

EXPERIMENTAL RESEARCHES TRIBOLOGICAL PROPERTIES OF HARD-ALLOY BLADES WITH A VACUUM-PLASMA COATING IN THE CHIPBOARDS MILLING PROCESS

Pavel Viktorovič Rudak¹, Ján Kováč², Dimitrij Valerievič Kuis¹,
Oxana Genadievna Rudak³, Štefan Barčík⁴, Jozef Krilek²,
Evgeny Jurievič Razumov⁵

¹ Department of Materials Science and Metal Technology, Belarussian State Technological University, Sverdlova str. 13a, 220006, Minsk, Belarus

² Department of Environmental and Forestry Machine, Faculty of Environmental and Manufacturing Technology, Technical University in Zvolen, Ul. T. G. Masaryka 24, 960 53 Zvolen, Slovak Republic

³ Department of Technology and Design of Wood Products, Belarussian State Technological University, Sverdlova str. 13a, 220006, Minsk, Belarus

⁴ Department of Machinery Control and Automation, Faculty of Environmental and Manufacturing Technology, Technical University in Zvolen, T. G. Masaryka 24, 960 53 Zvolen, Slovak Republic

⁵ Volga State University of Technology, Lenin sq. 3, Yoshkar-Ola, 424000, Russia

Abstract

RUDAK PAVEL VIKTOROVIČ, KOVÁČ JÁN, KUIS DIMITRIJ VALERIEVIČ, RUDAK OXANA GENADIEVNA, BARČÍK ŠTEFAN, KRILEK JOZEF, RAZUMOV EVGENY JURIEVIČ. 2015. Experimental Researches Tribological Properties of Hard-Alloy Blades With a Vacuum-Plasma Coating in the Chipboards Milling Process. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 63(5): 1543–1547.

While developing effective ion-plasma coatings compositions of woodcutting tools special conditions of its use should be taken into account particularly the force rate acting on the cutting wedge. With the penetration of the blade into the wood material normal pressure and friction appear on the connection surface. For the analysis of the cutting processes the connection surface can be divided into several zones. The cutters with vacuum-plasma coatings based on TiN are characterized by a lower coefficient of friction in comparison to uncoated cutters in real conditions. The developed technique of tribotechnical tool tests of milling woodchip board is of great importance to establish the regularities of chip formation, chips movement and dust in the timber cutting areas as well as wood materials at milling in a wide parameter range of cutting conditions, for the development of methods and devices of chips and dust suppression.

Keywords: tribological properties, vacuum-plasma coating, ion-plasma coating, milling process, blade, chipboard, friction

INTRODUCTION

While developing effective ion-plasma coatings compositions of woodcutting tools special conditions of its use should be taken into account particularly the force rate acting on the cutting wedge (Rudak, 2009). These forces can be calculated from the known analytical relation of cutting wood

theory and timber based material. The accuracy of these calculations depends on the constants validity including the coefficient of friction (Rudak, 2008).

It is known that a change in the coefficient of friction at cutting is equivalent to changing the cutting angle and leads to the shape change of chip formation. With the decrease of the friction

coefficient chips will approach the drain. Therefore, reducing the coefficient of friction also leads to improved quality of wood-working (Beršadski, 1975). Friction peculiarities in cutting wood in comparison to the processing of other materials poses make serious limitations on the use of standard methods for determination of the tribological properties of the wood-cutters.

Wood milling is carried out at high frequencies of the instrument what characterizes this process of cutting as high recurrence process (Rudak, 2009). The cutting force with an up-milling varies from a minimum to a maximum value with increasing thickness of the chips when the knife moves along the arc of connection with the work material.

The work wood material and chips have low thermal conductivity, so almost all the heat generated during cutting is absorbed by limited area of a cutting tool which can be heated to high temperatures (about 800 °C and more). Thermal phenomena in cutting influence the change of blade microgeometry as well as tool deterioration. It is known that products of thermal wood degradation significantly increase tool deterioration especially their fraction containing organic acids.

The wood has a high elasticity. Some elastic recoveries are possible in cutting areas and due to the fibrous structure of the wood-based cutting process starts only after reaching the fibers sufficient mechanical stresses – before it the blade crushes the particles of the material.

Due to the peculiarities of manufacturing technologies the physical and mechanical properties of wood chip board of flat-pressed have different thickness and as a result the blade tool experience uneven mechanical, thermal and other loads along its length – coefficients of friction is also unstable.

The presence in the solid wood chip board of hard particles of a condensed binder (as a rule 8–12% of urea-formaldehyde resin) has a significant effect on the cutting process even the implementation of contact fatigue mechanisms is possible. Low

moisture of wood-based boards, presence of a condensed polymer at high cyclicity of the cutting process can lead to the deterioration of electro erosion cutting tools (Rudak, 2008).

These features of the process of chipboard cutting are significant and unique and cannot be fully reconstructed on the test machines for the research of the tribological characteristics according to standard methods (for example, by the scheme of the reciprocating motion of the bodies at tribometer).

Thus, the coefficient of friction should be set according to the results of experimental studies in a real cutting process. Such data are not available.

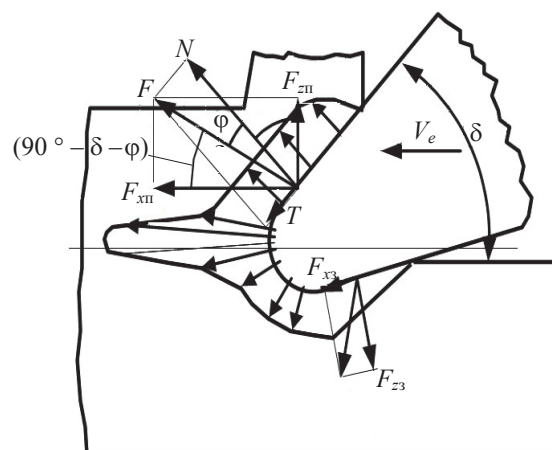
Purpose of the research is to set friction coefficients characterizing the processing of woodchip board (chipboard) by instrument equipped with knives of tungstencobaltous alloy of vacuum plasma coatings.

MATERIALS AND METHODS

With the penetration of the blade into the wood material normal pressure and friction appear on the connection surface. For the analysis of the cutting processes the connection surface can be divided into several zones. Division of the connection circuit into two zones (Rudak, 2009) – the front and back surfaces is typical of A. L. Beršadski' schoold.

The front surface of the blade deforms cut layer and chips, creates voltage in them and removes chips (Rousek, 2004). Compression layer and chips takes place in a semi-enclosed space. The theory of cutting wood and wood materials tells that the pressure stedially distributed on the front surface of chips (Kováč, Krilek, 2011). Cutting edge makes incision on the cut layer and the front edge removes it.

The backoff surface of the blade experiences normal pressure of the material due to the elastic recovery of the machined surface (Holopírek, Rousek, 2005). As the deformations under the backoff surface are elastic, the normal pressure profile on it can be taken as triangular. Replacing normal pressure profiles along the connection pads of the blade let's move to the cutting forces.



1: Circuit of the forces on the knife blade (Beršadski, 1975)

Let's replace the normal pressure profile in the front blade surface by concentrated force N and add friction force T to it (Fig. 1). The resultant force F will project in direction of the speed V_ϵ of the main motion and the normal to it. We get the following forces: $F_{x\Pi}$ – tangential cutting force along the front surface; $F_{z\Pi}$ – normal cutting force along the front surface.

The radial component of the cutting force is found by the following considerations. Force N and F form an angle of friction between each other φ ($\varphi = \arctg \mu$ where μ – the coefficient of wood friction on the front face). At the same time forces $F_{z\Pi}$ and $F_{x\Pi}$ linked by the following equation:

$$F_{z\Pi} = F_{x\Pi} \operatorname{tg}(90^\circ - \delta - \varphi), \quad (1)$$

where

δcutting angle.

Referring to the cutting forces on the back off surface you can get the tangent cutting force on the back of the F_{x3} and normal cutting force on the back of the F_{z3} . The elastic-plastic deformation of the cutting surface of back off surface is small (on the radius of the cutting edge rounding, that is not more than 0.06 mm), so a tangent force on the back side can be considered as the friction force:

$$F_{x3} = f \times F_{z3}, \quad (2)$$

where

fthe coefficient of friction on the back surface of the blade.

The force F_{z3} is efforts necessary to penetration into the surface of the cutting blade on the radius of curvature of the cutting edge.

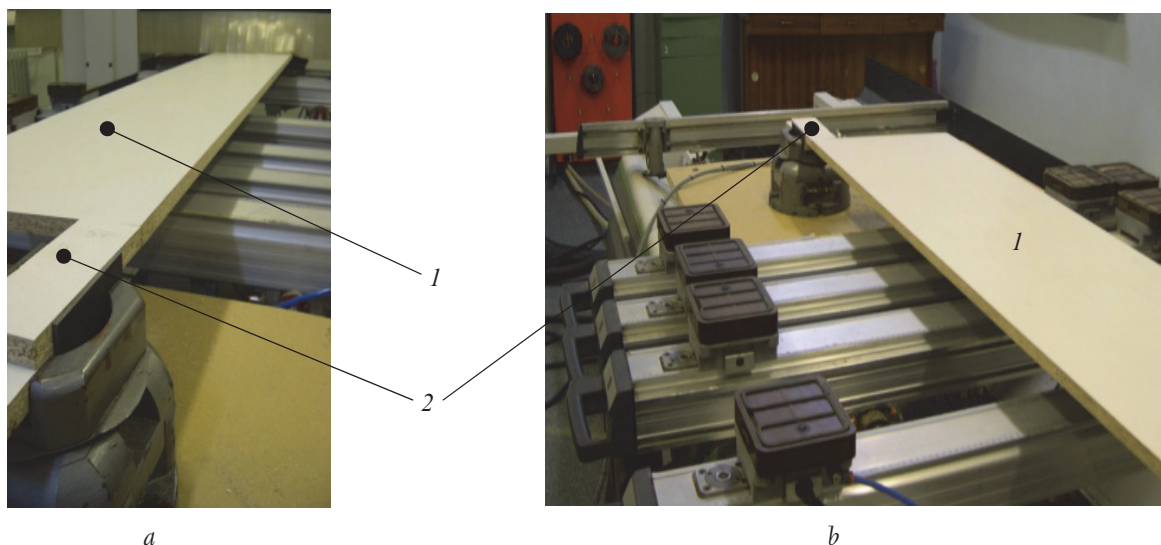
It is reasonable to determine the value of the friction coefficient of the blade back during the investigation studies of the tribological properties of indexable inserts with vacuum-

plasma coatings in order to develop effective coating formulations focusing on cutting chipboard.

The method developed at the Department of Materials Science and Technology of Metals BSTU of determining the friction coefficient f of the back blade surface and its cutting edge part on the back of the blade during milling with zero height of dimensional allowance. Experimental setup for the implementation of the developed technique is created using modern CNC-machining center ROVER B 435.

Chipboard blank on the first machine Tab. I (Fig. 2a) is installed butt-to-butt with the blank for dynamometer test 2 (Fig. 2b). The dynamometer with a fixed blank 2 is fixed on the second machine table. The recorder – tensiometric measurement system EX – UT10 with i.Link interface (brand SONY, Japan) examine UDM strain gauges and allows synchronously to determine the efforts on three perpendicular mutually directions as well as the value of the moment in the horizontal plane. Calibration of the measuring system of the experimental setup was carried out by loading a sample chipboard used in experimental studies, strain gauges of universal UDM dynamometer by three coordinate axes X, Y, Z statically with the hepl of universal dynamometer sample DOU-3-1 kN to 0 at range of 1000 N. Linear dependence of the sensors' indicators used by the universal dynamometer from the applied load confirms the performance of sensors in the area of elastic deformation within the range of applied loads.

Cutting elements used as a basis for the coating are indexable carbide plates of tungsten cobalt alloy SMG 02. After each experiment mill with cutter shifted (replaceable blade) – processing was conducted by acute side of the cutter. Work material is a woodchip board with laminate cover on both sides (EN 14322) manufactured by the company «Pfleiderer Grajewo S.A.» (Poland). Plate thickness is 18 mm.



2: The scheme of blank fastening on the machine table during the experiments: 1 – chipboard desktop blank; 2 – woodchip board blank for dynamometric

Average density – 650 kg/m³ – was controlled by certain average weight measured for 5 dice 18×18×18 mm cut from different parts of the slab.

Uncut dimensions for dynamometer is 68×300×18 mm. Uncut dimensions for pre-processing is 2700×500×18 mm. The type of tool is a single-shank end mill. The diameter of the cutting circle of the end mill is 21 mm. The type of chuck is ISO32.

To determine the required number of observations we based on the condition that the variance of the measured value is constant and known and its distribution is normal. The data is identified as a result of preliminary experimental measurements of the output values in the debugging phase of the experimental setup. The hypothesis of the normal distribution of the measured values was tested by Pearson χ^2 criterion (Pižurin, 2004). Series of experiments were conducted in the center

of the experiment with the greatest variation of the measured value. Number of experiments – 128 samples (fixing components of cutting forces with the recalculation to the appropriate friction coefficient values f) in the range of stable flow of the cutting process.

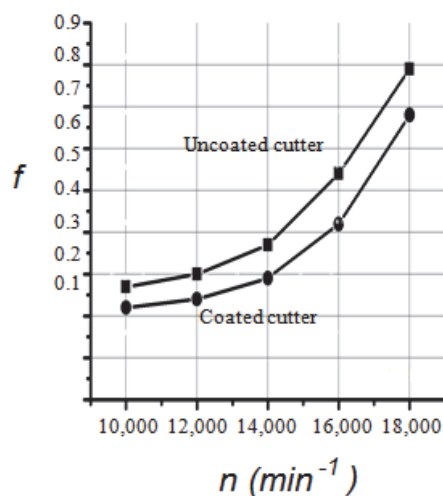
As a result of the all calculations required number of duplicate experiments was 2.34 times during the research of the friction coefficient f .

During the experimental researches threefold repetition of each experiment of the methodical grid was made and the mean value of the friction coefficients of the back surface of the blade and parts of the cutting edge connected to it were determined for the rest and slip periods.

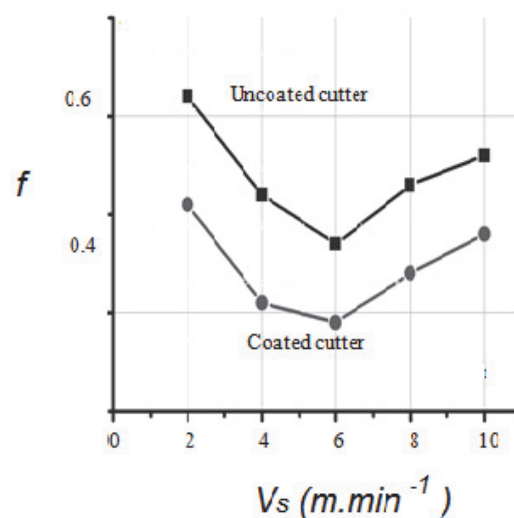
The structure of the experimental studies of the friction coefficient f for milling woodchip board included a series of single-factor experiments with duplication. The speed was 14,000 min⁻¹ and the

I: Methodical grid of experiments

No.	Cutter rotational speed n (min ⁻¹)	V ^s (m.min ⁻¹)	f	No.	Cutter rotational speed n (min ⁻¹)	V ^s (m.min ⁻¹)	f
Cutter without coating							
Speed impact				Feed rate impact			
1	10,000	6	0.37	6	14,000	2	0.62
2	12,000		0.4	7		4	0.52
3	14,000		0.47	8		6	0.47
4	16,000		0.64	9		8	0.53
5	18,000		0.89	10		10	0.56
Coated cutter							
Speed impact				Feed rate impact			
11	10,000	6	0.32	16	14,000	2	0.51
12	12,000		0.34	17		4	0.41
13	14,000		0.39	18		6	0.39
14	16,000		0.52	19		8	0.44
15	18,000		0.78	20		10	0.48



3: Friction coefficient f dependency on speed of shank-type milling cutter



4: Friction coefficient f dependency on feed rate

feed rate was $6 \text{ m} \cdot \text{min}^{-1}$ during the stabilization of one of the factors. Uncoated and coated cutters TiN tested separately.

RESULTS

Methodical grid of the experiments with the results is presented in the Tab. I.

Milling of the fixed butt blanks on the first and second machine table with the removal of excess material of 3 mm to eliminate setting blank errors was made before dynamometer. The data were filtered using a mathematical DSO and after then friction coefficient was calculated (Goldenber, 1990). The experimental results are presented in the form of graphic dependences (Fig. 3, 4).

CONCLUSION

The cutters with vacuum-plasma coatings based on TiN are characterized by a lower coefficient of friction in comparison to uncoated cutters in real conditions.

Graphical analysis of dependences in Fig. 3 and Fig. 4 allows us to conclude about the rationality of the cutting conditions – feed rate $6.2 \text{ m} \cdot \text{min}^{-1}$, speed cutter $10,000\text{--}12,000 \text{ min}^{-1}$ from the point of minimization of friction coefficient. The results allowed to produce a scientific justification of tribotechnical properties of vacuum-plasma coatings applied to the cutting elements of the tool which is the basis of optimizing the coatings parameters and processing modes of wood chipboard by milling.

The developed technique of tribotechnical tool tests of milling woodchip board is of great importance to establish the regularities of chip formation, chips movement and dust in the timber cutting areas as well as wood materials at milling in a wide parameter range of cutting conditions, for the development of methods and devices of chips and dust suppression.

REFERENCE

- BERŠADSKI, A. L. 1975. *Rezanie drevesni*. Minsk: Vyš. Škola.
- GOLDENBERG, L. M. 1990. *Cifroba obrabotka signalov*. Minsk: Radio i sviaz.
- HOLOPÍREK, J., ROUSEK, M. 2005. Energy dependencies with sawing hardboard materials. *Roczniki Akademii Rolniczej w Poznaniu-CCCLXVIII, Poznań*, 40: 193–199.
- KOVÁČ, J., KRILEK, J. 2011. The possibilities for measurement of saw blades wearing. *Acta Universitatis Agriculturae et Silviculturae Mendelianae*, 59(5): 137–143.
- PIŽURIN, A. A. 2004. *Modelovanie i optimizacia processov derevoobrabotku*. MGUL.
- RUDAK, P. V. 2009. Efektivnaja expliatacia koncevovo frezernovo instrumenta pri obrabotke plitnych drevesnych materialov. In: *Nauka i tehnologija stroitelnych materialov: sostrojenie i perspektivi ich pazvitija*. Materiali medzunarodnich naučnich tehnologii, 27.–28. maj, Minsk, 145–146.
- RUDAK, P. V. 2008. Experimentalnija issledovanija procesa rezanija plitnych drebesnych materialov koncevych frezernym instrumentom. In: *Resurso i energoberegajušije tehnologii i oborudovanie, ekologičeski bezopasnije tehnologii*. Materiali medzunarodnich naučnich tehnologii, 19.–20. november, Minsk, 260–264.
- RUDAK, P. V. 2009. Sovremennij koncevoj frezernij instrument dlja obrabotki plitnych drevesnych materialov. In: *Nauka i tehnologija stroitelnych materialov: sostrojenie i perspektivi ich pazvitija*. Materiali medzunarodnich naučnich tehnologii, 27.–28. maj, Minsk, 140–141.
- RUDAK, P. V. 2008. Povyšenie effektivnosti obrabotki kromok plitnych drevesnych materialov koncevym frezernym instrumentom s pozicii sistemnogo podchoda k procesu rezanija. In: *Resurso i energoberegajušije tehnologii i oborudovanie, ekologičeski bezopasnije tehnologii*. Materiali medzunarodnich naučnich tehnologii, 19.–20. november, Minsk, 245–249.
- ROUSEK, M. 2004. *Specifické problémy vysokorychlostního obrábění dřeva*. Folia Universitatis Agriculturae et Silviculturae Mendelianae Brunensis. Brno: Mendelova zemědělská a lesnická univerzita v Brně.

Contact information

Pavel Viktorovič Rudak: RudakPV@belstu.by
 Ján Kováč: jan.kovac@tuzvo.sk
 Dimitrij Valerievič Kuis: dmitrykuis@mail.ru
 Oxana Genadievna Rudak: RudakOG@belstu.by
 Štefan Barčík: barcik@tuzvo.sk
 Jozef Krilek: jkrilek@gmail.com
 Evgeny Jurievič Razumov: evgeny.razumov2011@yandex.ru