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Influence of the Sharpness Angle on the Initial Wear of the Wood Milling Knives

Gintaras KETURAKIS*, **Vytautas LISAUSKAS**

Department of Wood Technology, Kaunas University of Technology, Studentų 56, LT-3031 Kaunas, Lithuania

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The influence of the sharpness angle β on the initial cutter wear in milling larch wood was studied. High-speed steel HS 18-0-1 tools were tested. The wear of knives was tested on the cutting stand by milling larch wood samples. The main characteristic to describe the wear of cutting tool was the rounding radius of the cutting edge ρ, μm. The cutting power P_c, W, was also measured during the cutting process. Milling cutter was measured on five points using method of lead prints the microscope and digital video camera. Received images were processed and measured with the help of special software.

Keywords: HS steel, wood milling, tool wear, larch wood.

INTRODUCTION

The wood milling tools undergo wear during the cutting process under the effect of force, temperature, electrical and chemical factors. Under the influence of these factors the mass of the tools decreases and the geometrical parameters change. When the tool undergoes wear and gets blunt, its effectiveness decreases, and such a tool becomes unsuitable for work after some time [1].

The experiments show that the wear of the cutting tool depends on the actual cutting path L, m, or work time T, min, composition of the material from which the cutter is made, peculiarities of the cutting regime and properties of the wood being processed. According to the wear dynamics (Fig. 1), the wear process of the cutting tool is divided into three stages: initial, monotonic and emergency [1–3].

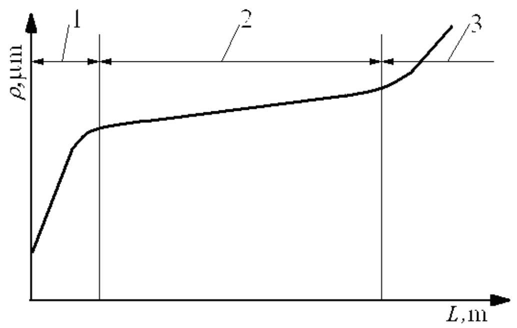


Fig. 1. The attrition process stages: 1 – initial; 2 – monotonic; 3 – emergency [2]

The wear of the tool tip is the most intensive in the first stage. The initial wear of the tool makes 40 % – 60 % of all wear of the tool, while its duration is 5 % – 10 % of all working duration [2]. The main reason of intensive wear is the crumbling and chipping of the top of cutting edge. Remaining metal burrs and other grinding defects also have negative impact. Angular tool parameters (Fig. 2) are also significant: cutting angle δ, sharpness angle β, rake angle γ, and clearance angle α. The following are considered to be microgeometrical parameters of the cutting edge: rounding radius of the cutting edge ρ, μm, recession of the cutting edge in the direction of bisector of sharpness angle A_μ, μm, wear area F, μm^2, and width of cutting edge b, μm [1].

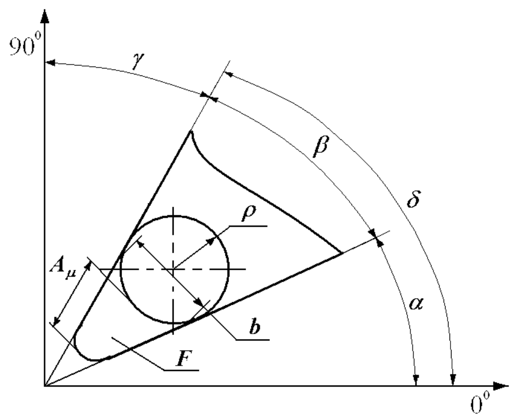


Fig. 2. Angular and microgeometrical parameters of the cutting tool [1]

The main reason of the monotonic wear is the mechanical wear of the cutting elements. The cutting edge of the tool gets hot while cutting up to the temperature t = 700...850 °C [4, 5]. High temperature causes changes in the metal structure. Undesirable electric and chemical processes begin in the cutting area: oxidation, electrostatic discharges, and electrochemical corrosion. These changes significantly reduce the strength of the cutting edge [4]. The dynamics of the cutting edge wear in various areas of the blades can vary very much. It depends on the maintenance conditions of the tool, geometrical parameters of its blade and properties of the material being processed. According to the data of the researches made by various authors, when the natural wood is processed and small thickness shaves (a < 0.1 mm) cut, the wear of the rake face of the blade decreases with the distance from the cutting edge, while the rake face acquires the shape of parabola in the cross section. In case of such wear, the rake angle γ of the tool decreases, while the sharpness angle β increases. When the thicker shave (a > 0.1 mm) is cut, the sharpness angle β decreases [1–8]. However, when various wooden materials are processed, different wear mechanism of the cutting tools is observed. When the

*Corresponding author. Tel.: +370-37-353863; fax: +370-37-353863.
E-mail address: *gintaras.keturakis@ktu.lt* (G. Keturakis)

particle board (PB), middle density fiber board (MDF) or plywood is cut, the wear of clearance face is so, that the clearance angle α decreases and the sharpness angle β increases. In the most cases the rounding radius of the cutting edge ρ increases. However, when PB and MDF are cut, the rounding radius ρ at first increases until it reaches certain size, depending on the properties of the material being cut, and then it stays constant for quite a long time [8 – 10].

In the stage of the emergency wear the changes in the mass of cutting tool and microgeometry of cutting edge reach the highest values. The tool does not cut the layers of wood any more, but swages and tears. The undesirable process of sliding on the wood surface starts. The problem of elastic recovery of wood also arises. Due to these reasons the cutting force F_x, N, and cutting power P_c, kW, increase. The quality of the processed surface does not meet any requirements any more. When the rounding radius of the cutting edge ρ comes close to the value of 30 µm, the cutter is considered to be blunt and has to be reground. Thus the emergency wear is rarely encountered in practice; it is more experimental stage of the tool's wear [11 – 15].

There is direct influence of the sharpness angle β on the strength of cutting tool. When the sharpness angle β is decreasing, the specific cutting pressure K, N/mm^2, to the rake face decreases and the durability of the tool increases. E. G. Ivanovskyj [16] analyzed the alloyed steel milling tools and determined that for milling soft deciduous wood, the optimal sharpness angle is $\beta = 36°$, while in case of hard deciduous wood it is $\beta = 39° – 40°$. When the sharpness angle β decreases, the specific cutting pressure K to the rake face also decreases. As a result the push-resistance force and power used for cutting decrease significantly.

According to N. A. Kriazhev [17], if the sharpness angle β_2 is reduced down to β_1 (Fig. 3), the additional wear area F is received.

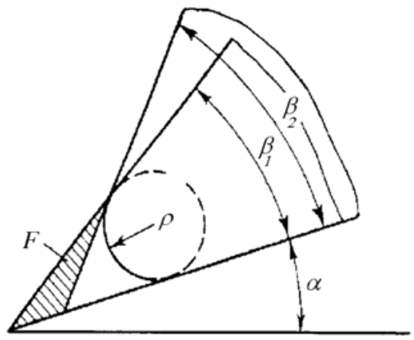


Fig. 3. Influence of the sharpness angle on the wear of the cutting edge [16]

This wear area F could be evaluated as the increase of the working duration of the milling knife up to certain value of rounding radius ρ. However, the reduction of the sharpness angle is determined by the strength characteristics of the tool material. When the hardness HRC of the knife material increases, the sharpness angle β also is increased. The recommended sharpness angle for wood milling tools, made of alloy steel, is $\beta = 30° – 40°$, while in case of high-speed steel (HSS) $\beta = 40° – 45°$, stellite $\beta = 45° – 60°$, tungsten carbide (HW) $\beta = 45° – 55°$ and polycrystalline diamond (PCD) $\beta = 60° – 70°$ is used [18, 19].

The main purpose of the research was is to determine the influence of the sharpness angle β on the wood milling cutter wear in the initial stage when the larch is milled and to determine changes of the cutting power P_c with increase of the sharpness angle β.

EXPERIMENTAL

The HS 18-0-1 (LST EN ISO 4957:2003) high-speed steel milling knives, with following dimensions – length 70 mm, width 35 mm and thickness 3 mm – were chosen for the experiments. The chemical composition of the cutters (Table 1) was determined by the method of spectral analysis, while the average hardness HRC 67.5 was measured using the Rockwell method. Three different sharpness angles $\beta = 40°$; 45° and 50° were formed on the grinding machine. Prior to the experiments, all the knives were sharpened under the same conditions. Then the blades were converged. The average sharpness angle of the blade β was determined with the 5' precision using a universal optical square protractor "Vogel".

Table 1. HS 18-0-1 steel chemical composition

Composition, wt.%						
C	Si	Mn	P	S	Cr	Mo
0.866	0.342	0.291	0.050	0.028	4.73	0.218
Ni	Al	Cu	Ti	V	W	Sn
0.307	0.017	0.236	0.003	0.825	13,4	0.041

The tests were done on the wood cutting stand made on the base of a thickness planning machine SR3-6. The samples were processed according to the longitudinal milling scheme, when the directions of the cutting v, m/s, speed and feeding u, m/min, vectors are opposite. Two cutters were fastened to the cutterblock for cutting diameter 103 mm. However, only one participated in the cutting process: the second was used for balancing. The cutters were mounted in the cutterblock, with the cutting angle $\delta = 60° \pm 1°$. The rotation speed of the cutterblock was $n = 5790$ min^{-1}, measured with the ± 10 min^{-1} precision using the stroboscopic tachometer SC-5. During the experiment the samples were processed at the cutting speed of $v = 31.2$ m/s. Set by the lift of the working table of the stand measured with a clockwork indicator, and the thickness of the layer cut in one step was $h = 2.0$ mm.

60 specimens of larch wood (*Larix sibirica*) were prepared for the tests. Their length was 1000 mm, width 100 mm and thickness 50 mm. The average moisture of the samples was $W = 14.4$ %, average number of annual rings per 1 cm was 4.84, average basic density $\rho_{bas} = 679$ kg/m^3. Initially samples were conditioned at temperature $t = 18$ °C ±2 °C and relative humidity of $\psi = 60$ % ±5 % for 30 days.

The main characteristic specifying wear of the cutting tool is rounding radius of the cutting edge ρ. The variable factors were chosen to be: cutting path L and thickness of the shave a. The thickness of shave a was changed indirectly, through the feeding rate per cutter $u_z = 0.5$; 1.0; 1.5 and 2.0 mm.

The average values of the cutting power P_c and rounding radius of the cutting edge ρ were determined in the following intervals of the cutting path L: 50; 100; 150; 200; 400; 800 and 1600 m. The factual values of the rounding radius ρ of the cutting edge were determined by the method of lead prints, using the tool microscope BMI and digital video camera with (640×480) dpi resolution. The rounding radius of the cutting edge ρ was measured in five places of the cutting edge of the knife. The received images were processed and measured on the personal computer. The error of measuring was ±2 μm.

The cutting power P_c was calculated by measuring the required power P and subtracting the idling power P_0. The required and idling powers were measured with the precision of ±5 W using the electric power gauge K506.

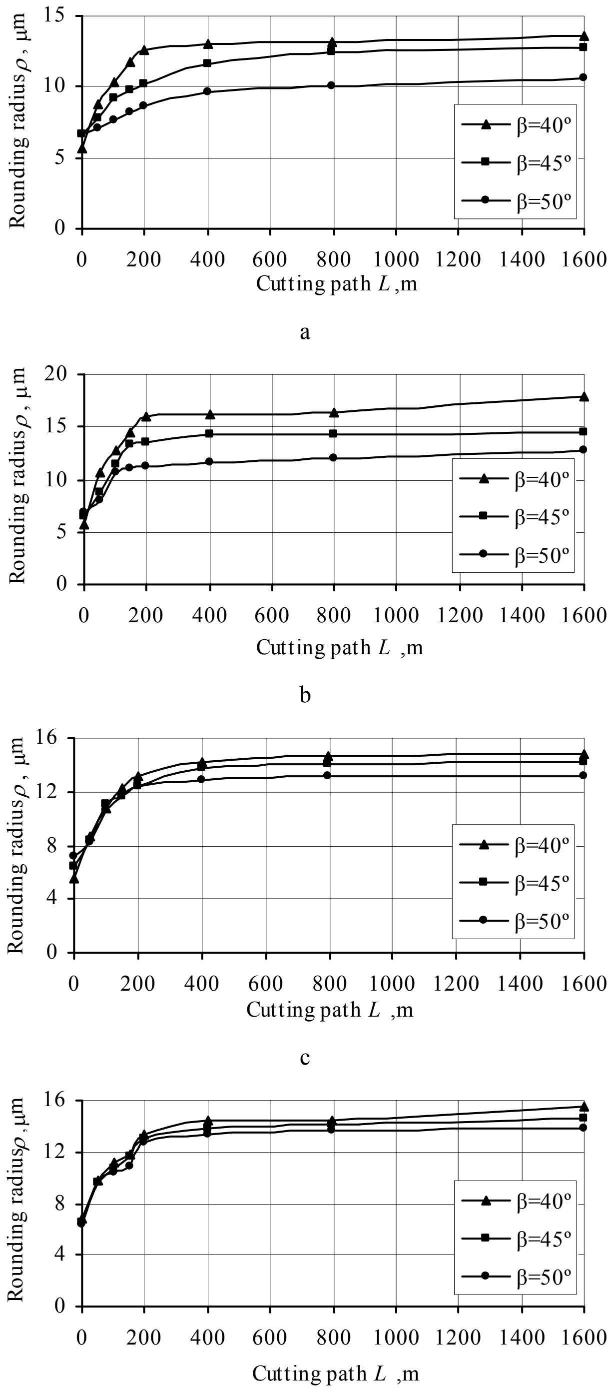
RESULTS AND DISCUSSIONS

The researches helped to determine the influence of sharpness angle β on the milling tool wear in the initial stage. It is also determined, how the cutting power P_c is changing with increase of the sharpness angle β. It has been monitored, what the influence of cutting path L and feeding per cutter u_z is on the wear of cutters.

The analysis of the diagrams of received results (Fig. 4) showed that the most intensive wear belongs to the cutter with sharpness angle $\beta = 40°$, while the cutter with $\beta = 50°$ is the most resistant to wear. The same tendency was also noted at the following values of feeding per cutter $u_z = 0.5$; 1.0; 1.5 and 2.0 mm.

The most intensive increase if rounding radius of the cutting edge ρ was noticed in the section of cutting path L until 200 m. The most significant difference between the dynamics of cutters was noticed at the feeding per cutter $u_z = 0.5$ mm. The difference in the values of rounding radius of cutting edge ρ between the cutters, which had the angles $\beta = 40°$ and $\beta = 50°$, made 46 %, whereas it made 18 % between the cutters with the angles $\beta = 50°$ and $\beta = 45°$. When the feeding per cutter u_z increases up to 2.0 mm, the difference between the cutters, which sharpness angles are $\beta = 40°$ and $\beta = 50°$, decreases down to 5 %, whereas the difference between the cutters, which sharpness angles are $\beta = 50°$ and $\beta = 45°$, made only 2 %. The reduced increase of the rounding radius of the cutting edge ρ with the increase of feeding per cutter u_z from 0.5 mm to 2.0 mm confirmed the theory that in case of small values of feeding per cutter, the shavings of smaller thickness are formed. Thus the wear of milling tool in this stage is very even, while the angular characteristics of the tool affect the wear of cutting edge directly. The cutting edge of the tool with smaller sharpness angle β is sharper and its separate segments crumble quicker. When the thickness of the shaving a increases, the cutting forces also increase and as the result separate segments of the cutting edge crumble or break [2, 16].

The deceleration of the tool wear in the section from 200 m until 400 m is noticed. However, all the milling tools wear more intensively at the feeding per cutter $u_z = 0.5$ mm and 1.0 mm. The increase of the rounding radius of the cutting edge ρ is much quicker if compared to the results received when the feeding is $u_z = 1.5$ mm and 2.0 mm. The difference between the values of rounding radiuses of the cutting edge ρ in the section of cutting path $L = 400$ m, when feeding per cutter is $u_z = 0.5$ mm between the cutters, which angles $\beta = 40°$ and $\beta = 50°$ made 35 %, whereas it was 21 % between the cutters, which angles are $\beta = 50°$ and $\beta = 45°$. When the feeding per cutter u_z increased up to 2.0 mm, the difference between the cutters, which angles $\beta = 40°$ and $\beta = 50°$, decreased down to 7 %, whereas the difference between the cutters, which angles $\beta = 50°$ and $\beta = 45°$, made only 3 %.



d

Fig. 4. Influence of the cutting path L on the rounding radius of the cutting edge ρ: a – $u_z = 0.5$ mm; b – $u_z = 1.0$ mm; c – $u_z = 1.5$ mm; d – $u_z = 2.00$ mm

The wear process in the section of cutting path L from 400 m until 800 m gets stable. Very even and small increase of the rounding radius of the cutting edge ρ is noticed. The difference between the values of rounding radiuses ρ in the section of cutting path $L = 800$ m, when feeding per cutter is $u_z = 0.5$ mm between the cutters, which angles are $\beta = 40°$ and $\beta = 50°$, made 31 %, whereas it was 23 % between the cutters, which angles are $\beta = 50°$ and $\beta = 45°$. When the feeding per cutter u_z increased up to 2.0 mm, the difference between the cutters, which angles $\beta = 40°$ and $\beta = 50°$, decreased down to 7 %, whereas the difference between the cutters, which angles $\beta = 50°$ and $\beta = 45°$, decreased only to 4 %. This is also manifested by the increase of cutting power P_c (Fig. 5).

A very small increase in the rounding radius ρ of the cutting edge is noticed in the section of cutting path L from 800 m until 1600 m. The numeric values of rounding radius ρ in this section increased only by 5 % at feeding per cutter of $u_z = 0.50$ mm and by 1 %, when $u_z = 2.00$ mm The difference between the values of rounding radiuses ρ in the section of cutting path $L = 1600$ m, when feeding per cutter is $u_z = 0.5$ mm between the cutters, which angles are $\beta = 40°$ and $\beta = 50°$, made 28 %, whereas it was 21 % between the cutters, which angles are $\beta = 50°$ and $\beta = 45°$. When the feeding per cutter u_z increased up to 2.0 mm, the difference between the cutters, which angles $\beta = 40°$ and $\beta = 50°$, decreased down to 13 %, whereas the difference between the cutters, which angles $\beta = 50°$ and $\beta = 45°$, decreased to 6 %. The milling tool wears evenly and gradually passes to the stage of monotonous wear.

To generalize received results at various values of feeding per cutter u_z, it is possible to state that the cutter, which sharpness angle is $\beta = 45°$, is more resistant to wear by 8 %, whereas the cutter, which sharpness angle is $\beta = 50°$, is more resistant to wear by 10 % if compared to the cutter, which sharpness angle is $\beta = 40°$.

When the results of these researches are compared to the works of E. Ivanovskyj [16] and G. Kowaluk [19], it is possible to state that they are universal and correlate with the results of these authors.

E. Ivanovskyj has analyzed the behavior of the milling knives made from tool alloy treated steel. According to the received results, the cutters of smaller sharpness angle β get worn more intensively than the cutters, which angle β is higher. However, the top of the cutters with smaller sharpness angle β gets worn without crumbling, but through plastic deformation of separate segments. The hardness of alloy treated tool steel HRC is much smaller than HSS.

G. Kowaluk was analyzing the resistance of various steels used for making the cutting blades to the wear. He has analyzed the resistance of high-speed steel (HSS), chromium-plated (Cr) and wolfram carbide (HM) milling tools to wear. The researches used cutters with the sharpness angle $\beta = 25$, 40, 45 and 55°. The shortening of the cutting edge was measured. When the results of G. Kowaluk are compared to the results presented in the article, it is possible to state that the wearing regularities of the HSS steel cutters are very similar. When the sharpness angle β increases, the resistance to wear also increases.

The analysis of the results of cutting power P_c (Fig. 5) helped to determine that the biggest numeral values are received when the cutter with sharpness angle $\beta = 50°$ is used, average – at $\beta = 45°$ and the smallest at $\beta = 40°$. This tendency was noticed with all values of feeding per cutter: $u_z = 0.5$; 1.0; 1.5 and 2.0 mm however, the most significant difference was received at the feeding per cutter of $u_z = 0.5$ and 2.0 mm.

The cutting power P is increasing the most intensively in the section of cutting path L until 200 m. This is related to crumbling of the top of blade's cutting edge. During this cutting stage the increase of the blade's rounding radius ρ is growing especially rapidly.

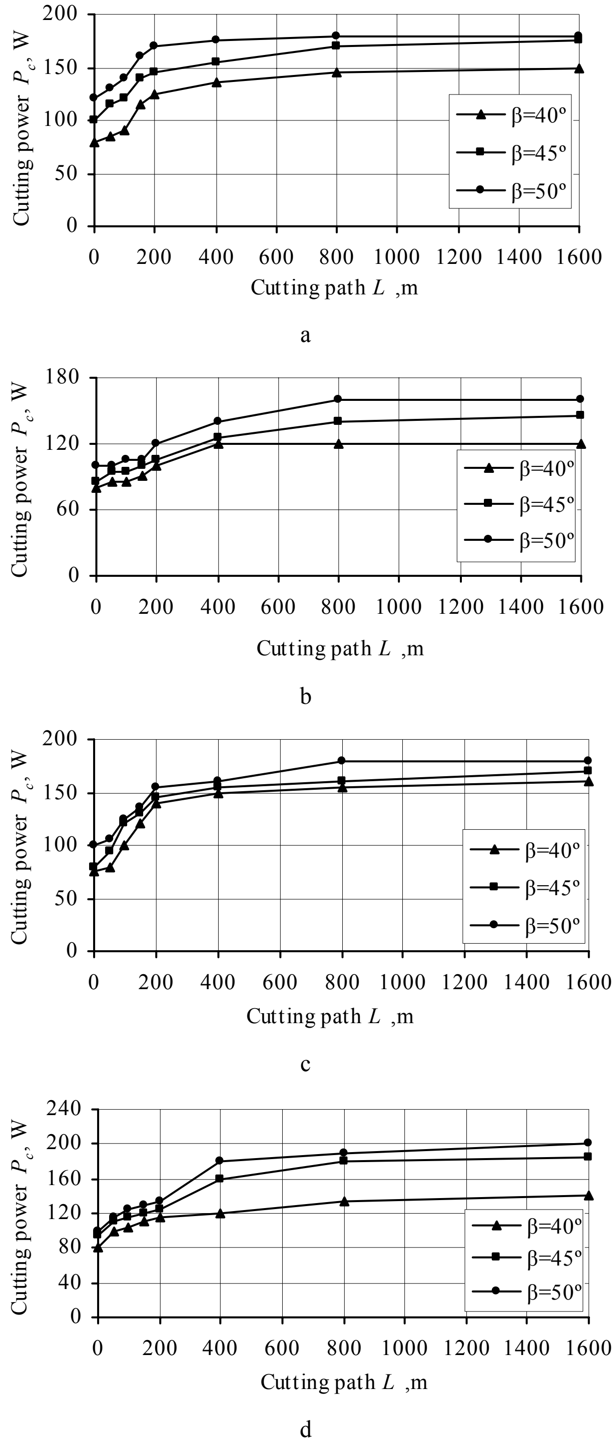


Fig. 5. Influence of the cutting path L on the cutting power P_c: a – $u_z = 0.5$ mm; b – $u_z = 1.0$ mm; c – $u_z = 1.5$ mm; d – $u_z = 2.00$ mm

The increase of the cutting power P_c gets smaller in the section of cutting path L from 200 m to 400 m. The cutting process got stable because the blades of all three cutters gradually pass from the wear by crumbling to the phase of plastic wear.

The small and non-linear increase of the cutting power P is noticed in the section of cutting path L from 400 m to 800 m. In this stage the blade of milling tool start wearing evenly, without crumbling.

The small and linear increase of the cutting power P_c is noticed in the section of cutting path L from 800 m to 1600 m. The difference of the cutting power P in the section $L = 1600$ m, when feeding per cutter is $u_z = 0.5$ mm, between the cutters with angles $\beta = 40°$ and $\beta = 45°$ made 17 %, whereas it was 20 % between the cutters with angles $\beta = 40°$ and $\beta = 50°$. When the feeding per cutter u_z increased up to 2.0 mm, the difference between the cutters, which angles $\beta = 40°$ and $\beta = 45°$, decreased down to 32 %, whereas the difference between the cutters, which angles $\beta = 50°$ and $\beta = 40°$, increased up to 43 %. These data confirm that the milling tool gradually passes to the stage of monotonous wear after 1600 m of cutting path.

The results of the cutting power P_c (Fig. 5) confirmed the theory that when the sharpness angle β is increasing, the cut shavings are deformed by stronger force. Therefore the shaving's attrition to front surface of the cutter increases [16]. This dependency was also determined in the works of E. Ivanovskyj.

The received results confirmed the presumption that the cutting power P_c increases when the feeding per cutter u_z is growing.

To generalize the comparisons, the received results are universal and may be used in other experimental tests.

CONCLUSIONS

1. In the initial wear stage up to 400 m of the cutting path, the most wear resistant cutter is with the sharpness angle $\beta = 50°$. It is caused by the crumbling of cutting edge.
2. The cutting power P_c increases with the increase of the sharpness angle β. It was determined that the consumption of the energy is the biggest at $\beta = 50°$, and the smallest at $\beta = 40°$.
3. The experiments helped to determine that the influence of the sharpness angle β on the rounding radius of the cutting edge ρ and cutting power P_c is non linear for the cutting path up to 400 m.
4. When the feeding rate per cutter u_z increases, the growth of the rounding radius of the cutting edge ρ decreases. The wear of the cutting tool is the smallest when the feeding rate per cutter is $u_z = 2.0$ mm.
5. It is recommended to form the sharpness angle β from 40° to 50° for the wood milling tools made from the high-speed steel (HSS).

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