INFLUENCE OF HIGH ENERGY TREATMENT ON WEAR OF EDGES KNIVES OF WOOD-CUTTING TOOL

VADZIM CHAYEUSKI[1], VALERY ZHYLINSKI[2], ALEXANDER GRISHKEVICH[3], PAVEL RUDAK[4], STEFAN BARCIK[5]

[1]Belarusian State Technological University
Department of Physics, Information Technology Faculty,
Minsk, Republic of Belarus
[2]Belarusian State Technological University
Faculty of Chemical Engineering and Technology
Department of Chemistry, Electrochemical Production
Technology and Materials for Electronic Equipment
Minsk, Republic of Belarus
[3]Belarusian State Technological University
Faculty of Forestry Engineering and Wood Technology
Department of Woodworking Machines and Tools
Minsk, Republic of Belarus
[4]Belarusian State Technological University
Faculty of Forestry Engineering and Wood Technology
Department of Material Science and Metal Technology
Minsk, Republic of Belarus
[5]Technical University in Zvolen
Faculty of Environmental and Manufacturing Technology
Department of Machinery Control and Automation
Zvolen, Slovak Republic
DOI : 10.17973/MMSJ.2016_12_201683
e-mail: chayeuski@belstu.by

PVD, combined electroplating and PVD methods were applied to increase wear resistance of the hard alloy cutting elements for woodworking. Laminated chipboards milled by a tool with knives were coated with ZrN, Mo-N, and ZrN-Ni-Co layers. Abrasive wear of tools blades occurred. The wear intensity of the knife blades with deposited coatings was reduced. The value of volume wear of knife blades with coatings was calculated. If compared with bare tool, wear resistance of ZrN-coated blade increased to 50%, while wear resistance of Mo-N-coated blade increased to 70%.

KEYWORDS
coating, milling tool, knives, blade, wear

1 INTRODUCTION

Nowadays high demand for quality of wood products makes it necessary for researchers to create new ideas and approaches to production of cutting tool elements. One of the most common types of tool materials for woodworking CNC machines are hard alloys based on tungsten carbide (WC) and cobalt. The cutting elements from hard alloys are widely used by such well-known companies as Leitz, TIGRA, Faba, LEUCO, and KANEFUSA [Leksikon 2011]. Different types of chemical wear (corrosion and oxidation) of these tools are proved to play a significant role in destruction of cutting edge during processing of plate wooden materials. Crystalline inclusions of adhesive (urea-formaldehyde resin and fillers) in the plate wooden materials demonstrate high abrasive properties due to the initiation of chemical interaction. This leads to pulling out of grain from the surface of tungsten carbide cutting element [Aronson 2002]. Wood-cutting tool with application of synthetic diamond is offered as technological novelty by foreign companies [Philbin 2005].

Physical vapor deposition (PVD) is proved to be one of the most effective ways of protecting knife blade surface made of steel and hard alloys. Hard layers of nitrides from plasma phase in a vacuum with ion bombardment of the surface cutting edges are deposited on the surface of cutting elements. As a result, cutters working resource increases essentially [Kuleshov 2011]. In addition, to improve wear resistance of woodworking tools electroplating is widely used in engineering [Popova 2001].

The first aim of this work is synthesis and investigation (phase composition, hardness, and etc.) of nitride ZrN- or Mo-N-layers and combined ZrN-Ni-Co-coatings on the surface of knife blades. The second aim of the study is to investigate the amount of wear of the modified cutting edges in the process of cutting of laminated chipboard.

2 MATERIALS AND METHODS

ZrN- or Mo-N-coatings were formed by the PVD method [Kuleshov 2011]. The WC hard alloy was used as substrate material. Prior to the deposition, the surface of the substrate was cleaned and heated by ion bombardment during 1 min with the substrate bias being −1 kV, the arc current of 100 A for zirconium and 180 A for molybdenum, the vacuum in the chamber 10^{-3} Pa. This stage resulted in heating the substrate to 450–500°C prior to deposition. All film depositions were initiated by introducing N_2 gas at a pressure of 10^{-1} Pa into the vacuum chamber and the bias was fixed at −120 V. Thickness of the coatings was 1.5 µm and lower [Kuleshov 2011].

Before the deposition of Ni-Co-coatings the surface preparation of sample was carried by chemical degreasing at a temperature of 60–80°C for 6–8 minutes, rinsing in hot (40–60°C) and cold (18–25°C) water, etching in solution H_2SO_4 (50–100 g/dm^3) with inhibitor at temperature of 18–25°C, cold rinsing, activation, washing.

Ni-Co alloy coatings were electroplated on the prepared surface of knives edges at direct current of 0.4–0.8 A using sulfate electrolyte (g/dm^3): $NiSO_4 \cdot 7H_2O$ – 200; NaCl – 20; $CoSO_4$ – 80; H_3BO_3 – 40, at a temperature of 40–50°C. The acidity (pH) of the electrolyte was measured by pH-meter 150-pH with accuracy of ±0.05%. The acidity level within desired value from 4.9 to 5.0 pH was adjusted by concentrated solution of H_2SO_4. The coating thickness should be not exceed 10 µm.

The microstructure of coatings and knife edges was studied on cross sectional samples using methods of electron probe microanalysis (EPMA) and scanning electronic microscopy (SEM) by JSM-5610LV electronic microscope (Japan).

The phase composition of coatings and knife edges was investigated by X-ray diffraction (XRD) using Cu-K_α characteristic of X-ray radiation. The XRD measurements were performed using the Ultima IV diffraction meter (Japan).

The microhardness of surface layers was measured by the Vickers technique using a diamond pyramid under load of 25–100 N. The microhardness instrument was AFFRI-DM8 (Italy) with an accuracy of ±15 HV.

For laboratory tests we used a mill with a diameter of 21 mm with mechanical fastening of the cutting element. Laminated particle board with a thickness of 25 mm was milled. We used the CNC processing center ROVER B 4.35 (Italy) at the following modes: the frequency of rotation of milling cutters – 12,000 min^{-1}; feed speed – 4 m / min; allowance – 5.0 mm / pass; chip thickness at the contact arc – 0.15 mm. Appearance of defects on the treated surface was the criteria of losing the cutting ability of the cutting element. The main type of defect was laminate chipped from the plate surface.

The volume wear of cutting edge was calculated by the method of transverse dimensions after laboratory testing. Field of wear was studied under the microscope. The worn surface was practically shown to be slightly convex and close to the plane (AFDE rectangle) (Fig. 1). Thus the volume of wear of the cutting edge corresponds to the volume of a triangular prism with the base in a triangle ABE and rectangular faces AFDE. The angle ABE (angle β) appeared to be a corner of sharpening of the blade. Also portions wear volume were summed together.

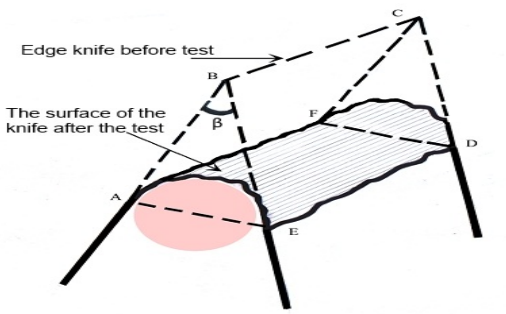


Figure 1. The scheme for calculating the cutting edge wear volume

3 RESULTS AND DISCUSSION

The scheme of interaction of the cutting element with processed wooden material is given in Fig. 2.

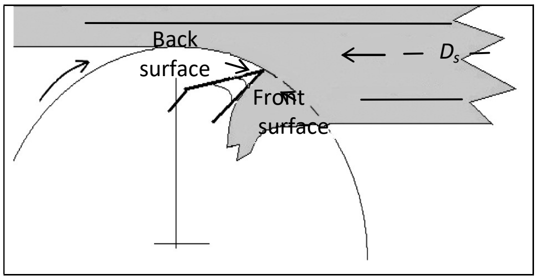


Figure2. Scheme of interaction of cutting element with processed material

When cut, plate material, unlike natural wood, is characterized with absence of solid chip on the front surface of the blade [Rudak 2013, Rapovets 2008]. This feature influences peculiarities of the cutter element wear, i.e. more intense wear occurs at the back surface of the blade than at the front one [Rudak 2015].

The PVD ZrN-coatings on hard alloy knives (Fig. 3a) was proved to have the body-centered cubic (BCC) structure. The BCC structure of ZrN with (111) texture was determined by the grain growth in the direction of plasma flows [Grishkevich 2008]. The PVD Mo-N-coatings contain the metal phase of α-Mo and δ-Mo_2N (Fig. 3b).

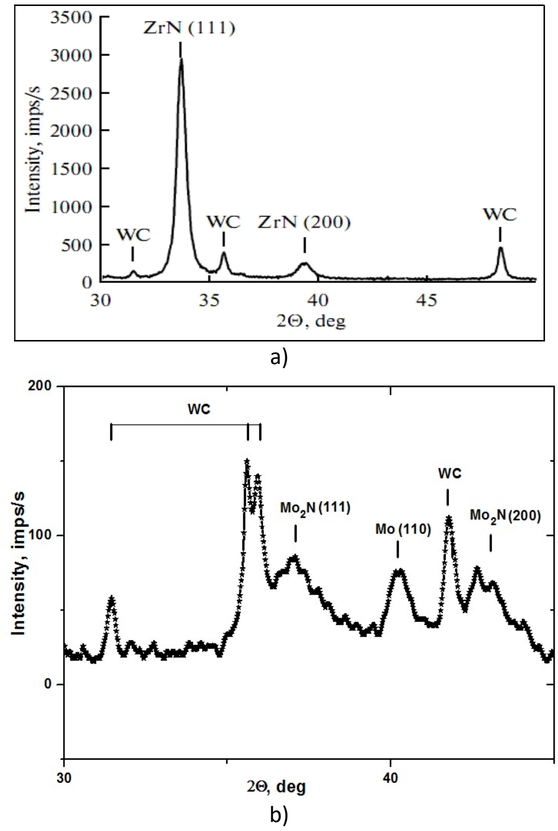


Figure 3. XRD diagrams of the ZrN (a) and Mo-N (b) coatings

The combined ZrN-Ni-Co-coatings consist of separate phases of ZrN, α-Co, and α-Ni (Fig. 4).

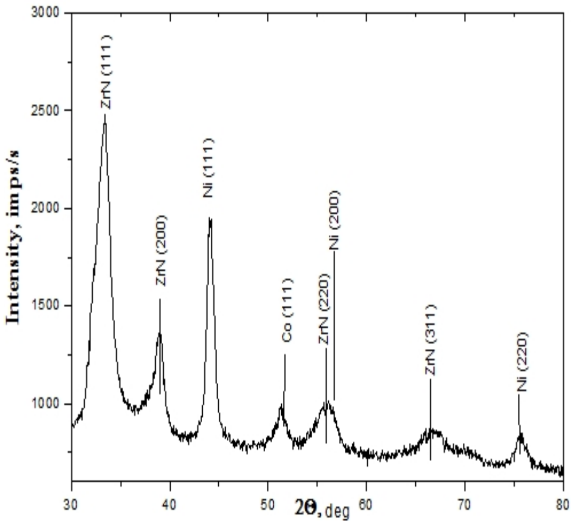


Figure 4. X-rays diagram of ZrN-Ni-Co-coating

The physical and mechanical properties of hard alloy are known to be strongly dependent on its phase composition [Kurlov 2011]. The binder (cobalt) amount directly affects the ability of the tool to take a static force and a pulsed load. Higher maintenance of cobalt corresponds to higher stress limit of the tool. Reduction of grain size leads to decrease of tool wear resistance at the same concentration of binded substance. However, the preparation of tool with low sharpening angle becomes difficult when grain size rises. Thus, high-quality preparation of hard alloy is extremely important for production of cutting elements of high quality [Luycks 2007].

Composition of knives appeared to be WC ~ 96%, Co ~ 4% (Table 1).

Table 1. Composition of hard alloy knives

Element[1]	Concentration[2] [*at.%*]	Error of measurement[3] [*at.%*]
C	32,89	±0,22
W	62,86	±0,33
Co	4,25	±0,34

[1] Element, [2] Concentration, [3] Error of measurement

The composition of knives corresponds to hard alloy (T03SMG) with fine grain [TIGRA 2014]. This hard alloy is widely used for manufacture of milling tools for processing of wood material and natural wood.

Fine-grain structure of knife material was practically proved in the process of our studying cutting edge morphology (Fig. 5). The SEM-image helped to find out the size of grain in knife material being less than 0.7 µm.

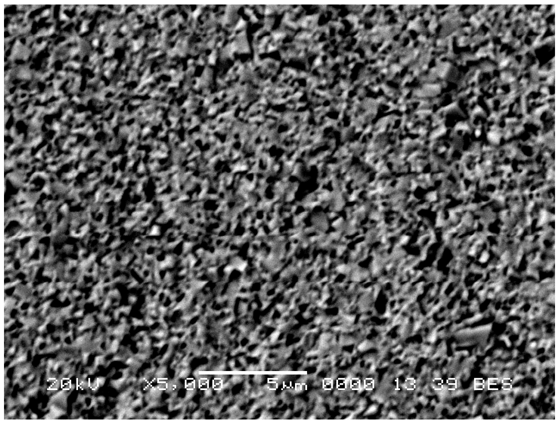
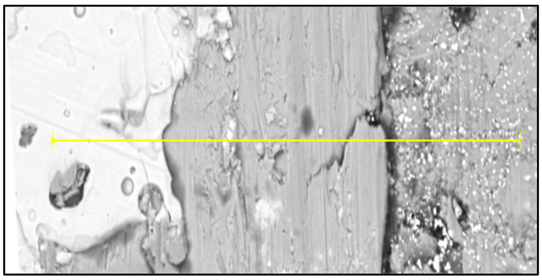
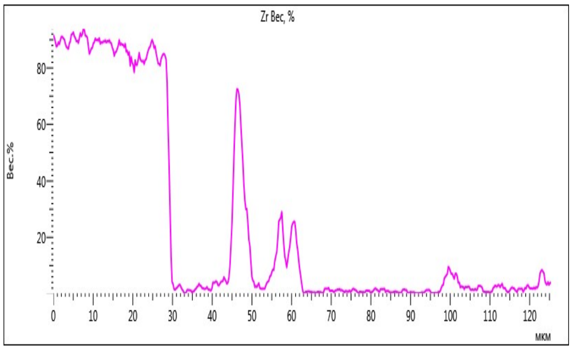


Figure 5. SEM-image of cutting edge surface

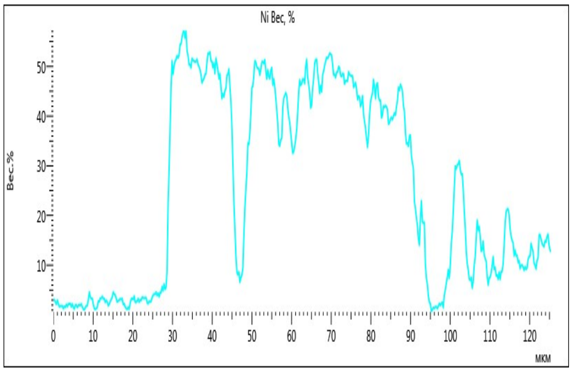
The electroplated Ni-Co-layers appeared to be separated from hard allow base and ZrN-coating (Fig. 6).



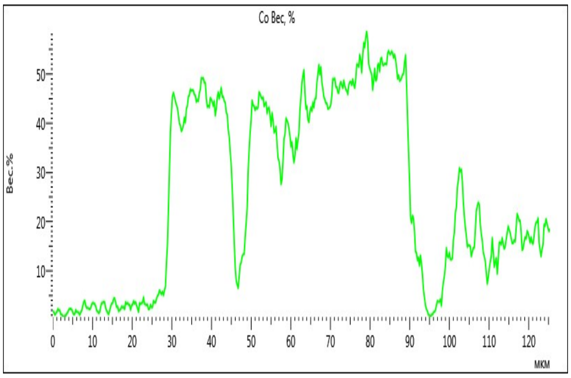
a)



b)



c)



d)

Figure 6. The SEM-image of fracture of cutting edge with the ZrN-Ni-Co-coating (a) and the distribution of Zr (b), Ni (c), Co (d) along the line (a)

It has been established that elementary composition of specimens of worn ZrN regions have the regions containing crumpled and separate remnants of coatings (Fig. 7).

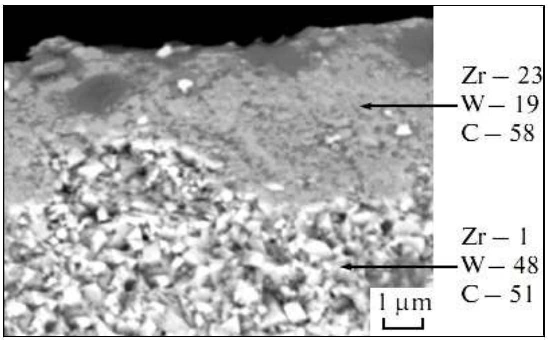


Figure 7. The SEM-image of knife fracture and the ZrN-coating application with elementary composition in different regions marked with arrows, when cutting laminated chipboard

The ZrN-coating microhardness was 32 GPa, while the Mo-N-coating was 25 GPa. The average value of microhardness was 9.6 GPa for the Ni-Co-coating and 13.0 GPa for the ZrN-Ni-Co-coating. It was higher in 1.3 times than the microhardness of the Ni-Co-coating.

The investigation of element composition of knife fracture showed abrasion (mechanical dispersion) of the Mo-N-coating on the cutting edge and substantial oxidation to occurre during cutting of chipboard. The mechanical dispersion was confirmed by the SEM-image of worn knife fracture (E area in Fig. 8).

The SEM-image of the worn knife edge with the Mo-N-coating (Fig. 8) proved the main wearing mechanism of uncoated hard-alloy knife at cutting of laminated chipboard to chip carbide grains (D area in Fig. 8). These results are confirmed by the known mechanism of abrasive wear of the hard-alloy knife free of cover [Grishkevich 2012].

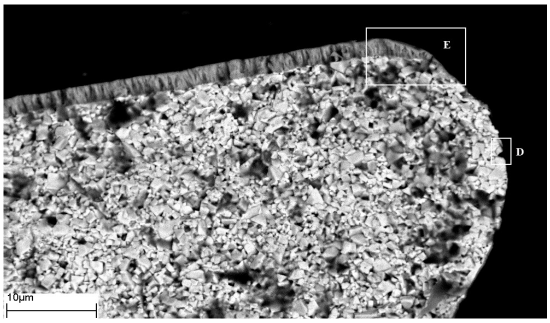


Figure 8. The SEM-image of fracture of worn knife edge with the Mo-N-coating

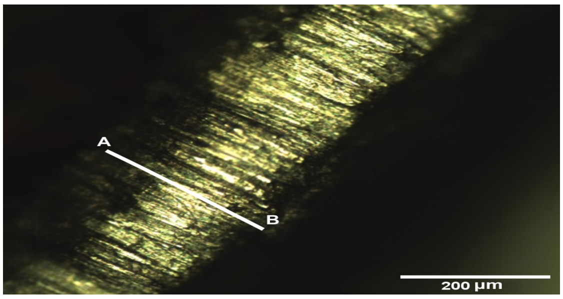
The XRD data shows the presence of significant proportion of the metallic molybdenum phase on the Mo-N-surface. It may help to reduce the coefficient of friction during the cutting process. Table 2 contains calculation of the averaged volume wears of knife edges after laboratory tests.

Table 2. Volume wear of hard alloy knives modified by coatings after laboratory tests of cutting laminated boards

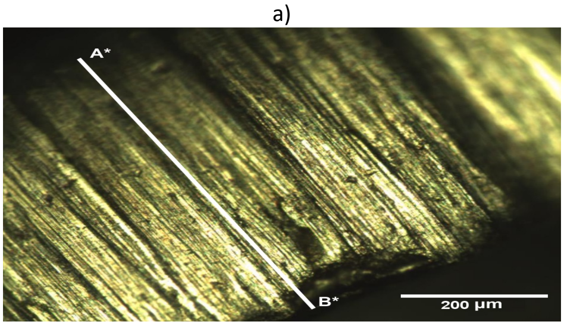
Machining type 1)	Volume wear 2), 10^6, [μm^3]
Bare edge knife	2.3 ± 0.4
Mo–N-coating	0.9 ± 0.2
ZrN-coating	1.1 ± 0.2
Ni-Co-coating	2.3 ± 0.4
ZrN-Ni-Co-coating	1.6 ± 0.3

1) Machining type, 2) Volume wear

Moreover, the images of the worn knife edge with the ZrN-Ni-Co- and Ni-Co-coatings (Fig. 9) confirmed the previous calculations of volume wear.



a)



b)

Figure 9. Images of the worn knife edge with the ZrN-Ni-Co-coating (a) and the Ni-Co-coating (b) after milling of laminated chipboard

The images show wear degree of blades with the ZrN-Ni-Co-coating (Fig. 9a) to be considerably less than the wear degree of blades with the Ni-Co-coating (Fig. 9b). A value of the cross section of the worn knife edge with the Ni-Co-coating (line A*B*, Fig. 9b) is considerably more than the worn knife edge with the Zr-Ni-Co-coating (line AB, Fig. 9a).

The abrasive wear of galvanic Ni-Co-coating as well as combined ZrN-Ni-Co-coatings was observed on blades in the process of cutting laminated chipboard. However, the wear degree of knife blade with the ZrN-Ni-Co-coating is significantly less than the wear of same blade with Ni-Co-coating [Kuleshov 2014, Kubrak 2014].

Though formed hard coatings possess high hardness and strength, brittle wear of resistant modified knives blade occurs during the cutting process. This change can take place when sharp increase in temperature at the junction "knife blade - chipboard" is followed by adhesion deterioration of the coating to the substrate and partial cover destroy. However, the presence of zirconium nitride (possessing high thermal and oxidative stability) in combination with ZrN-Ni-Co-coating can significantly reduce the impact of these processes on the wear of the knife blade.

The pilot tests of the modified cutter for laminated chipboard were carried out by the following enterprises of the Belarusian Holding "Bellesbumprom": JSC "Minskdrev" (Minsk), JSC "Pinskdrev" (Pinsk), JSC "Borisov DOK" (Borisov). The previous calculation of volume wear of knifes blades was practically proved by these tests. Moreover, the pilot tests showed that the durability period increases for the ZrN-coated (50%) and the MoN-coated (70%) milling tools if compared to bare hard-alloy tools. When cutting pine wood at the JSC "Minskdrev", the modified ZrN-Ni-Co-coated cutters demonstrated increase of the durability period (30%) if compared with bare hard-alloy tools.

4 CONCLUSIONS

Treatment of hard alloy knives with the PVD, combined electroplating and PVD methods was proved to provide increase of durability period of cutting tools for laminated chipboard milling. The durability period increases for the ZrN-Ni-Co-coated, ZrN-coated, and Mo-N-coated milling tools if compared to bare hard-alloy tools. When cutting laminated chipboard, abrasive wear of the ZrN-, Mo-N-, Ni-Co-, and ZrN-Ni-Co-coated knife blades is the main type of wear. The presence of zirconium nitride with high thermal and oxidative stability reduces the impact of wear of knife blade.

The research relevance, the need to increase the durability period and the service life of woodcutting tools were proved and confirmed by industrial tests of modified tools with hardened layers formed on the knife blades.

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CONTACTS

Vadzim Vitalievich Chayeuski, PhD. Assistant Professor
The Belarusian State Technological University
Information Technology Faculty
Department of Physics
13a Sverdlov srt., 220006, Minsk, Republic of Belarus
tel.: (+375 17) 399 49 60
e-mail: chayeuski@belstu.by