 13%.

4 CONCLUSIONS

Wood mass is a heterogeneous material and its components adversely affect the process of its processing. This fact significantly affects the service life of tools during its processing. The production of high-quality wood chips requires the correct selection of the cutting tool, its adjustment and careful maintenance. The use of a quality knife leads to an increase in productivity and a decrease in specific fuel consumption. Quality is very important in cases where wood chips are used as primary raw material and the production of small chips is to be ensured and the production of very fine chip fractions is to be eliminated. For this reason, it is necessary to conduct experiments with new methods of surface treatment of cutting materials. It can also be a knife coated with CROSAL plus coating based on AlCrN (Aluminum Chromium Nitridate), which was compared with an uncoated knife in this work. Based on the achieved results of the laboratory tests, it can be concluded that the sample with the CROSAL plus coating achieved:

- relative resistance to abrasive wear $\Psi_{abr.}$=1.07, i.e. better than the coated sample ($\Psi_{abr.}$=1.0),
- the hardness coefficient K_T=1.13, i.e. higher than on the uncoated sample, with the considered abrasive hardness H_a=54HRC.

The HRC hardness, the microstructure of the steel as well as the chemical composition, determined by EDX analysis, were compared with the data declared by both the manufacturer and the processor of the knife, which ensured the coating of the knife. We can therefore conclude that a coated knife is more suitable for the process of processing wood by chopping.

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