Investigation of Milled Wood Surface Roughness

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The surface roughness of longitudinal milled birch wood samples as a function of main milling regimes such as milling tool edge blunt radius ρ (10 μm ÷ 40 μm), feed rate of milling tool u_z (0.5 mm ÷ 2.0 mm) and milling tool cutting speed v (22.4 m/s ÷ 40.8 m/s) were investigated. The test bench with required testing regimes was created on the basis of planning machine and by imitation milling edge radius blunt. The qualitative analysis of milled wood surface was performed according to the results of optical microscopy. For quantitative analysis parameter $Rm_{\max}$ was calculated. It was accepted as a difference between highest and lowest values of obtained surface irregularities in optical microphotographs of samples cross-sections. It was obtained that the decrease of both milling tool edge blunt radius and feed rate during milling, decreases the surface roughness and the quality of surface processing increases. The increase of milling tool radial velocity leads on to the increase of surface processing quality, also. That leads on decrease of energy consumption, too.

Keywords: roughness, surface, milling, blunt, blunt radius, surface quality.

INTRODUCTION

A sharp knife during milling sustains its initial micro-geometry for a very short period of time. Experiments have shown that especially intensively the cutting edge turns blunt in the first period, i.e. just after sharpening. In the second period, changes in the parameters of micro-geometry of the cutting edge slow down. It is a situation when it is sought to process wood with sharp tools, however, one has to proceed inevitably with a blunt tool [1 – 3].

Studies on longitudinal milling were conducted during planning of birch wood samples. Birch is an diffuse porous broadleaved species, having only small vessels with the diameter ranging from 0.02 mm to 0.1 mm [4, 5]. Annual layers are almost of the same structure, therefore, the influence of wood microstructure uneven on the studied process is maximally eliminated [6, 7].

Dried birch wood is considered to be hardwood [8, 9]. Usually density of birch growing in the European part may vary from 520 kg/m^3 to 665 kg/m^3 [10].

Table 1. Influence of the rounding radius ρ, μm, of blade on the surface roughness $Rm_{\max}$, μm [1]

Rounding radius ρ, μm	Surface roughness $Rm_{\max}$, μm			
	Longitudinal milling		Cross milling	
	softwood	hardwood	softwood	hardwood
<10	16…60	16…30	320…500	200…320
<20	60…200	30…100	320…500	200…320
<40	200…320	60…200	500…800	320…500

According to the survey of the bibliographical sources, the majority of tests on the surface roughness was done while processing the soft and hard deciduous wood. The surface roughness of coniferous wood was analyzed less.

Demjanovskyj published the thorough testing results about the influence of various factors on the surface roughness of deciduous and coniferous wood. He has done the majority of complex tests with various wood sorts, which grown in the Russian territory [1]. Ohta and Kawasaki analyzed the surface roughness of Japanese larch processed by various cutting regimes [11]. The larch belongs to the group of coniferous wood. Therefore we cannot compare the numeral values of the received results. However it is possible to analyze the influence tendencies of various factors. Costes and Larricq have used wet and dry beech wood for their tests [12]. As the beech and birch belong to the same group of soft deciduous trees, their physical-mechanical properties are similar. The received results may be compared with each other.

Table 2. Influence of the discharge for one cutter u_z, mm on the surface roughness $Rm_{\max}$, μm [1]

Feed per cutter u_z, mm	Surface roughness $Rm_{\max}$, μm
0.1…0.4	32
0.4…1.0	60
1.0…1.5	100
1.5…2.0	200
2.0…2.5	320
2.5…3.0	500

The analysis of the works of these authors showed that the following factors have the biggest influence on the surface roughness: sort of wood, milling mode of the surface, the rounding radius of blade, discharge for one cutter, and cutting rate v, m/s [1, 12]. It was determined that the bigger the rounding radius ρ, μm, of blade gets, the bigger the surface roughness becomes (see Table 1). When the discharge for one cutter u_z is increased from 0 mm to

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3.0 mm, the surface roughness Rm_{max}, μm also increases (see Table 2). The experiments determined that when the cutting rate is increased from 20 m/s to 40 m/s, the surface roughness Rm_{max}, μm decreases. The regularity is valid not only when the milling is done along but also across the fiber [12].

The purpose of the research is to determine the influence of the rounding radius ρ of cutter's blade, cutting rate v and discharge for one cutter u_z on the surface roughness of processed birchen wood.

DESCRIPTION OF A WOOD CUTTING PROCESS

Milling is a wood cutting process during which the rotating cutter head with knives of the cut off from the processed surface a cycloid shaving. This process occurs only under cutting and feeding movements. Any milling tool characterized by cutting radius R (mm) performs a constant rotating movement which is described by an rotational speed ω (rad/s), or linear speed v (m/s). Feeding movement u (m/min) is considered to be a constant advance of a wood sample towards the cutting zone. Only in exceptional cases the cutting tool is performing cutting and feeding movements at the same time. [1].

Longitudinal milling is most frequently applied to obtain flat and profiled surfaces. This method of processing ensures a sufficiently high surface quality, and necessary precision [13 – 15].

In the milling zone (Fig. 1) three main surfaces are distinguished: processable surface, processed surface and cutting surface.

In almost all milling machines feeding movement is provided for wood samples. Milling process may be of two types: against and in the direction of feeding. However, any regime is described by the same values:

1) thickness of the cut layer h (mm);
2) milling width b (mm);
3) feed per cutting u_z (mm);
4) cutting speed v (m/s).

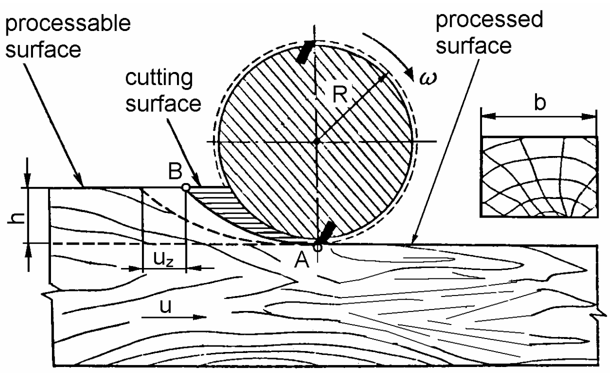

Fig. 1. Technological scheme of longitudinal milling [1]

Thickness of the cut layer h is a layer of wood removed by one movement. In the case of flat surfaces the thickness of the cut layer is the same over the whole width of a wood sample. Meanwhile, in the case of profiling it may change.

Milling width b is equal to the width of the processable wood sample. Usually this characteristic is called as processing width.

Feeding per cutting u_z is a distance between two adjacent cutting trajectories, measured parallel to the vector of feed speed. It is one of the most important milling regime characteristics. Feeding per cutting u_z and the number of knives z predetermine the size of feeding per one rotation:

$$u_v = u_z z\,, \tag{1}$$

where u_v is feeding per one tool rotation (mm), z is number of cutting edges in a cutting tool.

Knowing feeding per cutting u_z or one rotation u_0, feed speed u (m/min) can be found:

$$u = u_v n = \frac{u_z zn}{1000}\,. \tag{2}$$

Cutting speed v is the main characteristics of the cutting process. Mathematically cutting speed $\bar{v}$ is a geometrical sum of cutting speed vector $\overline{v_0}$ and feeding speed vector $\bar{u}$:

$$\bar{v} = \overline{v_0} + \bar{u}\,, \tag{3}$$

where v_0 is linear speed of the cutting tool, (m/s).

However, when cutting wood, feed speed u is always considerably less than linear speed v_0 of the cutting tool. Therefore, practically it is accepted

$$v = v_0 = \frac{(\pi Dn)}{60 \times 1000}\,, \tag{4}$$

where D is cutting diameter (mm), n is number of rotations of the tool (min^{-1}) [1].

EXPERIMENTAL

Studies on surface roughness after longitudinal milling were carried out. Birch wood samples with dimensions of (1000 × 100 × 45) mm, average humidity ω = 9.5 % and average number of annual growth rings per 1 cm equal 6.04 were selected. Initially samples were preconditioned at temperature t = 18 ±2 °C and relative humidity of ψ = 60 ±5 % for 30 days.

Table 3. Matrix of experiments

Cutting speed v, m/s	Feed per cutter u_z, mm			
	0.50	1.00	1.50	2.00
	Feeding u, m/min			
40.8	4.00	8.00	11.0	15.0
31.2	3.00	6.00	8.50	11.5
22.4	2.00	4.00	6.00	8.00

As changeable factors were chosen: rounding radius ρ (μm) of the cutting edge feed u_z (mm) and cutting speed v (m/s). Evaluating these factors, a matrix of experiments was constructed (see Table 3).

For the studies, three knives from special steel 85X6NFT were prepared, with dimensions of (60 × 40 × 3.0) mm, while cutting edge rounding radius ρ = 6.57; 20.4 and 40.0 μm (see Fig. 2). Cutting edges of the knives were modeled artificially, i.e. a sharp knife was made blunt by abrasing into marble plate. Actual ρ values were ascertained by the method of lead imprints using a microscope and a digital camera.

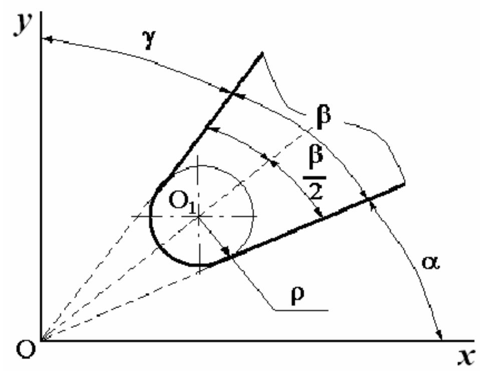

Fig. 2. Microgeometrical parameters of the cutting tool

The stand was created on the basis of planer – thicknesses machine. Modernized cutting and feeding mechanisms, three levels of speed were obtained, i.e. 22.4; 31.2 and 40.8 m/s, and a necessary range of feed speed – 2…15 m/min. Two knives were mounted on the shaft. However, only one took part in the cutting process [14]. Feed height of the working table was measured by an indicator. Thickness of the layer cut during one movement h = 2.0 mm.

Roughness of the processed surface was estimated by $Rm_{\max}$ (μm) parameter. The greatest and the smallest heights of roughness S_1 and S_2 were measured with microscopes MIS-11 and TSP-4M. Measurement error failed to exceed 5 %.

According to the requirements for the ascertainment of roughness parameters, not less than five measurements were conducted on the studied surface. One series contained 10 samples. Thus, actual number of measurements according to one set regime comprised 50. All experimental series comprised 1800 measurements.

The greatest height of roughness $H_{\max}$ was calculated according to formula:

$$H_{\max} = h = \frac{l}{N\sqrt{2}} = 10E(S_2 - S_1)\,. \quad (5)$$

Roughness parameter $Rm_{\max}$:

$$Rm_{\max} = \frac{1}{n}\sum_{i=1}^{n} H_{i\max}\,, \quad (6)$$

where n is the number of measured rough spots (units), $H_{i\max}$ is the height of i rough spot (μm).

RESULTS AND DISCUSSIONS

The research helped to determine the influence of the rounding radius ρ of cutter's blade, discharge for one cutter u_z and cutting speed v on the surface roughness of processed birchen wood $Rm_{\max}$.

The rounding radius ρ of cutter's blade showed the biggest influence on the surface roughness $Rm_{\max}$. The bigger the rounding radius ρ of blade gets (at any value of discharge for one cutter u_z (0.5; 1.0; 1.5 and 2.0 mm) and cutting speed v (22.4; 31.2 and 40.8 m/s), the worse the quality of the processed surface becomes (see Fig. 3), i.e. the values of surface roughness $Rm_{\max}$ get higher. The smallest surface roughness $Rm_{\max}$ was achieved when milling was done with sharp cutter ρ = 6.57 μm (see Fig. 3, a), while the biggest one was in case of blunt cutter ρ = 40 μm (see Fig. 3, c).

When the rounding radius ρ of blade increases from 6.57 μm to 40 μm, the numeral values of surface roughness $Rm_{\max}$ increase by 70 % on average. It is possible to state that when the rounding radius ρ of cutter's blade increases by 1 μm, the processed surface roughness $Rm_{\max}$ increases by 5 % on average. It is related to the attrition mechanism of the cutting tool. When the rounding radius ρ of blade increases, the width of cutting edge b (μm) also increases, and this effects the increase of the cutting force F_x (N). When the rounding radius ρ of blade radius the value of 30 μm, the cutter is considered to be blunt and has to be sharpened. If the rounding radius ρ of blade increases further, the undesirable process of sliding on the processed surface starts. The cutter's blade slides on the surface and makes it deformed and compressed. Under the influence of fiber's resilience, the surface damps the compressing effect of the cutter's blade. However, due to plastic deformation and residual deformation, in front of the cutter's blade the resilient layer of the wood is formed, and it rolls as a wavelet. When the strains of this surface layer reach the critical point, the decomposition process starts. If the fiber ruptures, the cutter's blade enters the wood. That is the end of sliding period and the beginning of the cut. During the cutting period the cutter's blade separate new and new layers by decomposing the fiber.

Due to the resilient changes that took place during the sliding period, the place of fiber abruption is remote much further from the cutting area. This causes the worsening of surface's quality; the fiber gets ruffled and fragmented. It is proved by the results received in case of the rounding radius of cutter's blade ρ = 40 μm (see Fig. 3, c).

According to the analysis of the results, when the cutting speed v is increased from 22.4 m/s to 40.8 m/s, (at any value of the rounding radius of cutter's blade ρ (6.57; 20.4 and 40 μm) and discharge for one cutter u_z (0.5; 1.0; 1.5 and 2.0 mm)), the surface roughness $Rm_{\max}$ gets smaller (see Fig. 4). When the cutting rate increases, the average thickness a (mm) of the cut shave decreases, as well as the cutting force F_x. The biggest surface roughness $Rm_{\max}$ was achieved when cutting speed v = 22.4 m/s, while the smallest was in case of v = 40.8 m/s.

When the cutting rate increases, the values of the surface roughness $Rm_{\max}$ get smaller on average: when the tool is sharp (ρ = 6.57 μm) – 8 % (see Fig. 4, a), when it is mid-blunt (ρ = 20.4 μm) – 20 % (see Fig. 4, b), and when it is completely blunt (ρ = 40.0 μm) – 17 % (see Fig. 4, c).

Fig. 3 shows the influence of the discharge for one cutter u_z on the surface roughness $Rm_{\max}$. According to the results, the bigger the discharge for one cutter u_z gets, the worse the quality of the surface roughness is. When the discharge for one cutter u_z increases, the average thickness a of the shave also increases, but the recovery of resilient fiber decreases. The shave may be cut down only when its average thickness a is significantly bigger than the rounding radius ρ of cutter's blade. This is proved by the received results. If the rounding radius of cutter's blade ρ = 6.57 μm, the values of the surface roughness $Rm_{\max}$

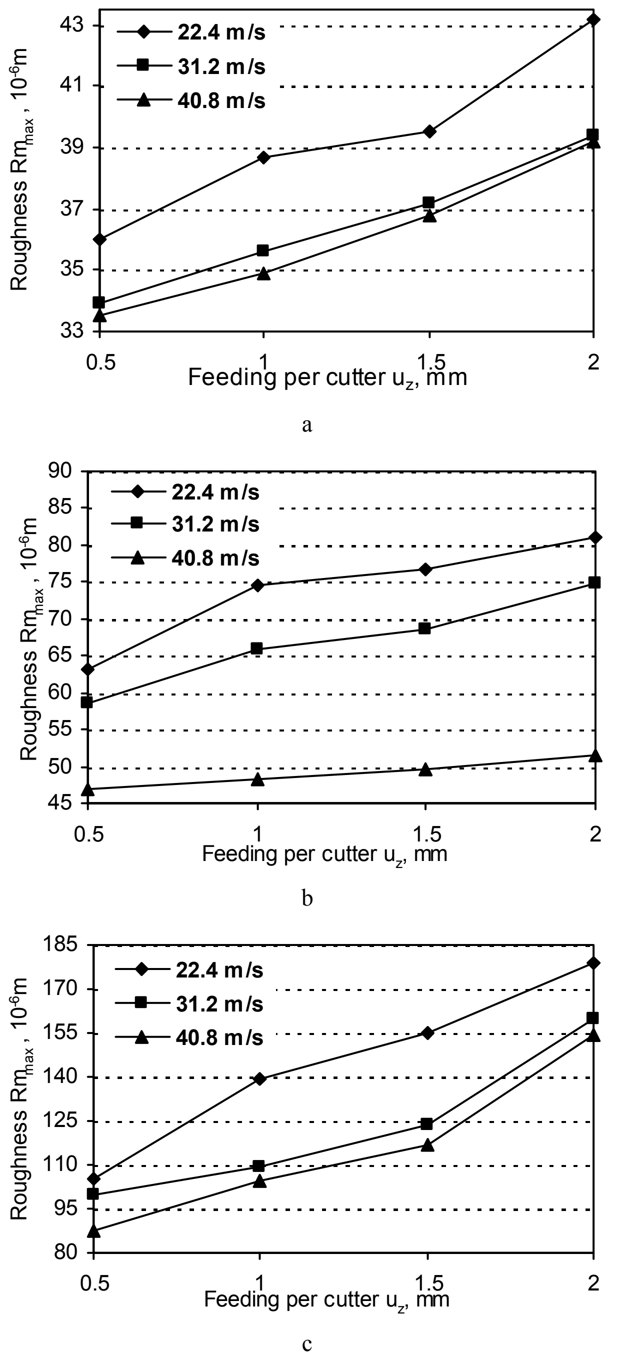

Fig. 3. Influence of feed per cutter u_z (mm) for different cutting speed (22.4; 31.2 and 40.8 m/s) on the roughness of processed surface Rm_{max} (μm): a – ρ = 6.57 μm; b – ρ = 20.4 μm; c – ρ = 40.0 μm

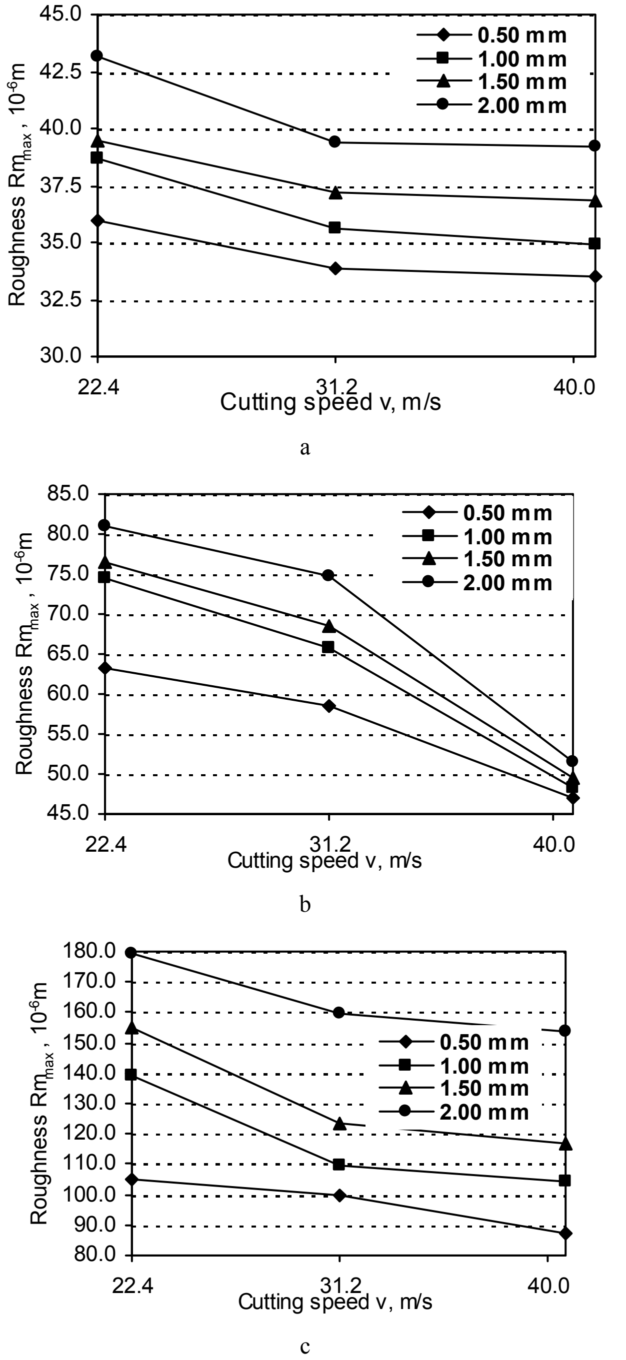

Fig. 4. Influence of cutting speed v (m/s) for different feeding per cutter (0.5; 1.0; 1.5 and 2.0 mm) on the roughness of processed surface Rm_{max} (μm): a – ρ = 6.57 μm; b – ρ = 20.4 μm; c – ρ = 40.0 μm

increases in case of exponential discharge for one cutter u_z from 0.5 mm to 1.5 mm (see Fig. 3, a and b). When the discharge for one cutter u_z = 2.0 mm, the numeral values of the surface roughness $Rm_{\max}$ are significantly bigger. This tendency repeats in case of other values of the rounding radius of cutter's blade ρ (20.4 μm and 40 μm). If the average thickness a of the shave increases, the wavelength l_b proportionally increases, as well as wave height h_b and cutting force F_x. In order to cut the wood, the bigger cutting force F_x. is used, and the process of shave formation is faster. The number of defects on the processed surface gets bigger. The surface becomes more wavy, fluffy, and ruffled; there are encountered nicks and bumps by the rings. This is proved by the results when the rounding radius of cutter's blade ρ = 40 μm (see Fig. 3, c).

When the results of experimental tests are compared with the results of other authors, it is possible to state that they observe the same regularities. The impact of the sort of wood, the rounding radius ρ of blade, and discharge for one cutter u_z is the same as in the work of Demjanovskyj [1]. However the numeral values of the surface roughness $Rm_{\max}$, determined by our experiments are smaller on average by 20 % if various factors are operating. This difference is regular because we have used for the tests the

Lithuanian birchen wood, which density is smaller, and the physical-mechanical properties are worse as compared to the wood that was growing in the northern Russian regions. If the influence of the cutting speed v on the roughness $Rm_{\max}$ is compared to the results of Costes and Larricq, the numeral values of our experiments are smaller on average by 12 %. It is regular because these authors have analyzed beech wood, and we have experimented with the birchen wood [12]. The birchen wood is on average softer by 7 %, i.e. its density is smaller. When our results were compared with Ohta and Kawasaki, who have analyzed the Japanese larch, the same influence tendencies of various factors were confirmed. The numeral values have not been compared in this case as the larch belongs to the coniferous group [11].

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

CONCLUSIONS

1. The bigger the rounding radius ρ of cutter's blade gets, the bigger the surface roughness of processed birchen wood $Rm_{\max}$ gets. The quality is the best when the sharp cutter is used ($\rho = 6.57$ μm), as the wood is cut and the spiral shave is formed. When the rounding radius ρ of cutter's blade reaches 40 μm, the wood is not cut, but deformed, compressed and pressed. The processed surface roughness $Rm_{\max}$ cannot satisfy the quality requirements any more.
2. The faster the cutting speed v gets, the better the quality of the processed birchen surface is, because the process of shave forming gets quicker and the wood is regularly cut, but not destroyed by compression. The quality is the best when the sharp cutter is used ($\rho = 6.57$ μm), and when the cutting speed $v = 40.8$ m/s.
3. When the feeding per cutter u_z is increased, the surface roughness $Rm_{\max}$ also increases. When the feeding per cutter u_z is increased, the average thickness of the shave a also increases. When the thickness of the shave a increases, the deep wood layers are not cut but torn. The quality is the best when the sharp cutter is used ($\rho = 6.57$ μm), and when the feeding per cutter $u_z = 0.5\ldots1.5$ mm.

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