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EXPERIMENTAL STUDIES OF TRIBOLOGICAL PROPERTIES OF HARD INDEXABLE INSERTS WITH VACUUM-PLASMA COATINGS AT CYLINDRICAL MILLING OF WOODCHIP BOARDS

The article presents the methodology and results of experimental studies of friction coefficients that characterize the processing of chipboard tail cutters, knives equipped with vacuum-plasma coatings. The developed technique for determining the coefficient of friction of the back of the blade and the adjacent part of the cutting edge in milling based on the simultaneous registration of the tangential and normal cutting forces on the back of the blade during the cutting process with zero height allowance being taken. The research results have allowed to perform scientific basis of tribological characteristics of vacuum-plasma coatings deposited on the cutting elements, optimization of coating parameters.

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 [1]. 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 [2].

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 [3].

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 [4]. 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 cyclicality of the cutting process can lead to the deterioration of electro erosion cutting tools [5].

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.

Main part. 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 [1] – the front and back surfaces is typical of A.L. Bershadski' schoold.

The front surface of the blade deforms cut layer and chips, creates voltage in them and removes chips. Compression layer and chips takes place in a semi-enclosed space. The theory of cutting wood and wood materials tells that the pressure stedialy distributed on the front surface of chips. 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. 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.

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).

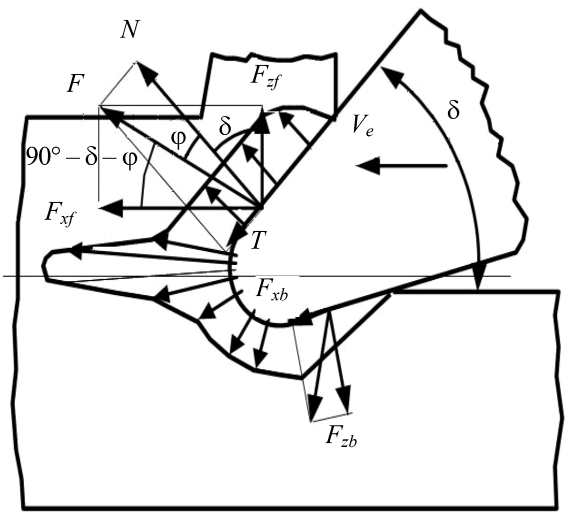


Fig. 1. Circuit of the forces on the knife blade

The resultant force F will project in direction of the speed V_e of the main motion and the normal to it. We get the following forces: F_{xf} – tangential cutting force along the front surface; F_{zf} – 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 (φ = arctgμ where μ – the coefficient of wood friction on the front face). At the same time forces F_{zf} and F_{xf} linked by the following equation:

$$F_{zf} = F_{xf}\,\mathrm{tg}(90° - \delta - \varphi), \quad (1)$$

where δ – cutting angle.

Referring to the cutting forces on the backoff surface you can get the tangent cutting force on the back of the F_{xb} and normal cutting force on the back of the F_{zb}. 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:

$$F_{xb} = f \cdot F_{zb}, \quad (2)$$

where f – the coefficient of friction on the back surface of the blade.

The force F_{zb} 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.

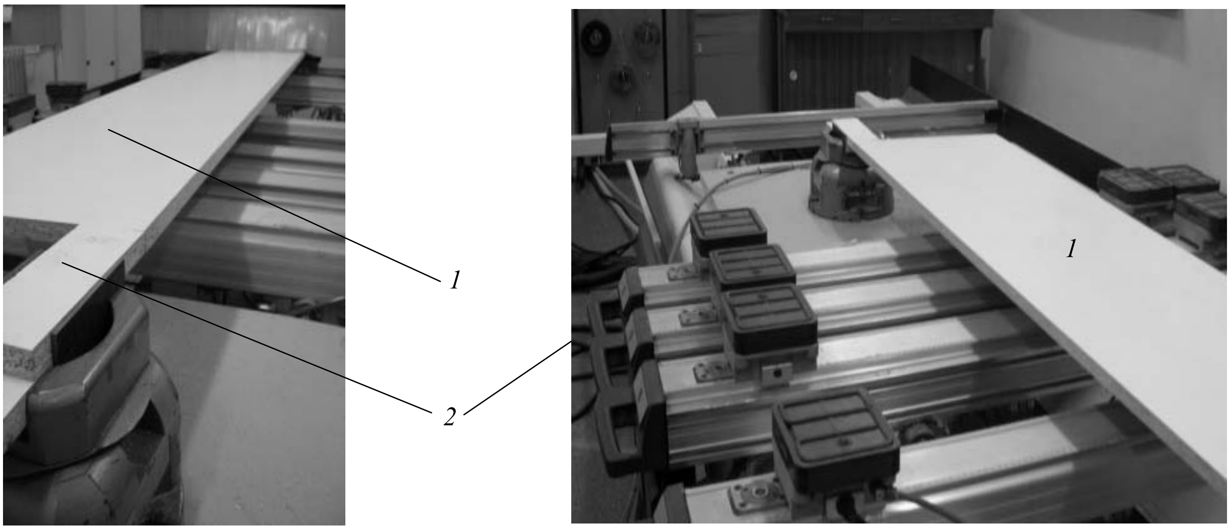
The method developed at the Department of Materials Science and Technology of Metals BSTU of determining the friction coefficient f of the back blade surface and its cutting edge part on the back of the blade during milling with zero height of dimensional allowance. Experimental setup for the implementation of the developed technique is created using modern CNC-machining center ROVER B 4.35.

Chipboard blank on the first machine table *1* (Fig. 2a) is installed butt-to-butt with the blank for dynamometer test *2* (Fig. 2b). The UDM 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 synchronouslly 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 1,000 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.

Average density – 650 kg/m^3 – was controlled by certain average weight measured for 5 dice 18×18×18 mm cut from different parts of the slab.



a *b*

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

Uncut dimensions for dynamometer is 68×300×18 mm. Uncut dimensions for pre-processing is 2,700×500×18 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 [6]. 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 feed rate was 6 m/min during the stabilization of one of the factors. Uncoated and coated cutters TiN tested separately.

Methodical grid of the experiments with the results is presented in the Table.

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 [7].

Methodical grid of experiments

Experience №	Cutter rotational speed *n*, min^{-1}	Feed rate and V_s, m/min	*f*	Experience №	Cutter rotational speed *n*, min^{-1}	V_s, m/min	*f*
Cutter without coating							
Speed impact			Feed rate impact				
1	10,000		**0.37**	6		2	**0.62**
2	12,000		**0.4**	7		4	**0.52**
3	14,000	6	**0.47**	8	14,000	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		**0.32**	16		2	**0.51**
12	12,000		**0.34**	17		4	**0.41**
13	14,000	6	**0.39**	18	14,000	6	**0.39**
14	16,000		**0.52**	19		8	**0.44**
15	18,000		**0.78**	20		10	**0.48**

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 m/min, speed cutter – 10,000–12,000 min^{-1} from the point of minimization of friction coefficient.

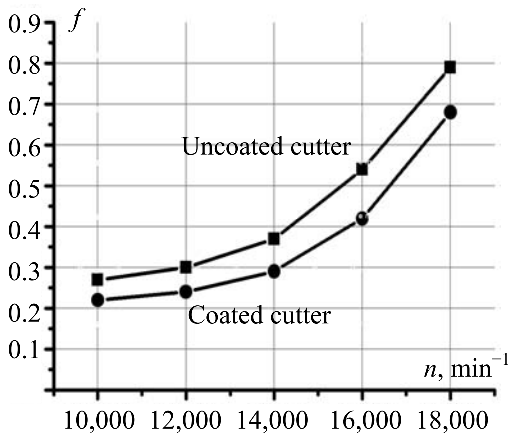


Fig. 3. Friction coefficient *f* dependency onspeed of shank-type milling cutter

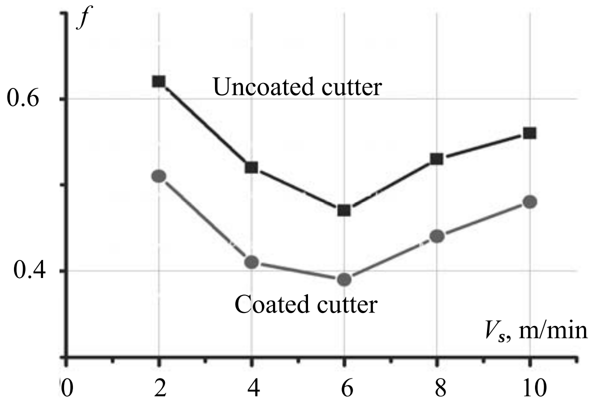


Fig. 4. Friction coefficient *f* dependency onfeed rate

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.

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