

IMPACT OF FEED RATE ON ROUGHNESS OF THE CUT SURFACE AND ENERGY CONSUMPTION DURING CUTTING DRY BEECH WOOD WITH A CIRCULAR SAW

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ABSTRACT

The feed rate during mechanical processing of wood is one of the factors that has a high influence on the roughness of the cut surface and energy consumption.

The roughness of the cut surface caused by traces of the cutting tool has an influence on the hydrothermal treatment and all other mechanical treatments of the wood. Greater roughness, due to faster evaporation of moisture from the wood, increases the percentage of drying errors. On the other hand, higher roughness values decrease the lumber yield.

Energy consumption is an indicator of the cutting resistance and it depends directly proportionally, or inversely proportionally when the thickness value of the sawdust is less than 0.1 mm. At the same time, the teeth do not cut the wood and they do not create sawdust but wood dust.

In this research, three different feed rates were applied ($U_1=12 \text{ m}\cdot\text{min}^{-1}$, $U_2=16 \text{ m}\cdot\text{min}^{-1}$ and $U_3=20 \text{ m}\cdot\text{min}^{-1}$) for a constant cutting height of 45 mm in dry beech wood with moisture content $W=10\pm 1\%$. The measurements were made with a circular saw with diameter of cutting tool $D=250 \text{ mm}$, number of teeth $Z=40$ and width of the cut $b=3,2 \text{ mm}$. The number of rounds was $n=5500 \text{ min}^{-1}$.

Roughness measurements were taken with a digital comparator, according to the R_{\max} criterion.

Measurement data for energy consumption were taken with a clamp amperemeter.

The obtained results showed a pronounced significance, directly proportional dependence of the roughness of the cut surface and energy consumption on the feed rate.

Key words: beech wood, circular saw, roughness, energy consumption, the feed rate.

INTRODUCTION

Circular saws are the most commonly used tools for mechanical wood processing, encompassing all production stages. Tool manufacturers in the market offer different types of saws with various diameters and different variety of numbers of teeth. Circular saws are also used for cutting other materials such as plastic, metal, ceramic, various types of construction materials, etc. (Djurkovic *et al.* 2017). When processing circular saws with the same diameter and the same peripheral cutting speed, the number of teeth actively participating in the cutting process per unit time differs. This significantly affects the thickness of the wood chips and the pressure on the teeth, especially on the back surface of the blade. (Paralidov *et al.* 2015) In the process of wood cutting, the cutting force and cutting power are the main output parameters, while chip length, chip thickness, tooth feed, tooth displacement, average kinematic. The secondary parameters are chip length, chip thickness, tooth feed, tooth displacement, average kinematic cutting angle, cutting speed, average pressure on the front side, and the fictive specific force on the rear side (Koljozov *et al.* 2019). The contact surfaces of the tools in the processing operation are exposed to high pressures and friction, resulting in tool wear. Tool wear is one of

the predominant factors in mechanical wood processing as it directly affects surface quality, cutting forces, cutting power, and energy consumption (Djurkovic *et al.* 2019).

The criteria that define the quality of the treated surface are surface roughness, machining accuracy, and durability. The traces from the processing due to machine vibration and the cutting tool, the structure, and the volume of the material being processed are part of the main cause for development of surface roughness. This occurrence caused by traces from the cutting tool has an impact on the hydrothermal treatment and all other mechanical processes of wood. In the processing and treatment of wood as an anisotropic material, some significant prerequisites for wood quantity (utilization) and quality can be highlighted: cut width, feed speed, and energy consumption. The cut width depends on the technical characteristics of the circular saw, while the feed speed depends on the technical and technological characteristics of the machine.

The feed speed in mechanical wood processing is one of the factors that significantly affects the roughness of the cut surface as well as energy consumption.

RESEARCH OBJECTIVES

The objective of this research is to determine the dependency of feed speed on the roughness and energy consumption in the process of cutting dry beech wood with a circular saw, with the aim of identifying optimal cutting conditions to achieve lower values of roughness and energy consumption.

MATERIALS AND METHODS

MATERIALS

For the purpose of this research, sawn beech lumber (*Fagus sylvatica* L.) without defects, with dimensions of 1500x150x15 mm, was used. All the sawn lumber was dried and conditioned. The average measured moisture content of the beechwood was 9.32%. Samples with a constant cutting height of 45 mm were cut from the boards.

METHODS

The research on the samples was conducted using a format circular saw machine, type NIKOLAIDIS TEMA 3800. The primary characteristic of this machine is that both the main and auxiliary movements are performed by the cutting tool. During the cutting process, the workpiece is held down with a pneumatic pressure beam. In this research, three different feed speeds were applied ($U_1=12 \text{ m} \cdot \text{min}^{-1}$, $U_2=16 \text{ m} \cdot \text{min}^{-1}$, and $U_3=20 \text{ m} \cdot \text{min}^{-1}$). Measurements were taken using a circular saw with a diameter of $D=250 \text{ mm}$, a tooth count of $Z=40$, and a kerf width of $b=3.2 \text{ mm}$ (Fig. 1). The rotational speed was $n=5500 \text{ min}^{-1}$. The cutting length for each sample was 1.2 m.

The roughness data were measured with a digital comparator, type Shane, according to the R_{max} criterion. For each sample (a total of 3), along a length of 1.0 m, 100 measurements were taken using a reference flange with a length of 100 mm (Fig. 2).

The current strength was measured with a voltage clamp, type MASTECH MS 2008B. For each sample (a total of 3), along a length of 1.0 m, 50 measurements were taken (Fig. 3).



Figure 1: Circular saw, $D=250$ mm, $Z=40$, $b=3.2$ mm



Figure 2: Digital comparator (for the surface roughness measurement)



Figure 3: Voltage clamp type MASTECH MS 2008B

RESULTS AND DISCUSSION

RESULTS OF ROUGHNESS MEASUREMENTS ACCORDING TO THE R_{MAX} CRITERION

Table 1: Results of roughness of beechwood samples at different displacement speeds ($U_1=12 \text{ m}\cdot\text{min}^{-1}$, $U_2=16 \text{ m}\cdot\text{min}^{-1}$ and $U_3=20 \text{ m}\cdot\text{min}^{-1}$), according to the R_{max} criterion

Displacement speed (U) for Z=40 and D=250 [mm]					
$U_1=12 \text{ [m}\cdot\text{min}^{-1}]$		$U_2=16 \text{ [m}\cdot\text{min}^{-1}]$		$U_3=20 \text{ [m}\cdot\text{min}^{-1}]$	
Cutting height h=45 [mm]		Cutting height h=45 [mm]		Cutting height h=45 [mm]	
Roughness	[mm]	Roughness	[mm]	Roughness	[mm]
Mean	0.0686	Mean	0.0708	Mean	0.0818
Standard deviation	0.0164	Standard deviation	0.0143	Standard deviation	0.0116
Coefficient of variation	23.84	Coefficient of variation	20.26	Coefficient of variation	14.18
Minimal value	0.044	Minimal value	0.047	Minimal value	0.063
Maximal value	0.118	Maximal value	0.108	Maximal value	0.113

The mean values from the measurements showed an increasing trend with increasing displacement speed. The standard deviation and the coefficient of variation showed sufficient resemblance of the measurement data.

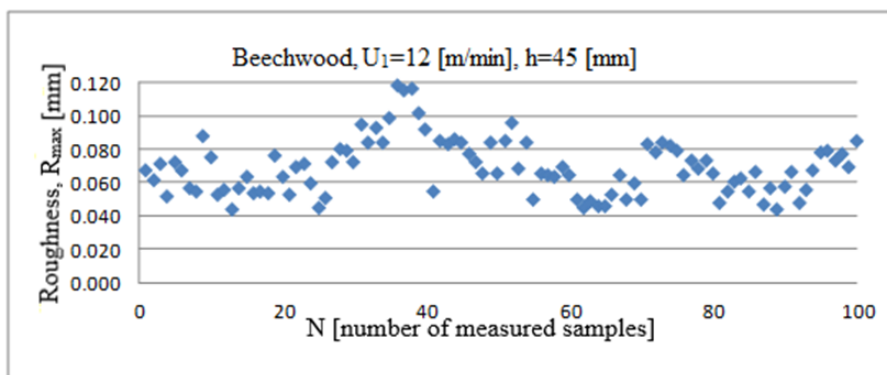


Figure 4: Roughness of the cut surface of beechwood samples at displacement speed $U_1=12 \text{ m}\cdot\text{min}^{-1}$

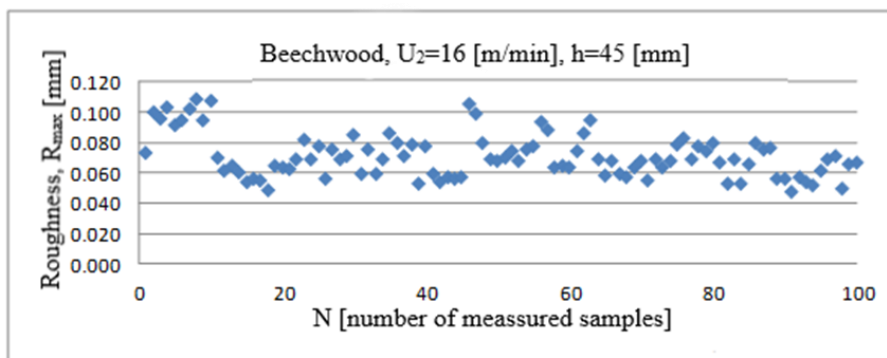


Figure 5: Roughness of the cut surface of beechwood samples at displacement speed $U_2=16 \text{ m}\cdot\text{min}^{-1}$

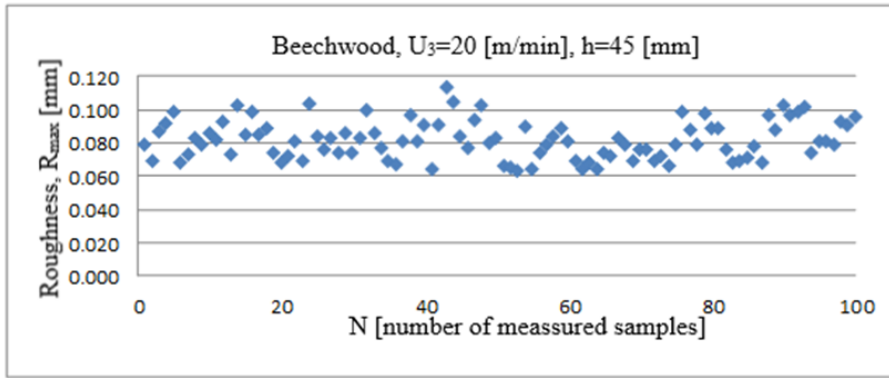


Figure 6: Roughness of the cut surface of beechwood samples at displacement speed $U_3=20 \text{ m}\cdot\text{min}^{-1}$

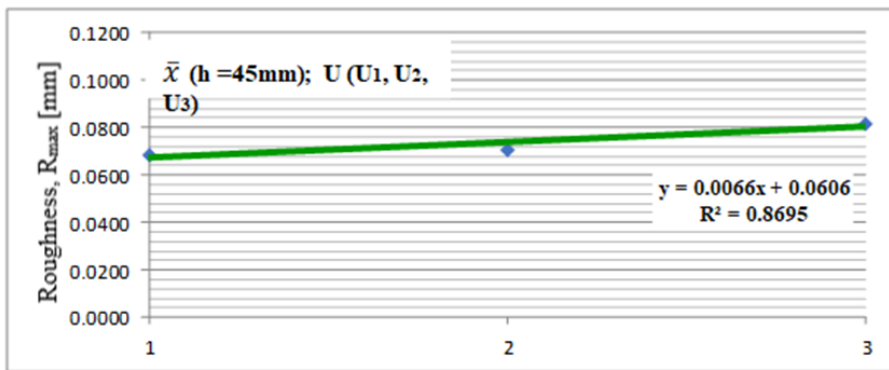


Figure 7: Regression analysis of the mean roughness values at all three displacement speeds ($U_1=12 \text{ m}\cdot\text{min}^{-1}$, $U_2=16 \text{ m}\cdot\text{min}^{-1}$ и $U_3=20 \text{ m}\cdot\text{min}^{-1}$)

From the presented results (table 1, Fig. 4, 5, 6 and 7), it can be concluded that with an increase in the speed of movement, the roughness of the cut surface increases directly. The dependence is expressed mathematically by the regression equation $y=0.0066x+0.0606$ and the correlation coefficient $R^2=0.8695$. Regression analysis showed that the measurements were best fitted to a line equation. The correlation coefficient shows high dependence.

RESULTS OF THE MEASURED VALUES FOR CURRENT STRENGTH

Table 2: Results of current strength of beechwood samples at different displacement speeds ($U_1=12 \text{ m}\cdot\text{min}^{-1}$, $U_2=16 \text{ m}\cdot\text{min}^{-1}$ and $U_3=20 \text{ m}\cdot\text{min}^{-1}$)

Displacement speed (U) for Z=40 and D=250 [mm]					
$U_1=12 \text{ [m}\cdot\text{min}^{-1}]$		$U_2=16 \text{ [m}\cdot\text{min}^{-1}]$		$U_3=20 \text{ [m}\cdot\text{min}^{-1}]$	
Cutting height h=45 [mm]		Cutting height h=45 [mm]		Cutting height h=45 [mm]	
Current strength [A]		Current strength [A]		Current strength [A]	
Mean	8.127	Mean	8.918	Mean	10.667
Standard deviation	0.8666	Standard deviation	0.9543	Standard deviation	1.1500
Coefficient of variation	10.66	Coefficient of variation	10.70	Coefficient of variation	10.78
Minimal value	6.860	Minimal value	7.490	Minimal value	8.960
Maximal value	9.800	Maximal value	10.700	Maximal value	12.802

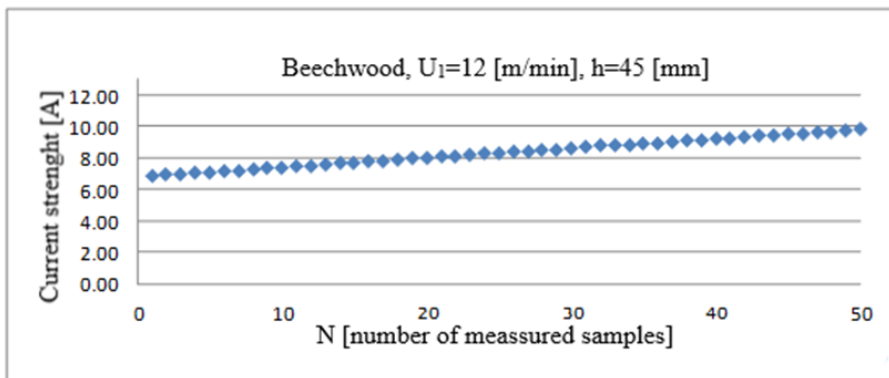


Figure 8: Current strenght of the cut surface of beechwood samples at displacement speed $U_1=12$ m·min⁻¹

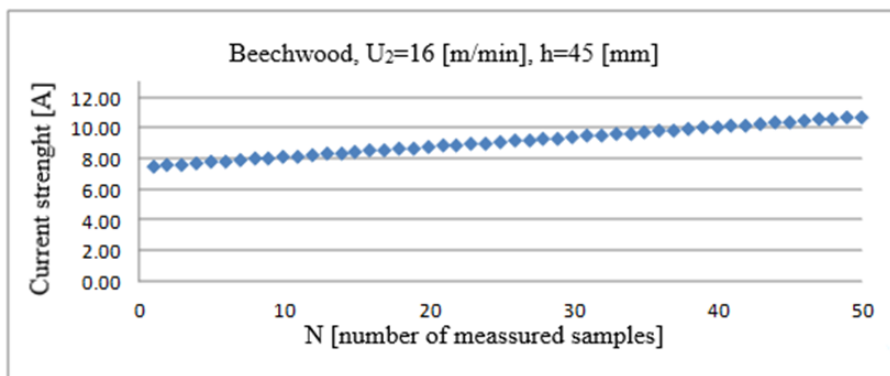


Figure 9: Current strenght of the cut surface of beechwood samples at displacement speed $U_2=16$ m·min⁻¹

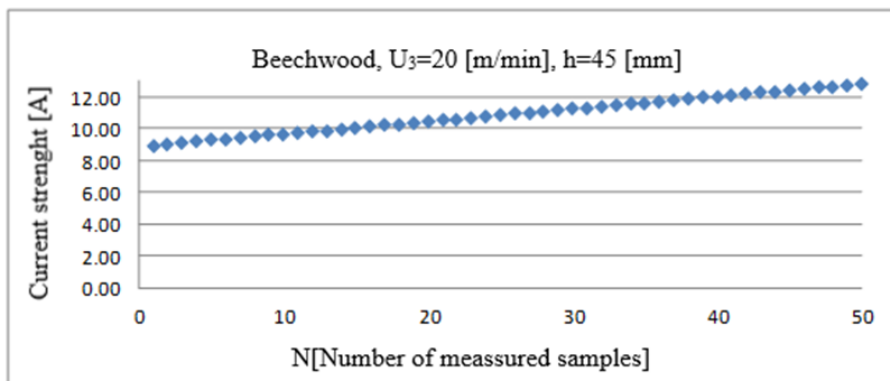


Figure 10: Current strenght of the cut surface of beechwood samples at displacement speed $U_3=20$ m·min⁻¹

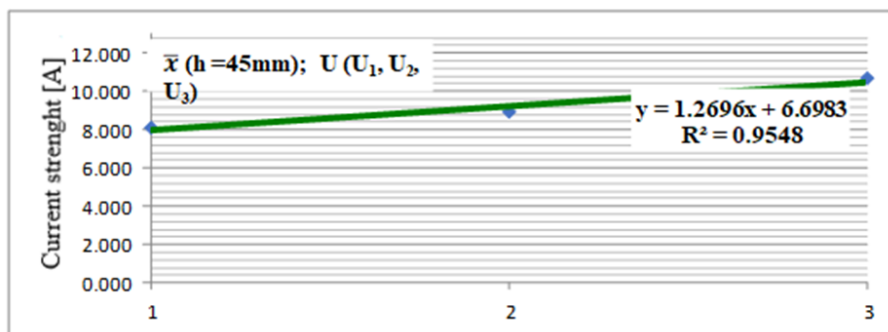


Figure 11: Regression analysis of the mean current strength value at all three displacement speeds ($U_1=12 \text{ m} \cdot \text{min}^{-1}$, $U_2=16 \text{ m} \cdot \text{min}^{-1}$ и $U_3=20 \text{ m} \cdot \text{min}^{-1}$)

The measurements of the current strength showed a gradual increase in the electric current flow, in all analyzed cases. This finding is clearly seen in Fig.8, 9 and 10. The mean values of the measurements showed an increase in relation to the increase in displacement speed. The regression analysis of the mean values from the measurements at different displacement speeds (U_1 , U_2 and U_3) showed that their dependence is best adapted to a straight-line equation $y=1.2696x+6.6983$, with a high correlation coefficient $R^2=0.9548$ (Fig.11).

CONCLUSIONS

According to the reviewed professional and scientific literature that was at our disposal, it was obtained that all authors agreed in the statement that with the increase in the displacement speed, the roughness of the cut surface increases, regardless of the type of mechanical processing. The causes mentioned for the occurrence of the deep uneven surfaces were: the geometric characteristics of the cutting tool, the type of wood, the vibration and tool wear, moisture content of the wood, the temperature of the wood, the thickness of the wood chips per tooth, etc. (Klincarov, Trposki, Koljozov 2000, Trposki, Klincarov, Koljozov 1999).

From the results shown, as well as from the reviewed professional literature, it can be concluded that with the displacement speed increase, the flow of electric current increases. The flow of electric current at high displacement speeds also caused increased vibration of the cutting tool, which unnecessarily increases the width of the cut. This causes an additional load on the electric motor, its heating, but also a reduction in the number of revolutions (Koljozov *et al.* 2012, Paralidov 2014). Low feed rates compared to high feed rates gave a better quality of the cut surface, but the productivity of the machine decreased.

It is very important to determine the optimum feed rate value to obtain favorable productivity and surface quality. In this research, the dependence of the displacement speed on the roughness of the cutting surface and energy consumption was confirmed.

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