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TOOL WEAR IMPACTS ON CUTTING POWER AND SURFACE QUALITY IN PERIPHERAL WOOD MILLING

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ABSTRACT

The aim of the research presented in this paper is to determine the impacts of tool wear on the cutting power and quality of the processed surface, as selected workability criteria for different peripheral milling regimes. The test was carried out on test samples made from beechwood (*Fagus silvatica L*) planks of uniform density and moisture content and without visible wood structure flaws. The tool wear in this paper was defined using the values of flank wear width before and after peripheral milling of beech samples. The dependences of the examined criteria (cutting power and surface quality) on the level of tool wear in different processing regimes were determined. On basis of the test results obtained, it can be concluded that tool wear undoubtedly significantly affects the cutting power and processed surface quality, which could be important when determining the cutting regime and the interval of tool replacement.

Key words: solid wood milling, tool wear, cutting power, surface quality

1. INTRODUCTION

The contact surfaces of tools in the machining process are exposed to high pressures and friction, which results in tool wear. Tool wear is one of the important factors in mechanical wood processing, since it directly affects surface quality, cutting forces, cutting power and energy consumption. The speed, intensity and character of the process of wearing cutting tools are influenced by: the material to be processed, tool material, tool geometry, the coefficient of friction, the temperature of the cutting zone, cutting speed, feed and depth of a cut, the static stiffness of the system, the dynamic behavior of the system and other technological processing conditions (Klamecki, 1979, Porankiewicz, et al., 2005, Ratnasingam, 2010, Ratnasingam et al., 2013, Nouari et al., 2003).

In general, indirect and direct methods can be used to measure tool wear (Castejón et al., 2007, Kurada and Bradley, 1997, Fadare and Oni, 2009, Danesh and Khalili, 2015). Some of the criteria for indirect tool wear measurement are: cutting power, cutting force, machined surface quality, deviation from the machining accuracy and the like. A more reliable way is to directly measure tool wear. One of the direct methods is measuring the loss of blade material due to mechanical, electro-chemical and temperature events during the cutting process. On the other hand, such measurements are highly complicated. A much simpler way is to measure the elements of wear, that is, to measure the changes in the geometry of the cutting wedge. Some researchers (Pahlitzsch and Sandvoss, 1970; McKenzie and Karpovich, 1975) found that changes in wear profile geometry are more closely related to the tool performance than to the amount of wear.

There are two main types of cutting tool wear that appear in the form of wear zones as flank wear and crater wear of the cutting wedge (Figure 1). The following cases occur depending on the technical conditions and processing regimes, i.e. depending on the dominant impact factors:

a) flank wear on the clearance surface is intense and the wear on the rake surface is poor, which means that the pressure on the clearance surface due to tensile stress relaxation is greater than the pressure of chip on the rake surface (figure 1a),
b) crater wear of the rake surface, the wear on the clearance surface is poor, which means that the pressure of the chip on the rake surface is greater than the pressure on the clearance surface due to tensile stress relaxation (figure 1 b),
c) intense wear on both surfaces of the cutting wedge (figure 1 c)

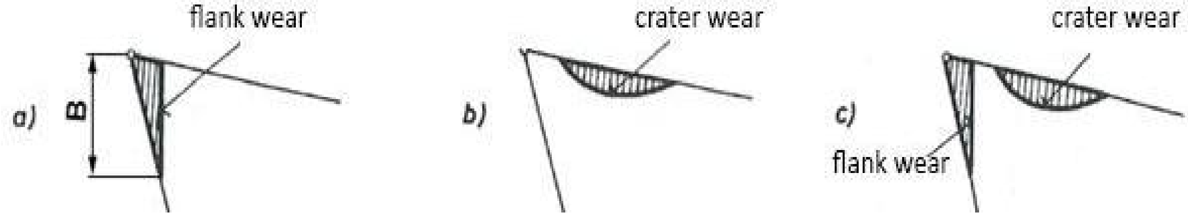

Figure 1. *Shapes and positions of the wear zones (flank and crater) on the cutting tool wedge*

The direct consequence of the tool wear is a gradual loss of its cutting ability in material processing, resulting in an increase of the cutting forces, and has an adverse effect on the quality of the processed surface (Itaya and Tsuchiya, 2003). The cutting force is directly related to the energy consumption (cutting power) during processing, that is, the greater the cutting force, the higher the energy consumption value (Orlowski et al., 2013, Aguilera and Martin 2001, Kovač and Mikleš 2010, Cristovao, 2013), which, in turn, incurs higher costs of processing.

The surface profile and roughness of a machined part are two of the most important product quality characteristics. Surface roughness is a widespread product quality index influenced by a number of factors such as processing conditions, tool wear, tool vibration, characteristics of the tool and workpiece materials, and technological parameters of processing which significantly affect product quality (Kilic et al, 2006, Lu, 2007, Csanadi et al, 2015,). The mechanism of creating surface profiles depends on the process of machining along with a number of other factors that are difficult to control, which makes it almost impossible to set an absolutely accurate prediction model for the achievement of the desired surface quality.

2. MATERIAL AND METHODS

A total of 10 radial beech (*Fagus silvatica L.*) wood planks were selected for testing, 150 mm in width, 30 mm in thickness and 1.100 mm in length and with no visible flaws in wood structure. From both ends of each of the planks, three test samples were produced for the laboratory testing of physical properties at the Laboratory for Wood Properties of the University of Belgrade Faculty of Forestry. Physical properties were tested in accordance with the standard for density determination (EN 323:1993) and the standard for determination of moisture content of wood-based panels (EN 322: 1993). The density and moisture of the boards were tested on a total of 60 samples with dimensions 50 x 50 x 30 mm.

The samples had been conditioned before testing in the laboratory environment conditions: relative humidity of 45 ± 5% and room temperature of 20 ± 3°C. These conditions brought samples to an equilibrium moisture content of 8 ± 1%, which is a standard recommendation for the values of moisture content for furniture in Serbian climatic conditions. The average beech samples density was 0.652 g / cm^3 in the oven-dry state, or 0.673 g / cm^3 with an average moisture content of 7%. In addition, the coefficient of variation of the measurement which is less than 5% indicates that there is no significant difference in the tested properties of the samples, and therefore there is no significant impact of density and moisture content on the tested criteria.

After cutting the samples for determining density and moisture, for the purpose of measuring the cutting power during peripheral milling, test samples were produced with dimensions 1000 x 150 x 30 mm. The machining regime was as follows: the speed was v = 38 m/s, the feed was u = 16 m/min and cutting depth was a = 4.5 mm. All experimental measurements were carried out at the Center for Woodworking Machines and Apparatus at the University of Belgrade - Faculty of Forestry. The cutting power was measured at each passing. The tests were repeated with a sharpened and blunt

milling cutter. After each fifth pass, for the purpose of measuring the processed surface roughness, a sample was cut out with dimensions 1000 x 30 x 10 mm. The cutting power was measured with a universal MiniMax machine equipped with a Maggi Engineering, Vario Feed device, which has the possibility of continuously changing the feed in the 3 to 24 m/min range.
The test was conducted by using a single-piece milling cutter D = 125 mm with four hard metal blades of width b = 40 mm with clearance angle $\alpha = 15^o$, rake angle $\gamma = 25^o$ and cutting angle $\delta = 65^o$ (figure 2).

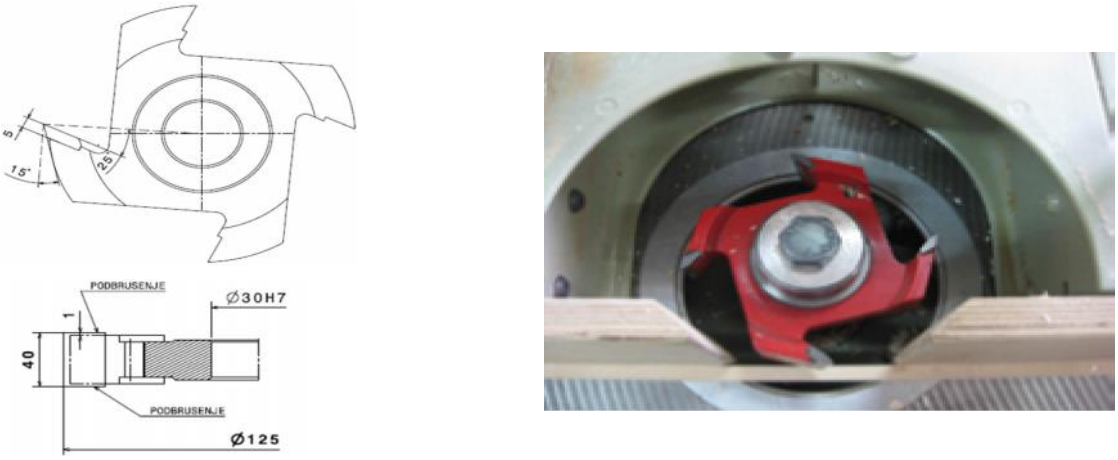

Figure 2. *A drawing and photo of the tool*

An SRD1 measuring device, which performs acquisition, analysis and processing of the obtained data, was used to measure the power. The device allows storage of data and enables later data display (figure 3).

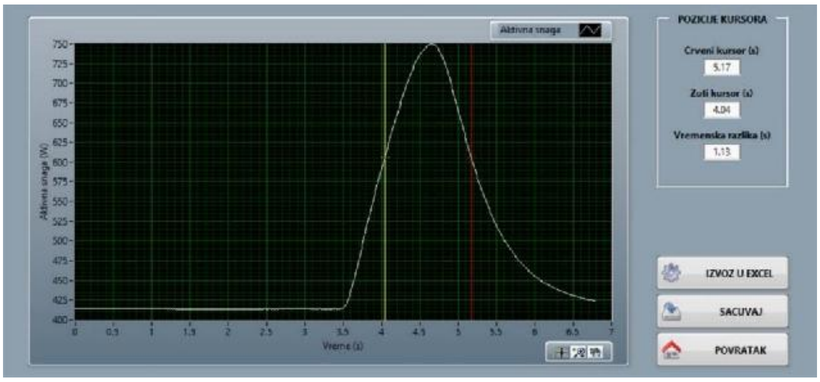

Figure 3. *The registered data interface in cutting power measurement*

The installation contains a CW-TAN wattmeter of the Circutor producer for unbalanced three-phase systems with the following characteristics: 300 V, 5 A, 230 VAC, 50 Hz with a 0.5% accuracy, with an analog 0-10 V output. The output signal is directly led to an acquisition card whose range can be adjusted (1, 2, 5 and 10 kW) depending on the power of the engine drive. The device uses the *Power Expert* software package, developed in cooperation with the Center for Woodworking Machines and Apparatus and the Unolux Company from Belgrade. The signals are software scaled and converted to real values with the corresponding units of measurement. The measuring device is portable and can be connected to different machines with a maximum power limit (of up to 10 KW).

The roughness of the processed sample surfaces was measured using a contact-mechanical roughness meter TIME3200 Surface Roughness Tester TR200 (figure 4a). The length of the needle movement path is determined in accordance with ISO 4288:1996, which provides for the selection of reference length and total length of observation based on the values of the basic roughness parameters. In accordance with the expected values for the roughness average (Ra) ($2 < Ra \leq 10$ μm), a reference length of 2.5 mm was selected, i.e. a total length of observation of 12.5 mm, for determining the roughness of the processed surfaces on the samples. At each passing of the milling cutter, changes in the cutting power were registered, and after each fifth pass, from the test plank for measuring the cutting power a test sample was extracted for processed surface roughness measurement at eight measuring points (figure 4b).

Figure 4. *TIME3200 roughness meter TIME3200 Surface Roughness Tester TR200 and surface roughness test sample*

The tool wear was measured using a Supereyes HD Digital Microscope B008 that has the ability to take photos, record, store and process data (figure 5). The camera software also has the ability to measure the length between two points, the angle between two lines and can automatically calculate the values of respective radii of registered circles.

Figure 5. *Digital microscope connected to a computer and the microscope*

The parameter through which the tool wear was defined in this paper is flank wear width (*B).* The flank wear width was measured in three different blade areas (figure 6).

Figure 6. *A blade with marked zones*

The length of the first zone (I) is 2 mm, measured from the beginning of the blade. The length of the second zone (II), which continues after the first one, is 3 mm, and the length of the central, third zone (III) is 30 mm. Ten measurements were performed in the first and second zones, five measurements at each of the two sides of the blade. Twenty measurements were performed in the third zone, which is the most active part of the cutting edge. The total number of measurements per blade was 40 and the procedure was repeated on all four blades.

3. RESULTS AND DISCUSSION

A total of 80 power measurements were performed, out of which 40 on a sharpened milling cutter and 40 on a blunted milling cutter. The measurements were divided into groups of 5, after which the test samples were taken for roughness measurement. Table 1 shows the results of cutting power measurement with sharpened and blunted milling cutters for the investigated cutting regimes.

Table 1. *The values of mean cutting power for the peripheral milling of beech wood*

Number of the group of measurement	Average cutting power values [W]	
	Sharpened milling cutter	Blunted milling cutter
1	662.64	695.69
2	715.29	669.47
3	524.34	658.16
4	526.29	653.97
5	523.66	662.81
Average	590.44	668.02

Apparently, the average cutting power values are lower in the peripheral milling with sharpened milling cutter, compared to the average cutting power values during peripheral milling with a blunted milling cutter.

Table 2 shows roughness measurement data with sharpened and blunted milling cutters for the investigated cutting regimes. The measurements were repeated after every five passes.

Table 2. *The values of the processed surface roughness during peripheral beech wood milling*

Number of the group of measurement	Average roughness values [μm]	
	Sharpened milling cutter	Blunted milling cutter
1	5,96	6,92
2	5,98	6,76
3	5,99	6,82
4	5,86	6,96
5	5,97	6.89
Average	5.96	6.87

As expected, the average roughness values are lower in the peripheral milling with sharpened milling cutter, compared to the average roughness values of the processed surface during peripheral milling with a blunted milling cutter.

Tables 3 and 4 show the mean flank wear widths of sharpened and blunted milling cutter before and after the completion of the experiment with a sharpened and blunted milling cutter.

Table 3. *Average values of the flank wear width of the sharpened milling cutter before and after the experiment*

Number of blade	Flank wear width [μm]					
	Before processing			After processing		
	I	II	III	I	II	III
Z_1	24.678	24.377	24.002	28.964	67.698	108.956
Z_2	25.804	23.596	25.987	28.976	59.876	109.787
Z_3	24.384	24.672	24.673	28.754	66.532	107.658
Z_4	24.981	24.479	24.941	27.543	61.256	116.507
Z_4	24.981	24.479	24.941	27.543	61.256	116.507
Average	24.96	24.28	24.90	27.56	61.84	116.73

Table 4. *Average values of the flank wear width of the blunted milling cutter before and after the experiment*

Number of blade	Flank wear width [μm]					
	Before processing			After processing		
	I	II	III	I	II	
Z_1	74.141	129.427	147.598	76.517	159.871	411.921
Z_2	87.517	130.833	156.118	88.476	175.894	389.267
Z_3	75.377	143.668	158.685	76.612	154.146	373.667
Z_4	52.601	147.368	156.789	56.233	163.022	327.031
Average	72.41	137.82	154.80	74.46	163.32	375.47

It is evident that the flank wear width is smaller before the processing, compared to the widths after the experiment with a sharpened and blunted milling cutter

The pictures below show an example of a cutting wedge flank surface on a milling cutter blade (with an indicated flank wear width) in the case of a sharpened and blunted blade (figure 7, figure 8, figure 9 and figure 10).

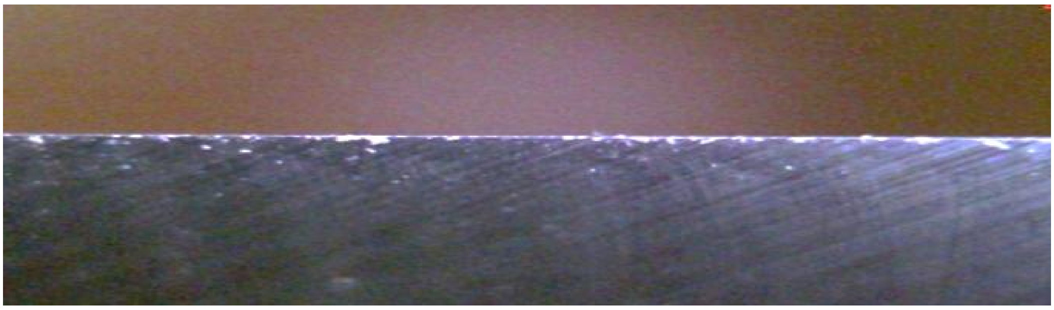

Figure 7. *A picture of a flank wear width on a newly sharpened blade*

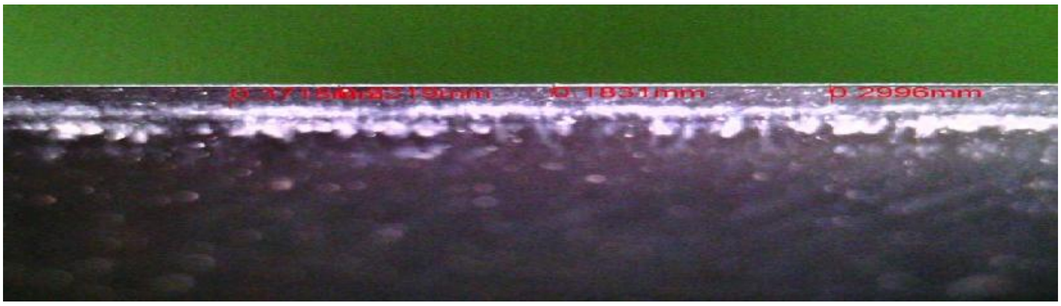

Figure 8. *A picture of a flank wear width after the experiment on a newly sharpened blade*

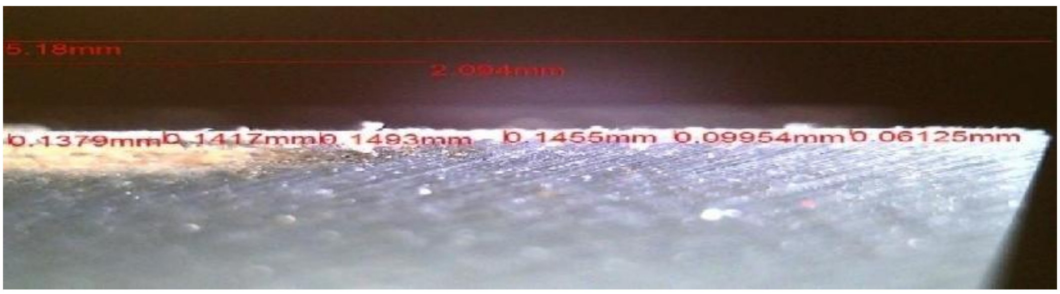

Figure 9. *A picture of the flank wear width on the blunted blade before starting the experiment*

Figure 10. *A picture of the flank wear width on the blunted blade after performing the experiment*

An electronic microscope was used to measure the radius of the blade (figure 11) at the cutting edge side in the case of a sharpened and blunted tool, which confirms the previously mentioned findings.

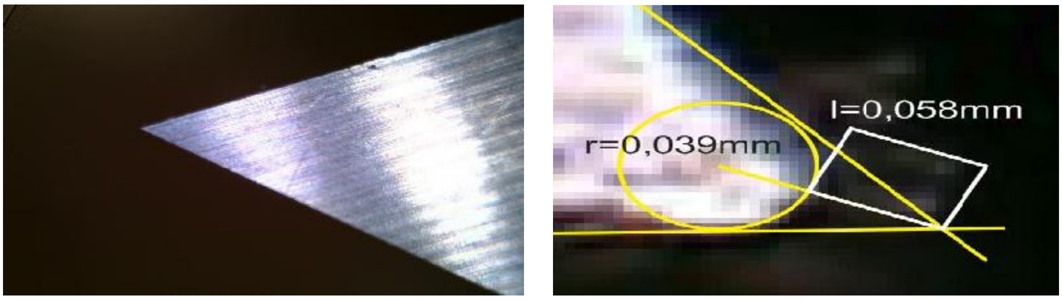

Figure 11. *Radius of the blade cutting edge*

It is evident that the flank wear width is smaller before processing, compared to the widths after the experiment. The highest values of the flank wear width were registered in the third zone, both before and after the material processing. Since the central part of the blade (third zone) is also the most active part, it is expected to be the most burdened part, and hence also to show the highest values of the tested wear parameter. The smallest wear was recorded in the first zone, which was expected, since in the process of material processing that part of the blade does not come into contact with the object of processing. The second zone located between the first and the third zones is partially loaded in the material processing, so the values of the flank wear width are expected to be in the ranges between the first and the third zone widths. These conclusions also apply to the situation from the beginning of the experiment, when the milling cutter was sharpened and when the experiment started with an already used milling cutter.

Table 5 shows parallel data on the average measured values of cutting power, processed surface roughness and flank wear width of the milling cutter blade

Table 5. *Summary average measurement results of the cutting power, processed surface roughness and blunting zone width of the milling cutter blade*

Starting with	Average cutting power	Average roughness of the processed surface
Sharpened tool	590.44	5.96
Already used tool	668.20	6.87
Difference [%]	13.17%	15.27%

The following can be concluded from Table 5:

- Tool wear causes an increase in cutting power. In this case it amounts to 13.17%;
- Tool wear affects processed surface roughness. In this case it amounts to 15.27%;

4. CONCLUSIONS

This paper shows that the applied measurement method can effectively be used to evaluate tool life in the wood cutting process, so that it can be applied in practice to monitor tool wear along with the monitoring of cutting power, and be used as a complement to that monitoring.

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