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EXPERIMENTAL RESEARCH CONCERNING THE WEAR OF THE MILLING EDGES UPON THE QUALITY OF WOOD SURFACES

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Abstract: *The objective of the present paper is to present some experimental results regarding the behavior of the profiled milling edges geometry during the milling process. The both phenomena regarding the processing surfaces quality and the edges milling geometry depends on the milling wear process. Five species of wood were analyzed, namely fir (Abies), poplar (Populus), oak (Quercus), maple (Acer Pseudoplatanus) and beech wood (Fagus Sylvatica). They were, subjected to profiled milling using various cutting conditions. For each of the three rotation speeds of the cutting tool, three feeding speeds were applied. The roughness of the samples was measured using laser beam method, the measuring direction being perpendicular to the wood grain. The results presented in the present paper were analyzed on the convex surface of the profile in three stages of the cutting edge wear. The obtaining conclusions on the experimental data regarding the profile surface quality could be extended on defining the milling edges geometry evolution in milling processing.*

Keywords: *profile milling, milling edges, roughness, surfaces quality, wood species, cutting conditions, cutter head, laser beam.*

1. INTRODUCTION

Milling is one of the most important wood processing operations. This fact leads the researchers to consider studies and analysis of the quality of the wooden components after milling straight or profiled surfaces.

Profiled milling of the wood involves numerous peculiarities compared to classical milling (of plane surfaces), so it can be classified as a special milling operation.

One of the factors of influence upon the quality of the profiled surfaces obtained by milling operation is represented by the wear degree of milling cutting edges.

The difficulty in analyzing the roughness of the profiled surfaces occurs because of the required specialized equipment, not enough developed in this field and the lack of technical specifications for wooden surfaces analysis. A multitude of studies are also oriented to analyze the quality of the flat sanded surfaces (Brenci et al., 2011:21-29) or coated ones. A distinct particularity when analyzing the wooden surfaces is defined by the non-homogenous structure of the wood in comparison with other materials (as metal), fact that make the process of the surface quality assessment and the interpretation of the results more difficult to be done. The most difficult problem in assessing the roughness of the wooden surfaces occurs in the case of complex profiles (concave or convex ones), formed in the connection of various sizes of shapes and surfaces (Brenci et al. 2008:67-74), (Brenci et al., 2009:0413-0415) and (Fotin et al., 2009:45-52). Other factors that have influence on the quality of the wooden surfaces are represented by the depth of the chip removal, direction of processing (depending on the direction of the grains orientation), wood moisture content, the non-homogenous anatomy of the wood, the parameters of the milling conditions (Fotin et al., 2010:269-274), etc.

The problem of an accurate analysis of the wooden surfaces quality is also connected to the type of equipment used to measure the roughness, appropriate for a more accurate determination. If the measurement of the roughness of the flat surfaces could be done both by the roughness equipment with mechanical contact (diamond peak) and by those without mechanical contact (laser beam and light beam), is not the case of the profiled surfaces measurement, where only equipment without mechanical contact can be used.

In order to study this influence in the case of profiled milling of wood, the behaviour of five different wood species was analyzed under different cutting conditions.

2. MATERIAL AND METHOD

The aim of this paper was orientated to the following research work:

- qualitative analysis of the roughness of the profiled surfaces obtained by milling five samples made of different wood species. The assessment was performed in three processing stages, as function of the profile shape and position:
    - at the beginning of processing;
    - in wear conditions after cutting over 600 linear meters of wood;
    - in wear conditions after cutting over 1000 linear meters of wood;
- study of the behaviour of the cutter edge geometry (clearance angle, hook angle, sharpness angle, profile angle, backing-off angle and side relief angle) under conditions of gradually increasing wear.

The material used within the experiments consisted of samples cut from five different wood species: fir (Abies), poplar (Populus), oak (Quercus), maple (Acer pseudoplatanus) and beech (Fagus sylvatica). These specific wood species were chosen considering the following criteria:

- fir, beech and oak are the most widely spread wood species within the Romanian forest areal (Zlate, 1990);
- poplar was selected due to its short growth period (25÷30 years) (Zlate, 1990), in comparison with other wooden species (beech 120÷130 years, oak and fir 120÷140 years).
- maple was choosed to create a comparison criteria for beech, taking into consideration that both species are hardwoods with uniform structure and close density values.

The machine used within the experiments to process the wooden species was a vertical milling machine, endowed with a mechanical feed device. A milling cutter head with four profiled cutters was used in the experiments, having the following characteristics: outer diameter D = 178 mm, width B = 40 mm, clearance angle $\alpha = 25^0$, sharpness angle $\beta = 47^0$, hook angle $\gamma = 18^0$ and side relief angle $\alpha' = 3^0$.

The value of the side relief angle was adopted according to reference literature (Dogaru, 2003), so to eliminate friction between the processed part and the cutter edges.

The processed samples had the following characteristics: radial section, humidity between 8÷10 %, length 1000 mm, thickness 50 mm and cutting was performed along the grains.

For a more precisely comparison analysis, the authors considered that it is necessary for each processed sample to accomplish to the different cutting conditions, according to the indications in Table 1.

The variable parameters within the research were: wood species, cutting speed, feed speed (see Table 1), wear of the cutting edges and values of the side relief angle. The roughness of the processed surfaces was chosen as reference parameter, defined as the average value of the maximum height of the irregularities, H_m.

Tabel 1. The cutting condition for all five wooden species

Wooden species	Rotation speed		
	n = 3300 [rot/min] n = 4852 [rot/min] n = 6594 [rot/min]		
	Feed speed [m/min]		
Fir	6.5	12.7	23.7
Poplar			
Beech			
Oak			
Maple			

According to the literature in the field (Dogaru, 2003), the average value of the deviation of the maximum height of irregularities H_m, equals with the maximum irregularities average which was measuring from the top to the bottom of the profile.

$$H_m = \frac{H_{\max 1} + H_{\max 2} + \ldots + H_{\max n}}{n} \quad [\mu m]$$

After milling processing the samples were cut into test samples with the following dimensions: length 60 mm, width 50 mm and weight 20 mm (Fig. 1).

Fig. 1. Test samples for measuring the roughness

Using the laser beam equipment for the qualitative assessment of the irregularities height H_m placed on the surfaces situated perpendicularly to the laser beam direction and assessing the quality of all profiled surfaces, the fidelity of roughness comparison for the same profile type was maintained.

The laser beam equipment works with the following technical specifications:

- laser beam moving angle: 0.036 degree;
- frequency for each measuring operation: 750 Hz.

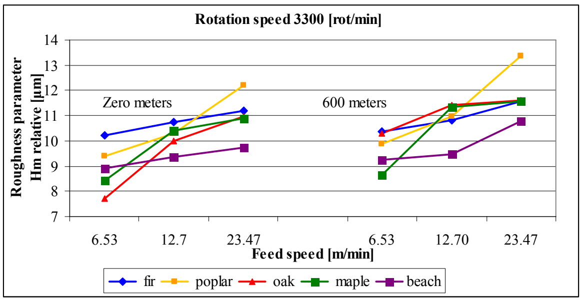
For an accurate analysis of the roughness of the processed surfaces, five samples were measured from each species of wood and five measurements were done for each sample.

The measurements were carried out in three stages: at the beginning of milling process, when the cutting edges compiled with the best quality conditions; after the wear of the milling cutter occurred by processing over 600 linear meters of wooden material and after the wear of the milling cutter occurred by processing over 1000 linear meters of wooden material.

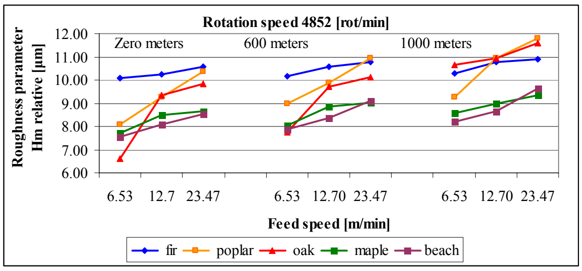
The profiled surface of the test samples was scanned by the laser beam in 3045 points, over a length of 40 mm and 16 mm in depth. After this operation was performed, the measured data were downloaded and processed by the computer and transformed the obtained results into two types of files: DXF files and TXT files for defining the position and the coordinates of the points defining the profile; coordinates of the laser beam, as well as its relative angle to the test sample.

3. RESULTS AND DISSCUSSION

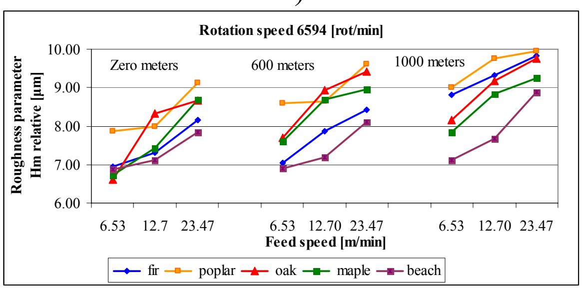
The experimental results regarding the influence of the cutting conditions and tool wear upon the quality of the profiled surfaces are presented in figure 2. All three diagrams refer to the same convex surface, represented by point "e" (Fig. 3). As noticed, the ordinate-axis (Y) in the diagram presented in Fig. 2. shows the relative roughness H_m. This is because the laser beam scanned inevitably under a certain angle (not perpendicular) to the analysed surfaces. Therefore, was considered that "relative roughness" is the most appropiate term for this case. The coclusions of this work were not influenced by this term because they were set out by comparison of the same types of profiles.



a)



b)



c)

Fig. 2. Influence of the cutting conditions upon the roughness of a convex surfaces
a – processing with a rotation speed of 3300 rot/min; b - processing with a rotation speed of 4852 rot/min; c - processing with a rotation speed of 6594 rot/min

Analyzing the diagrams presented in Fig. 2, in the situation of using wear cutters for milling operation ($\rho_0 \geq 40$ µm), the roughness of the surfaces increases drastically for all species of wood, being more evident for resinous wood and especially for poplar wood (having a high pilling degree – Fig. 4 and Fig. 5). In the area of the profile with a contour angle $\varepsilon < 10^0$ resulted after milling operation, the roughest surfaces were obtained, together with grains tearing and failures and even small marks of wood burns. The grains tearing and failures were observed especially to the soft species of wood and the burn marks were observed especially to hardwood.

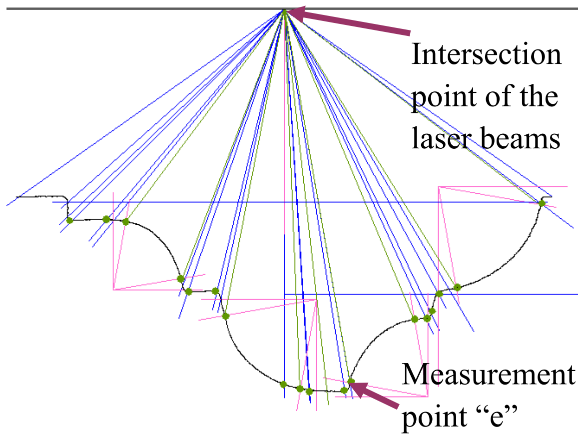
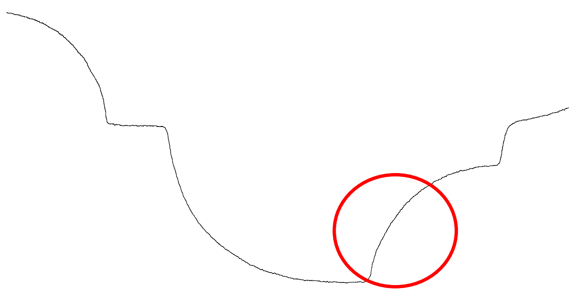
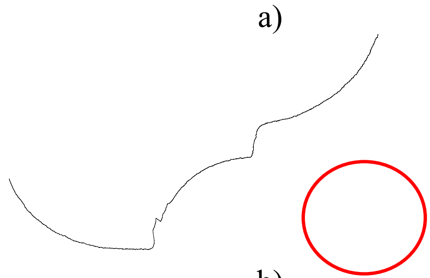


Fig. 3. Indication on the sample drawing of the measuring and roughness evaluation area



a)

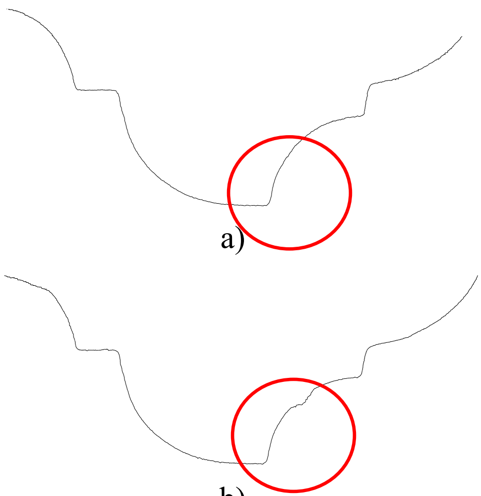


b)

Fig. 4. Convex surface of poplar (rotation speed = 4852 rot/min and feed speed = 23.74 m/min)

a – after processing over 600 linear meters of wooden material; b – after processing over 1000 linear meters of wooden material

Due to the wear of the milling cutter, high values of the roughness were registered for oak wood, which also has apart structure.



a)

b)

Fig. 5. Convex surface of fir
(rotation speed = 4852 rot/min and feed speed = 23.74 m/min)
a – after processing over 600 linear meters of wooden material; b – after processing over 1000 linear meters of wooden material

The most stable behavior (identified by low values of the roughness) was registered for beech wood compared with the other species of wood, no matter of the wear stage of the milling cutters or of the processing conditions, due to its homogeneous structure.

Another factor of influence regarding the roughness of profiled surfaces is the variation of the clearance and hook angles over the profile height. Having a view to the tool design, the angular values of the cutter edges in case of profiled cutters should vary with the profile shape and according to the processed wood species.

It was also concluded that the tools sharpening has to be done in case of profiled milling of over 600 meters of soft species of wood if low values of the roughness are to be obtained (for cutters made of rapid steel).

4. CONCLUSIONS & ACKNOWLEDGMENT

As the results of the experiments made on the five species of wood processed using various cutting parameters, it was concluded that the side relief angle of the profile angle have influence upon the quality of the profiled surfaces. After analysing the diagrams, the following conclusions regarding the geometrical characteristics of the profiled milling cutters are to be emphasized:

- If a modification of the wooden profile is not possible within the areas where the profile angle ranges between 0^0 and 8^0, it becomes compulsory to back-off the edges: $\tau>2^0$, higher values being indicated only for soft species;
- In order to maintain unmodified the clearance and the hook angle over the height up to 30mm should be processed;
- The side relief angle α', with profile angles $\varepsilon < 10^0$ specific to surfaces which lie perpendicularly to the rotation axis, must range between 5^0 to 9^0, depending on the wood species (higher values for soft hardwoods and resinous woods);
- For high or deep profiles, the following values of hook and clearance angle are recommended: $\gamma_{max} = 15^0$-20^0 (depending on wood species and the material the tool in made of) and $\alpha = 10^0 – 16^0$.

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