INFLUENCE OF THE CUTTING MODE ON THE SURFACE QUALITY DURING LONGITUDINAL PLANE MILLING OF ARTICLES FROM SCOTS PINE S

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ABSTRACT

The current study investigates the changes in the surface quality of experimental samples of Scots pine (Pinus sylvestris L.) wood during a milling process, performed with different rotation speed of the cutting tool (n), feed rates (U) and different thicknesses of the removed layer (h). On the basis of the performed experiments, graphical dependencies, representing the relationship between the different factors have been derived. In order to achieve a higher quality of the milled (processed) surfaces, practical recommendations for the optimal values of the evaluated factors have been suggested. The surface roughness of the material (surface) was measured with a roughness tester, type „SurftestSJ-210“ (Mitutoyo, Japan).

Key words: milling, surface quality, cutting mode, Scots pine (*Pinus sylvestris*).

INTRODUCTION

Milling is one of the main technological processes involved in the processing of solid wood and wood-based materials, which aims to give a certain shape of the processed details and at the same time to ensure a higher surface quality (higher roughness class). It is well-known that the quality of the processed surfaces may be influenced by different factors, related to the characteristics of the processed material (Sandac et al., 2004), of the cutting tool and at last but not least, to the cutting mode during the material's processing (Keturakis, 2007; Gochev, 2014[b]). When determining the roughness of the wood surfaces, the direction of the wood fibers in which the measurements will be carried out is also important. Due to the anisotropic structure of the wood, the roughness of the surface is different and depends on the orientation of the fibers (Sandac et al., 2004). Some of the influencing factors can be controlled during processing, therefore they should be given more attention and become subject to wider and more comprehensive study in order to be managed in a more adequate way. In the recent years, a number of studies have been focused on investigating the processes related to the longitudinal plane milling and the resulted surface (Costesetal., 2002; Keturakis, 2007; Prakasvudhisarnetal., 2009; Rouseketal., 2010; Gonzalez-Adradosetal., 2012; Pinkowskietal., 2013; Wilkowskietal., 2013; Gochev, 2014[a]; Gochev, 2014[b]; Durkovicetal., 2017). Their common goal was to assess and determine the optimal parameters and conditions, assuring higher surface quality.

In relation to this, the aim of the current experimental study was to investigate the influence of the following factors: the rotation speed of the cutting tool (*n*), the feed speed (*U*) and the thickness of the cut-out layer (*h*) on the surface quality of details from Scots pine (*Pinus Sylvestris* L.) wood during longitudinal plane milling.

METHODOLOGY

The experiments have been performed using woodworking spindle moulder machine, type T1002S (ZMM “Stomana” GmbH, Bulgaria) (Fig. 1). The machine was equipped with a two-speed three-phase electric motor with power 3,2/4,0 kW, which through a belt drive provides the following rotating frequency of the working shaft: 3000, 4000, 5000, 6000, 8000 and 10000 min^{-1}.

Figure 1: Woodworking spindle moulder machine, type T1002S – general view

Acuttingtoolwithanassembledconstruc-tionforlongitudinalplanemilling (Metal-World, Italy) was used. The technical characteristics of the tool are presented in Table 1, where: *D*is the diameter of the milling cutter, *d* – diameter of the threaded hole, *L* – longitude of the main cutting blade of the tooth, γ – hook angle, *z* – number of teeth.

Table 1: Technical characteristics of the used cutting tool

General look of the milling cutter	*D* mm	*d* mm	*L* mm	β °	γ °	*z* no.	Material of the teeth
	125	30	50	47	16	4	Hard alloy (HM)

In the course of the study, details from Scots pine (*Pinus sylvestris* L.) wood, with the following characteristics: density ρ =490 kg.$m^{-3}$and moisture content *W* = 12,7%, determined respectivelyin accordance with BDSISO 3131 andBDSISO 3130, have been processed. The processed details were with the following dimensions: longitude (*l*) 1000 mm and milling width (*b*) 40 mm. The details were fed automatically by a roller feeder.

In order to evaluate the complex influence of the rotation frequency (*n*) of the milling tool, the feed rate (*U*) and the thickness of the cut-out layer (*h*) (milling height) on the quality of the processed surfaces, the methodology of multifactorial planning and subsequent regression analysis have been used (Vuchkov et al. 1986). The measurements were performed in accordance with a preliminary designed matrix for three-factorial experiment plan of G. Box (Box et. al. 1951;

Box et. al. 1999). In Table 2 the levels of the input variables in explicit and coded formare presented. The values are in line with the most frequently used in practice.

Table 2: Values of the variable factors: *n*, *U* and *h*

Variables	Minimum value		Average value		Maximum value	
	explicit	coded	explicit	coded	explicit	coded
Rotation frequency$n = X_1$, min^{-1}	4000	-1	6000	0	8000	1
Feed rate$U = X_2$, m.min^{-1}	3,5	-1	7	0	10,5	1
Thickness of the cut-out layer$h = X_3$, mm	1	-1	2	0	3	1

In order to assess the quality of the treated surfaces, depending on the variables, the roughness parameter R_z, µm, was used. It has been determined separately for five base lengths in the longitudinal direction of the wood fibers of each part. For each base length R_z is determined by the mathematical equation:

$$\boldsymbol{R_z} = \frac{\sum_{i=1}^{5}\left|y_{p_i}\right| + \sum_{i=1}^{5}\left|y_{v_i}\right|}{5}, \boldsymbol{\mu m} \qquad \textbf{(1)}$$

where: y_{pi} is the height of the biggest roughness of the profile, µm;

y_{vi} is the depth of the greatest slot of the profile, µm.

The surface roughness of each detail was determined using the mean average value $\overline{R_z}$ from the five measurement. The applied methodology is in accordance with BDSENISO 4287 and is described in details (Gochev, 2005). The measurements were performed with the digital roughness tester, model, SurftestSJ-210 (Mitutoyo, Japan) (Fig. 2).

Figure2.Roughness tester, model SurftestSJ-210 – general view

For the statistical analysis of the data QstatLab software was used.

RESULTS AND DISCUSSION

Based on the performed experiments and after statistical analysis of the data, we received the following regression equation:

$$y = 28{,}568 + 2{,}574X_1 + 1{,}243X_2 + 1{,}177X_3 + 4{,}093X_1^2 - 2.092X_2^2 - 1{,}962X_3^2 - 1{,}202X_1X_2 - 1{,}145X_2X_3 + 0{,}005X_1X_2 \qquad \textbf{(2)}$$

where: y is the expected surface quality of the processed detail, defined by the roughness parameter R_z in coded form; X_1 – rotation frequency of the cutting tool (n) in coded form; X_2 – feed speed (U) in coded form; X_3 – thickness of the cut-out layer(h)in coded form.

By using the equation (2) the surface quality, depending on the changes in the rotation frequency (n), feed speed (U) and the thickness of the cut-out layer(h) can be predicted.

In Table 3, the planning matrix for the three-factorial experiment and the mean average value of the roughness parameter, determined for different factor combinations are presented. The regression coefficients are given in Table 4.

Table 3: Planning matrix for three-factorial experiments and mean average values of the roughness parameter $\overline{R_z}$ (μm)

№	$X_1=n$ min^{-1}		$X_2 = U$ m.min^{-1}		$X_3 = h$ mm		$\overline{R_z}$ μm	№	$X_1=n$ min^{-1}		$X_2 = U$ m.min^{-1}		$X_3 = h$ mm		$\overline{R_z}$ μm
1	-1	4000	-1	3,5	-1	1	26,47	9	-1	4000	0	7	0	2	36,18
2	-1	4000	-1	3,5	1	3	36,55	10	1	8000	0	7	0	2	31,30
3	-1	4000	1	10	-1	1	32,10	11	0	6000	-1	3,5	0	2	26,70
4	-1	4000	1	10	1	3	28,66	12	0	6000	1	10	0	2	28,41
5	1	8000	-1	3,5	-1	1	28,12	13	0	6000	0	7	-1	1	28,46
6	1	8000	-1	3,5	1	3	29,28	14	0	6000	0	7	1	3	26,91
7	1	8000	1	10	-1	1	20,00	15	0	6000	0	7	0	2	28,25
8	1	8000	1	10	1	3	25,52								

Table 4: Regression coefficients

Coefficient	Coded value	Coefficient	Coded value	Coefficient	Coded value
b_1	-2,574	b_{11}	4,093	b_{12}	-1,203
b_2	-1,243	b_{22}	-2,092	b_{23}	-1,145
b_3	1,177	b_{33}	-1,962	b_{13}	0,005

From the absolute values of the regression coefficients (Table 4) itis visible that during processing of details from Scots pine wood, the greatest influence on the surface quality has the feed speed $U = X_1$with regression coefficient b_1 = 2,574, followed by the rotation frequency of the cutting tool n = $X_1$with regression coefficient b_2 = 1,243. The least influence among the investigated factors has the thickness of the cut-out layer h = $X_3$with regression coefficientb_3 = 1,177.

The changes in the surface roughness, expressed with the roughness parameter R_z, depending on the rotation frequency of the cutting tool at three different feed speed are graphically presented in Figure 3. From the roughness curves it is clearly visible that the increase of the rotation frequency of the cutting tool (n) from 4000 to 5500 min^{-1}, resulted in a significant decrease in the roughness of the surface, measured at the two higher feed speeds (7and 10m/min). At feed speed U = 3,5m/min, the value of the roughness parameter R_z decreases with the increase of the rotational frequency of the cutting tool up to 7000 min^{-1}. At the three feed speeds, the similar tendency in the variations of the roughness curves is observed. The lowest values of the surface roughness are observed at rotation frequency of the cutting tool from 6000min^{-1}to 7000 min^{-1}. The quality of the surfaces, processed at the three speed feeds is assessed as roughness class IX. However, it has to be noted that at speed of $U = 3{,}5$m/min the values of the roughness parameter R_z are lower when compared to the other two feed speeds.

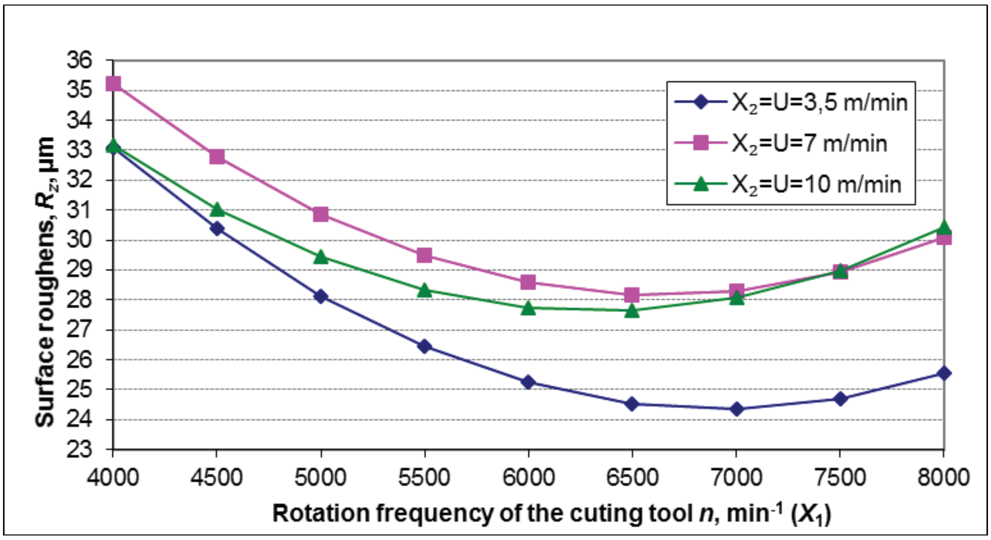

Figure 3: Changes in the surface roughness (R_z) depending on the rotation frequency of the cutting tool (n) at different feed speeds (U)

The relationship between the changes in the surface roughness(R_z) and the rotation frequency of the cutting tool at three different thicknesses of the cut-out layers is presented in Figure 4.

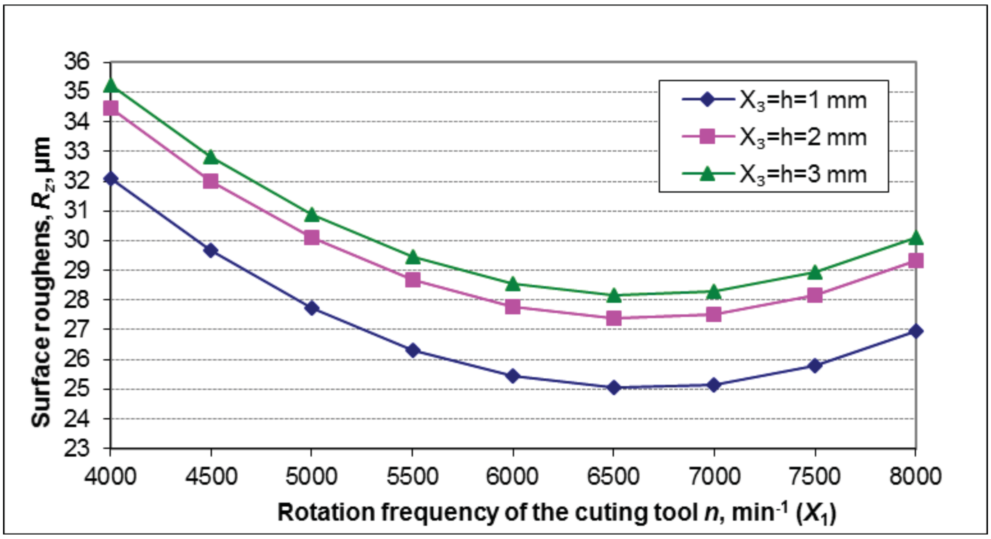

Figure 4: Changes in the surface roughness (R_z) depending on the rotation frequency of the cutting tool (n) at different thickness cut-out layers (h)

From the roughness curves it is visible that at three different thicknesses, the best surface quality was observed at rotation frequency interval of the cutting tool (n) from 6500 min^{-1} to 7000 min^{-1}. Similar tendency in the variations of the roughness curves are observed at the three thicknesses of the cut-out layer. A slight increase in the surface roughness is observed at rotation frequency of the cutting tool over 8000 min^{-1}. The lowest values of the roughness parameter R_z are measured at the lowest thickness of the cut-out layer (h = 1 mm), while at the h of 2 and

3 mm, the values of the roughness parameter $R_z$are increased by 15%.

CONCLUSION

The current paper presents results from experimental study, investigating the surface quality, after milling, of details from Scots pine (*Pinus Sylvestris* L.) wood, determined by the roughness parameter R_z (μm), measured along the length of the wood fibres of the specimens.

From the results obtained under the conditions of this study, the following conclusions can be made:

- The quality of the milling surface is influenced by the cutting mode at which the details are processed. Among the investigated factors, the greatest influence on the surface quality exerts the feed speed (*U*), followed by the rotation frequency of the cutting tool (*n*) and the thickness of the cut-out layer (*h*).
- The results from our experiments show that regarding the surface quality of the processed material, the optimal rotation frequency of the cutting tool is $n = 6500$ min^{-1}. This frequency, combined with the thickness of the cut-out layer $h = 2$ mm, gives the following values of the roughness parameter, measured at different feed speeds: at $U = 3{,}5$ m/min, $R_z = 24{,}54$ μm; at $U = 7$ m/min, $R_z = 28{,}18$ μm; at $U = 10{,}5$ m/min, $R_z = 27{,}63$ μm (see Fig. 3).
- At feed speed $U = 7$ m/min and rotation frequency of the cutting tool $n = 6500$ min-^{1}, the values of the roughness parameter, measure at different thickness of the cut-out layer are as follow: at $h = 1$ mm, $R_z = 25{,}04$ μm; at $h = 2$mm, $R_z = 27{,}4$ μm; at $h = 3$mm, $R_z = 28{,}18$ μm (see Fig. 4).

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