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The effect of nitrogen ion implantation on nano-scale hardness and elastic modulus of WC-Co indexable knives for wood materials machining

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Abstract: *The effect of nitrogen ion implantation on nano-scale hardness and elastic modulus of WC-Co indexable knives for wood materials machining.* The paper presents the results of a study investigating the effects of nitrogen ion implantation into the surface layer of WC-Co blades, used for machining wood materials, on their hardness and modulus of elasticity at the nano-scale. The modified blades were analyzed in six variants of implantation process parameters, and compared with control blades (virgin, unmodified). Three energies of accelerating nitrogen ions were used in the implantation process (5, 50 and 500 keV) and two doses of implanted ions (1e17 and 5e17 cm^{-2}). The nano-hardness and elastic modulus of all blades were measured using an Anton Paar TriTec (UNHT) hardness tester.

Keywords: ion implantation, WC-Co indexable knives, nitrogen ion implantation, nano-scale mechanical behavior, hardness, elastic modulus, wood materials machining

INTRODUCTION

The basic wear mechanisms of cutting blades during the machining of wood materials are: abrasive wear, strength, erosion and oxidation. With few exceptions, the intensity of abrasive mechanisms such as micro-cutting, grooving (plastic deformation) and cracking is inversely proportional to the hardness of the blade material. A blade with high hardness is also characterized by increased fragility, and therefore low plasticity in the conditions of the microcutting process [Ndlovu 2009].

Strength mechanism-related chipping and cracking result from exceeding the constant static load strength or fatigue due to cyclic loads during friction, causing a change in compressive and tensile loads during cutting [Kupczyk 2009].

The erosive mechanism during chipboard machining results from the impact of mineral particles (sand), which remove fragments of the blade material under the influence of momentum.

Oxidation, being one of the mechanisms of chemical wear, when machining with WC-Co cemented carbide blades, proceeds intensely at temperatures above 970 K (≈700°C). Chemical synthesis with oxygen mainly affects the matrix through cobalt (Co), thus increasing the porosity of the blade material and extending the effect of oxidation to a greater depth. As a result of this process, brittle phases are formed, which are easily removed by sliding friction [Kupczyk 2009].

Therefore, in order to limit the intensity of the above mechanisms, it is necessary to ensure high hardness of the blade material (also at elevated temperatures) while maintaining its low brittleness and high strength (toughness) for impact loads, as well as a low coefficient of friction of the blade against the workpiece [Kupczyk 2009].

The relations between hardness and modulus of elasticity, and between friction and wear can be investigated on the microstructural scale [Ndlovu 2009, Staedler and Schiffmann 2001, Wilkowski et al. 2019].

The aim of the work was to determine the impact of nitrogen ion implantation, with selected process parameters, on the nano-scale hardness and modulus of elasticity of the surface layer of WC-Co indexable knives dedicated for wood materials machining.

MATERIAL AND METHODS

The WC-Co indexable knives with dimensions of 29.5×12.0×1.5 mm^3, produced by Ceratizit Co (Austria) were used for the tests (Fig. 1). Selected properties of the tested WC-Co composites are shown in Table 1.

Table 1. Properties of the tested WC-Co indexable knives [www.ceratizit.com]

Material symbol	WC grain size [µm]	Binder content Co [%]	Density [g/cm^3]	Hardness HV30	Bending strength [MPa]
KCR08	0,5-0,8	3,2	15,20	1790	2300

The modification of the flank surface of WC-Co blades in the process of nitrogen ion implantation was carried out at Helmholtz-Zentrum Dresden Rossendorf (HZDR) according to the plan shown in Table 2. In this way, six variants of modification of indexable knives were obtained. They were compared with unmodified (virgin, control) knives.

Table 2. Main parameters of the nitrogen ion implantation process

Energy (keV)	Dose (cm^{-2})	Temperature (°C)
5	1e17	<20°C
5	5e17	<20°C
50	1e17	<50°C
50	5e17	<50°C
500	1e17	<200°C
500	5e17	<200°C

Hardness and modulus are calculated from the load-displacement data for each indentation by the Oliver and Pharr method [Oliver and Pharr 2003, Kempf 2002, Wilkowski et al. 2009]. The local properties were measured using an Anton Paar TriTec Ultra Nano Hardness Tester (UNHT) (Fig. 2).

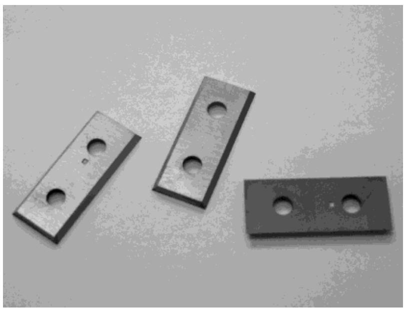

Figure 1. WC-Co indexable knives for wood materials milling

Figure 2. Anton Paar TriTec Ultra Nano Hardness Tester (UNHT)

The Berkovich indenter was used. The measurement parameters were as follows: maximum load: 1 mN; loading / unloading speed: 2 mN/min; pause: 5 s. The measurement was repeated five times on each sample.

RESULTS AND DISCUSSION

Fig. 3 shows the results of the nano-scale hardness (top) and modulus of elasticity (bottom) of the examined indexable knives. Bar charts with standard deviation indicate changes in hardness and modulus of elasticity as a result of the nitrogen ion implantation process. The highest values of hardness and modulus of elasticity were obtained for modifications with the following parameters: ion energy: 5 keV and ion dose: 5e17 cm^{-2}. The values obtained were higher than those for virgin knives.

With an increase in ion energy (50 and 500 keV), the properties of the WC-Co surface layer measured at the nano-scale decreased, irrespectively of the ion dose. The lowest hardness and modulus of elasticity were obtained for the following modification parameters: ion energy of 500 keV and ion dose of 5e17 cm^{-2} for the lowest hardness, and dose 1e17 cm^{-2} for the lowest modulus of elasticity.

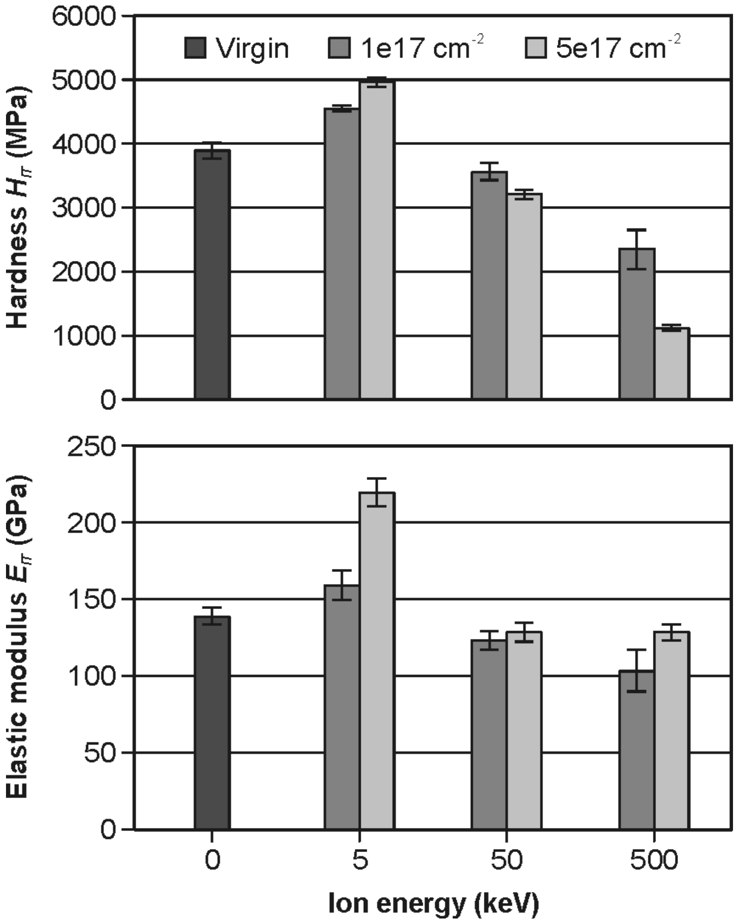

Figure 3. Nano-scale hardness and elastic modulus of tested WC-Co indexable knives

The values of the tested properties are lower when the implantation energy is increased to 50 and 500 keV, which happens to a greater extent for hardness than for modulus of elasticity. A viable interpretation is that this is due to the fact that nitrogen implantation produces nitrides (e.g. WN, W_2N, W_3N), which are not harder than WC tungsten carbide, but exhibit higher impact strength and fracture toughness. This is explained by the Samsonov theory based on the configurational solid state model.

Samsonov's research showed that the hardness of nitrides is less than that of carbides of the same metals (including tungsten) and, at the same time, their plasticity is greater. This is due to differences between nitrides and carbides based on a smaller statistical weight of atoms in a stable s^2p^6 configuration [Samsonov and Kosolapova 1975].

Abrasion resistance generally increases with hardness. According to Samsonov, this relation is not confirmed in the case of carbides. This is attributed largely to the fragility of these compounds, manifested by their minimal plasticity in the conditions of the micro-cutting process [Wilkowski et al. 2018].

CONCLUSION

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

1. The highest values of hardness and modulus of elasticity were obtained for modifications with the following parameters: ion energy of 5 keV and ion dose of 5e17 cm^{-2}. The values obtained were higher than those for virgin knives.

2. Together with an increase in ion energy (50 and 500 keV), the properties of the WC-Co surface layer measured at the nano-scale decreased, irrespectively of the ion dose.

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REFERENCES

1. KEMPF M., 2002: Nanohärtemessungen mit dem Rasterkraftmikroskop. Der Andere Verlag, Osnabrück, 160 pp.
2. KUPCZYK M.J., 2009: Wytwarzanie i eksploatacja narzędzi skrawających z powłokami przeciwzużyciowymi. Wydawnictwo Politechniki Poznańskiej, 445 pp.
3. NDLOVU S., 2009: The wear properties of tungsten carbide-cobalt hardmetals from the nanoscale up to the macroscopic scale. Doctoral thesis, 134 pp.
4. OLIVER W.C., PHARR G.M., 2003: Measurement of hardness and elastic modulus by instrumented indentation: Advances in understanding and refinements to methodology. *J. Mater. Res.* 19/1: 3-20
5. SAMSONOV G.V., KOSOLAPOVA T.J., 1975: Vysokotemperaturnye karbidy. Naukova Dumka
6. STAEDLER T., SCHIFFMANN K., 2001: Correlation of nanomechanical and nanotribological behavior of thin DLC coatings on different substrates. *Surface Science* 482-485: 1125-1129.
7. WILKOWSKI J., BARLAK M., WERNER Z., BÖTTGER R., KONARSKI P., PISAREK M., 2018: The effect of nitrogen ion implantation on the properties of WC-Co composites used in wood-based materials machining. *Poster presentation at Yucomat 2018 Conference, Herceg Novi, Montenegro, 3-7 September, 2018*
8. WILKOWSKI J., BARLAK M., WACHOWICZ J., BÖTTGER R., WERNER Z., 2019: Nano-scale hardness and elastic modulus of WC-Co composites and their relationship to the tools life during particleboard milling. *Ann. WULS - SGGW, For. and Wood Technol.* 106: 62-66

Streszczenie: *Wpływ implantacji jonów azotu na twardość i moduł sprężystości w nano-skali noży wymiennych WC-Co do obróbki materiałów drzewnych.* W artykule przedstawiono wyniki wpływu procesu implantacji jonów azotu do warstwy wierzchniej ostrzy WC-Co do obróbki materiałów drzewnych na ich twardość i moduł sprężystości w nano-skali. Analizowano ostrza modyfikowane w sześciu wariantach parametrów procesu implantacji, oraz w celach porównawczych, ostrza kontrolne (niemodyfikowane). Zastosowano trzy energie przyspieszenia jonów azotu w procesie implantacji (5, 50 i 500 keV) oraz dwie dawki implantowanych jonów (1e17 oraz 5e17 cm^{-2}). Pomiaru twardości i modułu sprężystości w nano-skali wszystkich ostrzy dokonano przy użyciu twardościomierza Anton Paar TriTec (UNHT).

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