

PROTECTIVE WOODCUTTING TOOL COATINGS

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Abstract

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The modern woodworking industry applies resource-saving, environmentally appropriate technologies, providing both the metal removal performance enhancement and functioning with the optimal economic factors. Progressive cutting parameters require the application of the high-reliability cutting tools, eliminating machine-tool equipment standstill and increased cost of the expensive tool materials. In this paper it is suggested to increase the wood-cutting tool efficiency by means of the vacuum-arc separated coating deposition process optimization.

The droplets are one of the main problems while generating vacuum-arc coatings, and they have a bad influence on the quality and operational coatings characteristics. The application of the separated system, allowing minimize the droplets content, is one of the most promising ways to solve this problem. Vacuum-arc deposition technique was used in this work to generate multicomponent coatings. The coatings deposition was directly carried out on the modernized vacuum-arc plant, equipped by Y-shaped macroparticles separator.

Keywords: tool coating, morphology, woodcutting, physical and mechanical properties, cutting plates

INTRODUCTION

The modern woodworking industry applies more and more resource-saving, environmentally appropriate technologies, providing both the metal removal performance enhancement and functioning with the optimal economic indicators (Kováč, Krilek, 2011). At the same time progressive cutting parameters require the application of the high-reliability cutting tool, eliminating machine-tool equipment standstill and increased cost of the expensive tool materials (Hanes *et al.*, 2014). By the way the wood-working tool cutters operate in the specific conditions different from the metal-

working tools, and it's primarily attributed to the fundamental differences in the cutting thermal physics of the nonmetallic material due to their physical-mechanical properties (low thermal conductivity, humidity, high hygroscopicity and etc), technological machining conditions (high frequency, dynamic cutters loading condition, lubrication-cooling fluids elimination) (Čierna, Ťavodová, 2013). As a result, heavy temperature gradients appear in the surface layer of the tool material and they generate both cyclic thermal stresses in the cutter and the backgrounds for fatigue wear mechanism development of the tool material (Grigoriev, 2009).

Hence, the protective layers, generated on the wood-cutting tool surface must function the following:

- 1) very hard surface layer, lowering the abrasive wear of working surfaces during cutting;
- 2) barrier layer, blocking the physical-mechanical material properties changing as a result of increased thermal power loads;
- 3) barrier layer, retarding the fatigue crack network propagation leading to microchipping.

The (Ti,Al)N compound is able to satisfy all the requirements under the certain ration between aluminum and titanium atoms in the crystal lattice possessing unique properties combination: high hardness, wear-resistance, thermal stability, and simultaneously, high coefficient of restitution and low friction factor (Vereshchaka, 2007).

In this paper it is suggested to increase the wood-cutting tool efficiency by means of the vacuum-arc separated (Ti,Al)N coating deposition process optimization.

MATERIALS AND METHODS

It is known, the droplets are one of the main problems while generating vacuum-arc coatings, and they have a bad influence on the quality and operational coatings characteristics. The application of the separated system, allowing minimize the droplets content, is one of the most promising ways to solve this problem. Vacuum-arc deposition technique was used in this work to generate multicomponent coatings. The coatings deposition was directly carried out on the modernized vacuum-

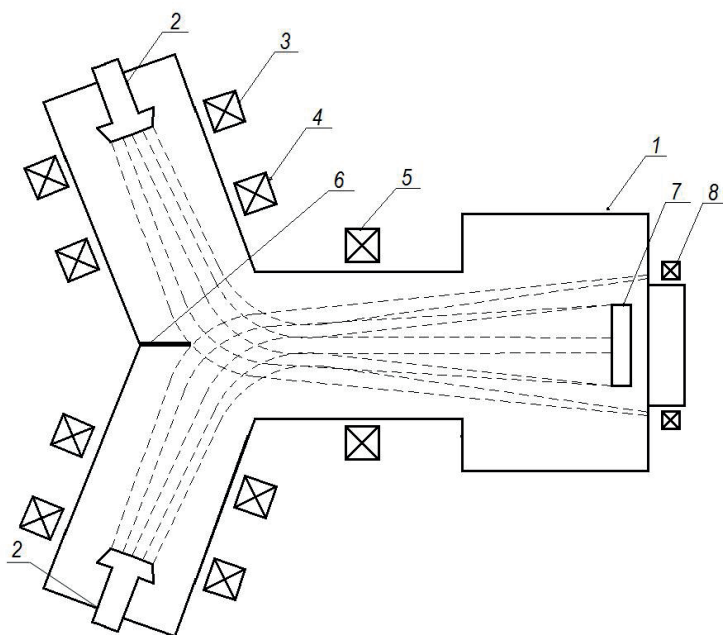
arc plant, equipped by Y-shaped macroparticles separator (Fig. 1).

The high-purity titanium and aluminum cathodes were used to generate the coatings on the silicon and cemented carbide substrates under different deposition conditions: partial pressure $0,2 \cdot 10^{-2}$ Pa, titanium arc current – 40–60 A, aluminum arc current – 40–70 A, substrate bias – 20–70 V. The disposable carbides for wood-working tools were used to determine both mechanical characteristics and life testing, while silicon substrates – for structure investigation and elemental and phase coatings compound. The morphology and structure of the deposited coatings were studied by means of transparent electron microscope S-4800 Hitachi. X-ray diffraction and X-ray phase analysis were carried out in the measuring range between 30° and 120° using CuK_α characteristic X-Ray radiation. By using the main characteristics of the diffraction maximum allowed estimating the lattice parameter (d), coherent-scattering region size (L). Microhardness was measured by nanoindenter Duramin under 0.25 N load. The tribological investigations were carried out using «ball-on-disc» test in the open air without any lubricant (counterbody HB = 200 MPa).

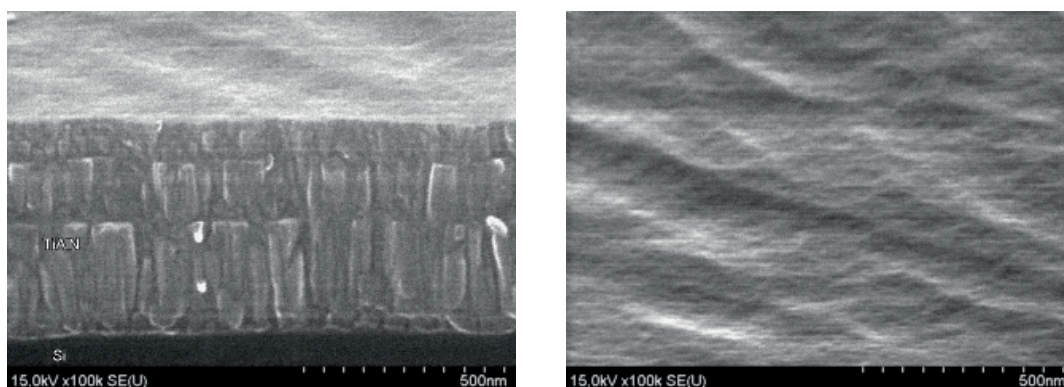
The coated cutting blades wear tests were carried out on the woodworking center Rover B 4.35 and the two-side laminated chipboard was used as work material.

RESULTS AND DISCUSSION

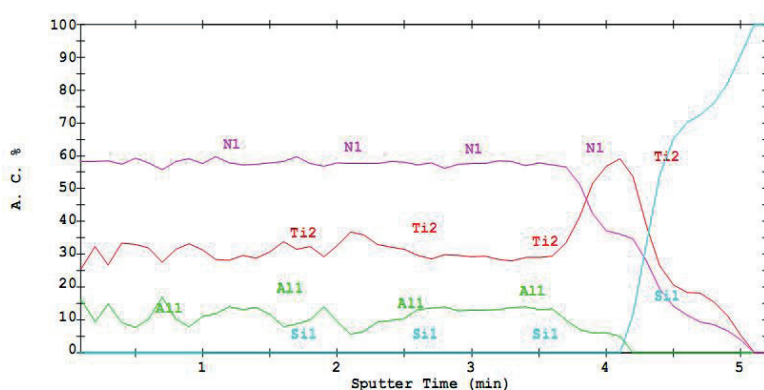
As can be noted from the carried out investigations, coatings surface morphology is



1: The scheme of multicomponent coatings deposition from the separated plasma flows: 1 – vacuum camera; 2 – arc evaporators; 3, 4, 5, 6 – electromagnetic coils; 6 – screen for droplets withdrawal; 7 – substrate



2: Surface morphology (a) and fractograph of the deposited coatings (b)



3: Element distribution into the depth of the (Ti,Al)N coatings

characterized by microcell structure similarly to the pure titanium-based coatings. The drops absence on and in the coating surface is evidence of an effective separated system (Fig. 2).

The application of the separated system allowed reducing the roughness of the deposited (Ti,Al)N coatings to 0.1–0.2 μm , and it's in 2.5–3 times lower in comparison with the coatings deposited from the unseparated plasma flows. It is known, the roughness brings considerable contribution into the friction process as a deformative component (Shtanskii, Levashov, 2001), so the achieved result is very important for the operational coatings properties enhancement.

The stepping etching of the (Ti,Al)N coating deposited under -60 bias by means of high-energy argon ion beam showed, that the element distribution into depth of the (Ti,Al)N coating was uniform, and it can be stated about the achievement of the necessary mixing level of the separated plasma flows (Fig. 3). It's a significant factor while using this technique for industrial applications, since the keeping of the elemental composition into depth during tool working in the real conditions provides the stability of its hardening properties during long-term work.

As can be seen from the Ti-Al-N system phase diagram (Holm, Ahuja, Li, Johansson, 2002),

aluminum and nitrogen are poorly soluble, in TiN and TiAl, correspondingly, in the equilibrium conditions, but ternary compounds Ti_2AlN , Ti_3AlN and $\text{Ti}_3\text{Al}_2\text{N}_2$ can be generated in the dependence of the nitrogen pressure and aluminum and titanium concentration under high temperatures.

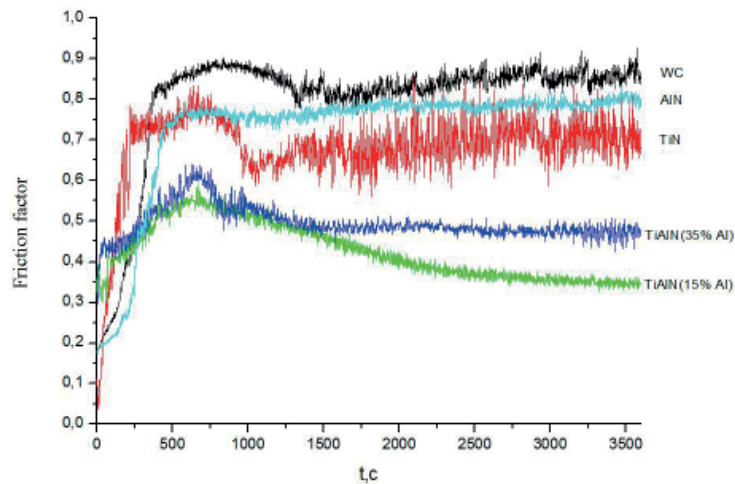
It's found from the X-ray investigations, the crystalline phase lines of TiAlN compound, representing the solid solution of Al in the TiN lattice with a cubic structure NaCl appear in the coatings depending on the aluminum concentration. The crystalline phase $\text{Ti}_3\text{Al}_2\text{N}_2$ lines of hexagonal structure are found in the coating composition while increasing aluminum concentration. The elemental composition of (Ti,Al)N coatings has a great influence on their physical-mechanical properties (table).

The obtained results are agreed with literature data, where it has been shown, the (Ti,Al)N coating (Tab. I) is characterized by TiN cubic structure with decreased lattice spacing, provided the aluminum atomic concentration is less than 60 at. % (Tentardin, Aguzzoli, Castro *et al.*, 2008).

The friction factor of the carbide cutting plates coated by Ti-Al-N is in the range from 0.31 to 0.50 (Fig. 4), and it's essentially lower in comparison with TiN coated cutting plates (0.7–0.8) and uncoated cutting plates (0.9). It is explained by the presence

I: Physical-mechanical properties of the (Ti,Al)N coatings

Coating	I_{TP} , A	I_{AP} , A	Ti, at. %	Al, at. %	d , nm	L , nm	H , GPa
TiN	60	–	60.21	–	0.429	28	26.5
(Ti,Al)N	60	40	91.81	8.19	0.423	12	29.8
		50	84.19	15.81	0.421	10	34.9
		60	73.32	26.68	0.419	8	32.1
		70	63.79	36.21	0.417	9	36.1
AlN	–	60	–	58.23	–	76	19.2



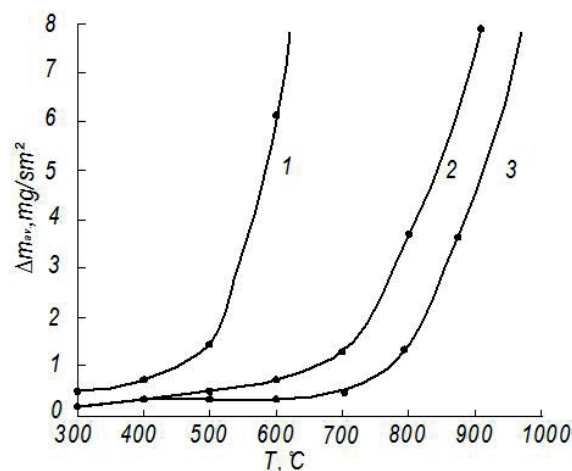
4: The friction factor of the vacuum arc coated cutting plates

of the plastic material (Al), which has a significant influence on the friction factor in the case of dry friction. The decreasing of the friction factor gives the temperature drop in the cutting area and consequently leads to the increasing of the coated tool wear resistance.

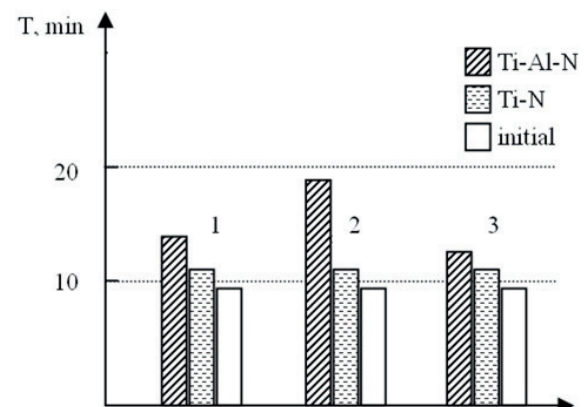
It's impossible to decrease the temperature in the direct contact zone under high processing speed. In this case the oxidative wear mechanism, caused by the interaction between the oxygen and

the coating material, takes place so it's necessary to control the high-temperature oxidation resistance of the deposited coatings. The (Ti,Al)N coatings oxidation characteristic when heating in the air in the temperature range 200–1000 °C and soaking 1 hour was studied (Fig. 5).

It's known, that the coatings oxidation is determined as the beginning of the coating mass change after thermal annealing owing to the oxide generation. The temperature, corresponding to the Δm significant increase, is determined as the



5: The mass increase of the vacuum arc coatings during heating in air under different aluminum concentrations: 1–TiN; 2–(Ti,Al)N (15 at.% Al); 3–(Ti,Al)N (35 at.% Al)



6: The dependence of the carbide cutting plates efficiency of (Ti,Al)N coatings on the aluminum concentration in the coating: 1–15 at.% Al; 2–35 at.% Al; 3–50 at.% Al (Tentardini, Aguzzoli, Castro et al., 2008)

maximum temperature when the coating has thermal stability. When the temperature is lower 700 °C the surface coating consists of homogeneous mixture oxides $\text{Al}_2\text{O}_3 + \text{TiO}_2$ and when it's above 800 °C the double-layered structure $\text{Al}_2\text{O}_3/\text{TiO}_2$ to be generated due to the enhancement of the aluminum atom diffusion towards the surface and the upper layer Al_2O_3 protects the coatings from the oxidation. It's found, that purposeful alloying

of the titanium nitride coatings by aluminum had a positive influence on the thermal stability, the best result being got for the coatings with aluminum concentration approximately 35 at.%.

The carbide cutting plates tests with (Ti,Al)N coatings during particle boards processing showed high working capacity at high speeds (temperatures) in comparison with TiN (Fig. 6). The resistance criterion was the clearance face wear.

CONCLUSION

The method of the nanostructural (Ti,Al)N coatings generation from the multicomponent separated plasma flows is technologically realized. The developed separated system was proved to be effective, and it allowed getting (Ti,Al)N coatings with uniform element distribution into depth, high dense structure, low friction factor and high hardness.

It is determined, that purposeful alloying improves operational coatings properties, and allows using them as protective layers, deposited on the working surfaces of the cutting tools during timber-based material processing.

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