

INFLUENCE OF MAIN PARAMETERS OF THE MILLING PROCESS ON THE ROUGHNESS WHEN PROCESSING SOLID WOOD OF MERANTI

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Abstract:

*The paper presents experimental results related to the influence of the main parameters of the solid wood milling process - feed speed v_f and uncut chip thickness a_e , on the roughness of the obtained surfaces during the processing of tropical meranti wood (*Shorea leprosula*). They are part of a more extensive study by the authors, which also applies to other wood species widely used in furniture production - Scots pine (*Pinus Sylvestris*) and beech (*Fagus Sylvatica*). The machines used are three in total - two jointers and a planer. The jointers have a different construction of the cutting shafts - with flat knives and with helical cutterhead. The planer has a cutting shaft with flat knives. The studied parameter is R_z , and an electronic profilometer was used for its reading. The experiments were carried out in actual manufacturing conditions using the method of planned regression analysis. The levels of variation of the studied factors were determined on the basis of preliminary experiments, as well as the technical capabilities of the respective feeding mechanisms. Based on the obtained results, regression equations were derived that can be used to calculate the roughness depending on the feed speed and uncut chip thickness within the studied limits. Practical recommendations were made, and the results were compared with previous studies.*

Key words: Roughness; jointer; planer; cutting shaft; meranti.

INTRODUCTION

The quality of the surfaces is a main parameter that characterizes the wood milling process. Most often, it is determined by the roughness of the surfaces, but some authors of fundamental books in the field of wood cutting also define it as a set of parameters, to which the accuracy of the shape and dimensions should be added (Ivanovsky *et al.* 1972, Bershadsky *et al.* 1975). Basically, after processing the wood by milling, the measured parameter is R_z , which is the arithmetic mean value between the five highest protrusions and the five deep recesses within the limits of one base length (BDS 4622: 86, BDS EN ISO 4287:2006).

There are a number of factors that affect the roughness of milled surfaces. They can be summarized in the following groups:

- Factors related to the processed materials – anatomical characteristics, temperature, moisture content, direction of the wood fibers, etc.;
- Factors related to the cutting process – cutting speed and feed, milling thickness;
- Factors related to the geometrical and operational accuracy of the machine, linear and angular parameters of the cutting tools, the rate of their wear, etc.;
- Factors related to working conditions - temperature and air humidity, as well as the degree of qualification of the machine operator.

Currently, there are a large number of experimental studies that study the influence of the second group of factors on roughness. For example, the authors of the current paper studied the influence of feed speed and uncut chip thickness on the roughness in the processing of Scots pine and beech wood, some of the results of these studies have already been published and others are also to be published soon (Atanasov *et al.* 2022). There are also numerous studies by other authors that determine the influence of cutting modes

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on roughness, when milling different wood species (Korčok *et al.* 2018, Vitchev and Gochev 2018, Vitchev *et al.* 2018, Sandak *et al.* 2020, Rajko 2021 *et al.*, Vitchev *et al.* 2021).

Mainly because of its beautiful appearance and texture, as well as its good mechanical properties, meranti wood is increasingly used in the production of furniture, doors, windows and other wood products. No extensive studies have been found in the literature regarding the influence of cutting parameters on the quality of the surfaces obtained when milling meranti. This determines the aim of the present study: To determine the influence of basic parameters of the milling process - feeding speed and uncut chip thickness, on the roughness of the resulting surfaces. At the same time, with different types of machines, as well as cutting shafts with different construction.

METHODOLOGY

The experimental studies were carried out under actual manufacturing conditions in the companies *Vic Stroy Ltd* – town of Montana and *Pentop Ltd* – town of Varshets, which are specialized in the production of children's toys and seating furniture. Three longitudinal milling machines were used to conduct the experiments. Two jointers - with a cutting shaft with flat knives and with helical cutterhead, and a planer - with flat knives. The general view of the machines can be seen in Fig. 1, and some of their main parameters in Table 1. Shafts with different constructions mounted to longitudinal milling machines can be seen in Fig. 2.

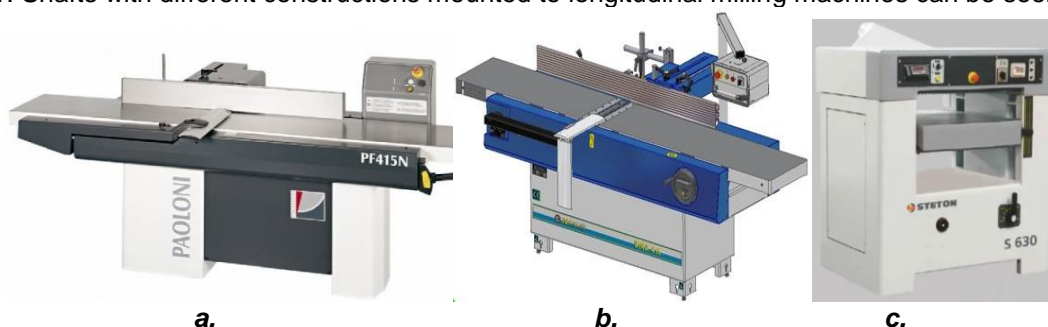


Fig. 1.

Title: General view of the studied machines

a – jointer with traditional flat knives (PAOLONI, PF415N, Italy- <http://www.paolonimacchine.it>); b – jointer with helical cutterhead (ZMM STOMANA JSC, DMA 41L, Bulgaria-<https://stomana.net>); c – planer with flat knives (STETON, S630, Italy-<https://www.steton.it>).

Table 1

Technical characteristics of the machines used

No	Model	PF415N	DMA 41L	S630
1.	Power of the electric motor driving the cutting mechanism, in kW	3	4	5.5
2.	Maximum milling width, in m	0.42	0.41	0.50
3.	Diameter of the knife shaft, in m	0.11	0.125	0.11
4.	Cutting diameter, in m	0.123	0.128	0.123
5.	Cutting speed, in m·s ⁻¹	32.2	31.5	30.5
6.	Number of flat blades/ *spatial screw lines	4	*3	4
7.	Sharpening angle of the cutting edges, in °	40	40	40



a.



b.

Fig. 2.

Title: General view of cutting shafts with different construction

a – cutting shaft with flat knives; b – shafts with replaceable carbide plates (helical cutterhead).

The test samples are from the tropical wood of meranti, which has a homogeneous structure, a minimal amount of defects and is increasingly used in the production of furniture, doors, windows and other wood products. In addition, the wood of this species is not inferior in mechanical properties to a large part of hardwood species, which grow in our latitudes (Sydor *et al.* 2022). The dimensions of the experimental samples are: cross-section 50^x50 mm and length 1500 mm. Their general view can be seen in Fig. 3.

The density of the wood was determined by measuring the dimensions using a caliper and tape measure, as well as the weight using an electronic scale. The moisture content is measured with a *Lignomat* moisture meter (Germany) and a contact thermometer.

To determine the levels of variation of the factors, preliminary experiments were carried out, taking into account the technical capabilities of the machines and their feeding mechanisms. Feed speed $v_f = 5, 10$ and $15 \text{ m} \cdot \text{min}^{-1}$ and uncut chip thickness $a_e = 1, 3$ and 5 mm were selected. Using a measuring indicator with a magnetic stand with an accuracy of 0.01 mm, the radii were also measured when mounting the flat knives on the machines whose cutting mechanisms have shafts with flat knives. Since, although to a lesser extent, the parameters of the work shops can also have an influence on the roughness, the device *MASTECH MS 6300* (China) was used, through which the temperature and relative humidity of the work rooms were measured.



Fig. 3.
Test samples.

The measurement of the surface roughness is in accordance with the standards BDS 4622: 86 and BDS EN ISO 4287:2006, and the measured parameter is *Rz*. Its reading was done with a profilometer *SJ-210*, *Mitutoyo*, Japan. Its general view can be seen in Fig. 4.



Fig. 4.
General view of profilometer SJ-210, Mitutoyo, Japan (<https://mitutoyo.eu>).

For the purposes of the study, a planned two-factor regression analysis was conducted. Since the methodology for its implementation is voluminous, it will not be presented in the current study, but can be seen in the literature. For example, in Vuchkov and Stoyanov 1986. In the current study, the results were processed using specialized software *QstatLab5*, as well as *Microsoft Excel*. The experimental matrix can be seen in Table 2. Factor level values are presented in explicit and encoded form. In order to better verify the results, additional experiments were conducted at average values of the levels of variation of the studied factors.

Table 2

Experimental matrix

№	v_f , in $m \cdot min^{-1}$	x_1	a_e , in mm	x_2
1.	15	+1	5	+1
2.	15	+1	1	-1
3.	5	-1	5	+1
4.	5	-1	1	-1
5.	10	0	3	0
6.	10	0	5	+1
7.	15	+1	3	0
8.	10	0	1	-1
9.	5	-1	3	0
10.	10	0	3	0
11.	10	0	3	0
12.	10	0	3	0
13.	10	0	3	0
14.	10	0	3	0

RESULTS

The arithmetic mean values for the measurements of the density and moisture content of the test samples are $W = 13\%$ and $\rho = 490 \text{ kg} \cdot \text{m}^{-3}$, and they apparently have a high degree of homogeneity and a minimal amount of defects. The average value of temperature and relative humidity in the workshops during the conduct of the experimental studies were $W_{r.p.} \approx 55 \%$ and $t \approx 19 \div 20 \text{ }^\circ\text{C}$. This shows that the conditions for the experiments are good and they would not have an adverse effect on the results of the experimental studies.

The resulting regression equations after mathematical processing with the specified software product are:

$$PF415N: R_z = 29.556 + 16.989v_f + 7.473a_e + 11.671v_f^2 + 7.925a_e^2 + 6.677v_f a_e; \tag{1}$$

$$DMA41L: R_z = 33.377 + 7.516v_f + 3.661a_e - 3.147v_f^2 - 3.175a_e^2 + 2.146v_f a_e; \tag{2}$$

$$S630: R_z = 25.275 + 5.083v_f + 2.527a_e + 2.095v_f^2 + 2.828a_e^2 - 0.648v_f a_e. \tag{3}$$

After obtaining the equations, a check for their adequacy was carried out. By comparing the calculated and the critical value of the Fisher criterion, it was found that the equations are adequate and can be used for the analytical determination of the roughness within the variation limits of the studied factors. From the equations, it is also observed that the feed speed factor has a greater influence on the objective function under study because the regression coefficient in front of it has a higher value. The mathematical signs in front of the coefficients of the two factors "+" show that as they increase, the output value will also increase.

Fig. 5 presents measurement results for the influence of the more significant factor (feed speed) on roughness at an average uncut chip thickness ($a_e = 3 \text{ mm}$). It shows that in the studied range, the roughness of the surfaces varies from ≈ 24 to $\approx 60 \text{ } \mu\text{m}$. Moreover, at lower feed speeds, the studied parameter increases significantly more slowly. For example, from a feed speed of $5 \text{ m} \cdot \text{min}^{-1}$ to $8.75 \text{ m} \cdot \text{min}^{-1}$, R_z only increased by $\approx 3 \text{ } \mu\text{m}$. Subsequently, the change in roughness is significantly more intense. This trend is even

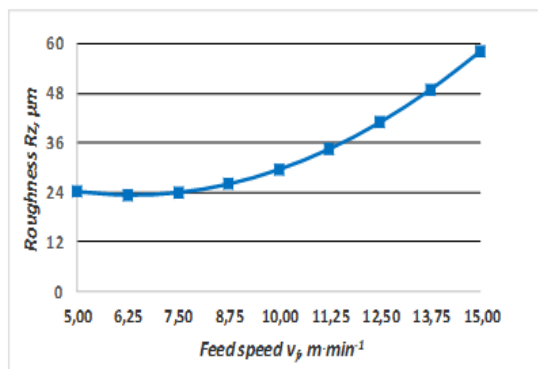


Fig. 5.

Effects of feed speed on surface roughness in longitudinal milling of meranti with jointer, model PF415N.

more pronounced at the largest uncut chip thickness $a_e = 5$ mm, where the roughness exceeds $80 \mu\text{m}$.

The following Figure 6 shows the effect of uncut chip thickness on roughness when machining meranti. At the same time, again at the average level of variation of the other studied factor – $v_f = 10 \text{ m}\cdot\text{min}^{-1}$. From the resulting curve, it is observed that the milling thickness has a practically visible effect after an uncut chip thickness of 3 mm. This confirms the practical recommendation that it is better to remove thicker layers of wood in more than one pass through the machine, even if it can be set to remove the entire layer in one pass. After increasing the uncut chip thickness above 3 mm, the intense increase in roughness is noticed.

The results of the effect of feed speed at all three levels of uncut chip thickness variation, during processing with the jointer *DMA 41L* (helical cutterhead), on roughness can be seen in Figure 7. It shows that at the lower values of the feed speed the roughnesses obtained are approximately the same for uncut chip thickness a_e from 3 to 5 mm, and only after a feed speed of $10 \text{ m}\cdot\text{min}^{-1}$ is it noticed that the curve corresponding to $a_e=5$ mm, begins to rise more intensively. In the case of $a_e = 1$ mm, the feed speed has the lowest influence and the difference in the roughness of the lowest and the highest value of this factor is only $10 \mu\text{m}$.

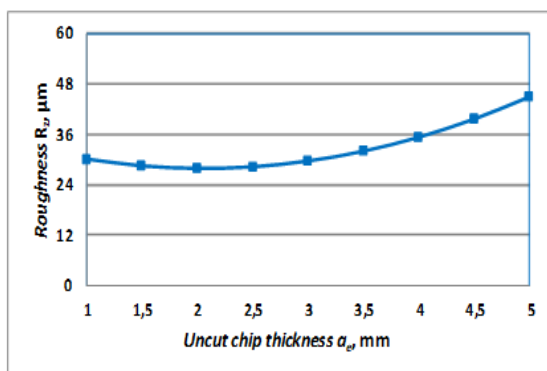


Fig. 6.

Effects of uncut chip thickness on surface roughness in longitudinal milling of meranti with jointer, model PF415N.

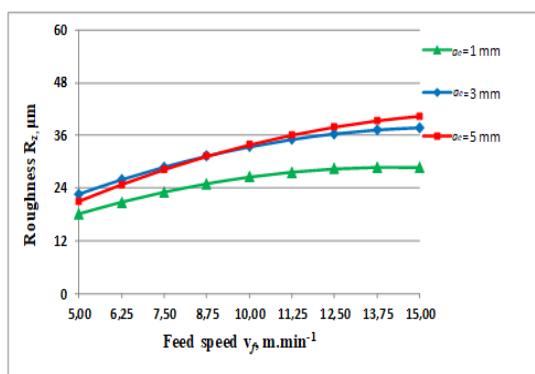


Fig. 7.

Effects of feed speed on surface roughness in longitudinal milling of meranti at different uncut chip thicknesses with jointer, model DMA 41L.

When comparing the results for the two jointers, it is noticeable that the one with helical cutterhead is better. Resulting in the highest levels of variation for this machine $a_e \approx 40 \mu\text{m}$, and as already mentioned, those for the shaft with flat knives $a_e \approx 80 \mu\text{m}$. The reason for the approximately twice as good results with the jointer *DMA 41L* is the better wear resistance of the cutting edges of the helical cutterhead, which preserves their proven serviceability for a longer time. The non-90° meeting angle between the wood fibers and the cutting edges should also not be forgotten. It is known from the Theory of wood cutting that this creates a prerequisite for smooth surfaces of better quality. This leads to higher feed speeds, and hence higher productivity. In this case, the main limitation on the feed speed will be the practical possibility of servicing the machine during operation. Of course, the available power of the engine that drives the cutting mechanism should not be forgotten either.

The influence of the feed speed on the roughness when milling the studied wood species, at an average value of milling thickness, with the planer is shown in Fig. 8. It clearly shows that of the examined machines for longitudinal milling, the surfaces after processing with this machine are of the best quality. The

main reason for this is the way in which the feed movement is carried out in these machines – the pulling force is frictional and is equal to the pressing force and the coefficient of friction. Fig. 8 shows the technological scheme of the machine. It shows that after the cutting shaft the workpiece is pressed by a smooth feed roller, and after calculating the necessary pressing force from this roller, using the methodology available in specialized literature, it was found that this force exceeds 700 N (Vlasev 2007). This means that some of the irregularities will be plastically deformed and smoothed out. The graph also shows that as the feed speed increases, the roughness also increases, which means that another part of the resulting kinematic waves have deformed elastically and after removing the force, they have recovered their original shape.

The roughness measured with the planer machine does not correspond to that obtained immediately after the knife shaft. However, the results can be accepted, since in all planers the feed movement is realized as a result of the pressure from the feed rollers and their friction with the wood. Furthermore, it can be seen from Figure 9 that the machine under study is also missing a rear pressure beam, which is very characteristic of planer machines and that would also have an effect on the resulting surface.

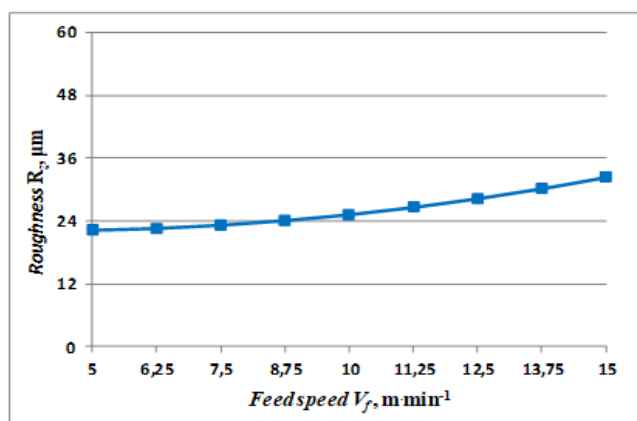


Fig. 8.

Effects of feed speed on surface roughness in longitudinal milling of meranti with planer, Model S630.

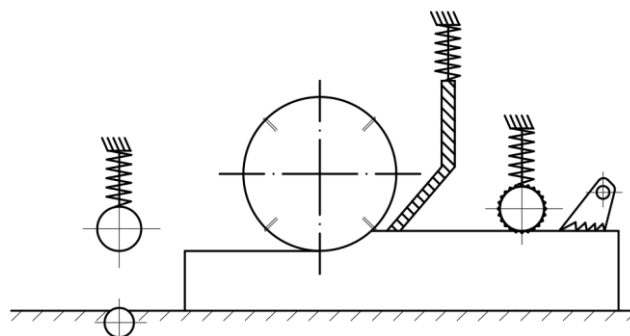


Fig. 9.

Technological scheme of planer, Model S630.

When comparing the results with previous studies, it can be seen that for the most part, they are different. The reason for this is complex, being a combination of the following more important things – the cutting radii of the edge cutters are different for different machines. In addition, they are not perfectly sharp and have varying degrees of wear. The conditions for conducting the experiments are not identical, as are the processed materials. For example, results when processing linden (*Tilia Sp.*), as well as beech (*Fagus sylvatica*), under the same conditions for conducting the experiments, are different (Vitchev *et al.* 2021, Atanasov *et al.* 2022). Comparing the roughness of different wood species is not very correct, as their physico-mechanical properties are different. It is possible even for wood of the same type, grown under different conditions, to have different density and strength, as well as permissible deformations (elastic and plastic) (Gochev 2018).

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the conducted experimental research on the influence of the main parameters of the milling process on the roughness of the surfaces when processing meranti with different longitudinal milling machines, the following more important conclusions and recommendations can be made:

- When it is necessary to determine the approximate roughness in advance, it is good to use the results of actual experimental studies. The reason for this is that the derived theoretical dependences refer only to the roughness due to kinematic waves, when the cutting edges lie in one rotational plane and do not include a number of other factors such as: wood species, construction of the cutting shaft, uncut chip thicknesses, radial runout of the spindle, wood anatomy, tool mounting clearances, precession movement of the cutting tool, type of bearings, etc. This means that the practical applicability of the theoretical dependencies is minimal. All this gives reasons to propose correction coefficients in future research that take into account the factors mentioned above and bring the theoretically calculated roughness closer to the actual one.
- When processing the tropical wood type of meranti, it is highly recommended to use knife shafts with replaceable carbide plates (helical cutterhead). This allows a higher feed speed – and therefore higher productivity.
- During the experimental study, it was established that the wood of meranti had an adverse effect on the efficiency of the edge cutters, and its processing led to their faster wear. For example, compared to other studied wood species such as Scots pine and even beech.
- The wood species studied is good to feed at lower speeds. The reason for this is its anatomical structure and the sharp increase in roughness when exceeding a certain feed speed of about $14 \text{ m} \cdot \text{min}^{-1}$. This tendency is most clearly observed at the highest studied uncut chip thicknesses – 5 mm.
- The pressure from the rear feed roller on planer machines has a beneficial effect on the roughness. This means that from a process performance perspective, when milling wood with planer machines, it is good to have a higher feed speed;
- During the preliminary experiments, it was found that as the feed rate increased, the pick-up of the processed materials after processing became difficult. This gives reason to recommend that the maximum feed speed for jointers should not exceed $20 \text{ m} \cdot \text{min}^{-1}$, and for planer $25 \text{ m} \cdot \text{min}^{-1}$. Regardless of the wood species.

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