INFLUENCE OF THERMAL MODIFIED PINEWOOD ON THE QUALITY OF MACHINING AT PLAIN MILLING

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Article assess the effect of thermal modification on the surface roughness (Ra) after the face milling of pinewood (Pinus sylvestris) at different cutting conditions. The experiment was performed with samples modified at four temperatures (T = 160 °C, 180 °C, 210 °C and 240 °C), at three feed speed (v_f = 6, 10 , 15 m.min^{-1}), at three cutting speeds (v_c = 20, 40, 60 m.s^{-1}) and at positions of three angles (γ = 15°, 20°, 30°). The roughness measurement was executed by a non-contact method using a laser profilometer LPM - 4. It was found the importance of influence of studied factors affecting the surface finish in the order: heat treatment, feed speed, cutting speed, angular geometry.

KEYWORDS
flat milling, thermo-wood, quality of surface, cutting terms

1 INTRODUCTION

Properties of thermally modified wood are studied for a quite long time and are well known to the professional public. Recently, the interest in such thermally modified wood is increased and it finds its application in various fields. Subsequent machining is also related with the growth of consumption of thermally modified wood what has connection with the issues of surface quality after machining such material [Reinprecht 2007]. Most prevalent method of mechanical machining of wood is cutting with the formation of chips. This group of machining includes the milling machining as last operation before its use in a specific product with the required surface quality without further machining, such as grinding. In practice, it is very important that the machining process ran with the best output quality of surface finish. The surface quality is dependent on both the physical and mechanical properties of wood, as well as technical and technological conditions of the milling process. Proper choice of cutting conditions can increase the quality of wood surface during operation.

The article deals with experimental monitoring of temperature influence of thermal modification on quality of surface finish at plain milling of pinewood. The focusing is on the difference between thermally modified and natural material. Surface quality after milling operation is very important in terms of further use of the material as well as its possible finish.

2 THEORETICAL ANALYSIS

The production of thermally modified wood is a thermal modification of natural wood at temperatures of 150 – 260 °C, which intentionally modifies the chemical structure of wood. The thermal modification of wood is based on the complex of intentional interference in its chemical structure. The main purpose of thermal modification of growth wood is to prepare such material that balances the following criteria: lower hygroscopicity; higher dimensional stability; higher resistance to wood-destroying fungi and insects, wood-coloring fungi and molds; to maintain or improve the aesthetic side – the color, the minimum proportion of cracks, gloss, texture, and others; maintaining or even improving of the mechanical properties – strength, hardness, rigidity [Reinprecht 2008; Cristiane 2012].

It is important that the following intentional operation does not cause greater changes in the wood polymer, in particular in the polymerization of the cellulose, which has a great influence on the strength of wood [Kacikova 2011]. Thermal wood modification processes are patent protected (e. g. EP0018446, 1982; EP0612595, 1994; EP0623433, 1994; EP0759137, 1995; US5678324, 1997).

2.1 *Milling*

Milling means machining with the rotating tool such as a milling cutter or a milling head. During this process, the depth of cut varies the nominal chip thickness from minimum to maximum value hmax (at the up milling), and on the other hand from minimum to maximum value at the down milling. Feed is carried out in a direction perpendicularly to the axis of rotation of the tool. This type of machining is used to achieve a smooth surface and precise dimensions of the workpiece or to create a contoured surfaces. Multiple wedge tools are used at milling. Individual cutting wedges come in and out of the cut sequentially [Siklienka 2013; Borsky 1992].

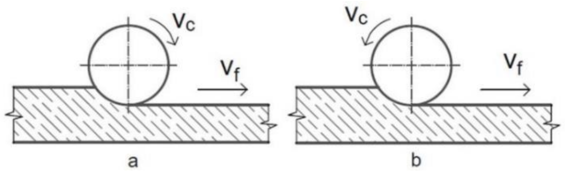


Figure 1. Feed milling process according to the workpiece

a) up milling b) down milling

2.2 *Surface roughness*

Quality of cutting process means the result of whole tool action on the overall quality of product conditional on three types of accuracy: shape, dimensional and surface (roughness rate). Shape and dimensional accuracy of the workpiece is affected mainly by stiffness of the tool, precision of cutting and feeding mechanism of work machine, as well as precision of the cutting edge in multiple wedges tool. Roughness and waviness are actually very small deviations from desired shape, which significantly affect the further machining of the element, especially its finish.

Roughness (micro roughness) and waviness (macro roughness) mainly dependent on the kinematic cutting conditions and they are affected by the following factors: method of particles separation, which depends not only on the method of machining, but also on the accuracy of operation of the tool and its geometry; cutting conditions (cutting speed, feed, etc.); Micro-geometry (dulling of cutting edge of the tool); physical and mechanical properties of the workpiece (density, hardness, texture) [Lisican 1988; Rousek 2012].

3 METHODOLOGY

3.1 *Selection and preparation of samples*

As the material for the experiment two logs of Scotch pine (Pinus sylvestris) were used, each for a series of different samples. First the boards of the radial center wood with thickness of 32 mm were manipulated out from the logs and they were dried to a humidity of 8%. Furthermore, cuts were obtained by the subsequent cross-cutting of planks, which had a length of 500 mm and a width of 100 mm. One part was not modified, whilst remained in the natural state. Other cuts have been thermally modified at a certain temperature (160 °C, 180 °C, 210 °C, 240 °C).

3.2 *Thermal modification of material*

The thermal modification of the material was made in equipment for heat treatment technology of wood – ThermoWood. The very technological process of heat treatment is determined by the parameters in Tab. 1 and Fig. 2.

Table 1. Phases of thermal modification of experimental samples

T [°C]	Phase 1 [hod]	Phase 2 [hod]	Phase 3 [hod]
160	4	5	2
180	5	5	2,5
210	6	5	3
240	7	5	3,5

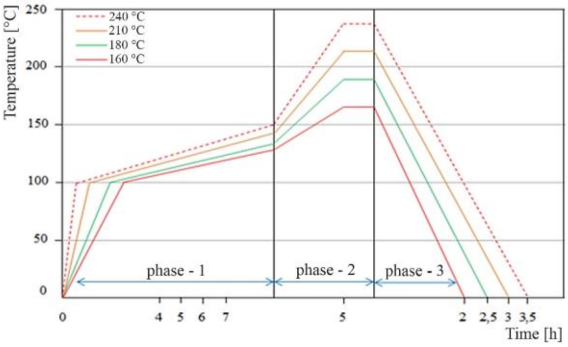


Figure 2. Time course of thermal modification of experimental samples

- Phase – 1: Increasing of temperature and drying
  The temperature rises rapidly to 100 °C by the action of water vapor. Then the temperature slowly increases up to 170 °C. The material at the humidity of 8 – 10% is dried to zero humidity, as the drying medium is used hot air.
- Phase – 2: Thermal modification
  The temperature was increased to 180 – 220 °C. The temperature affects the wood for 3 – 5 hours. The darkness of the wood increases with increasing temperature and time.
- Phase – 3: Cooling a humidity stabilisation
  Gradual decrease of temperature; at a temperature of 90 – 100 °C the humidity stabilization is carried to the final wood humidity of 3 – 6 % [Barcík 2014].

3.3 *Determination and measuring of density*

The density of experimental samples was determined before and after heat treatment according to STN 490130. Results from measured data show that the maximum volumetric bulk density has the natural material, whereby the density decreases with a greater degree of thermal treatment (Tab. 2).

Table 2. Measured values of volumetric bulk density of wood

Thermal treatment [°C]	Density ρ [kg.m^{-3}]	Percentage change [%]
Native	452	-
160 °C	421	6,86
180 °C	404	4,04
210 °C	376	6,93
240 °C	365	2,93

3.4 *Machinery characteristic*

Samples were milled on an experimental device which was lower spindle milling machine, feeding was ensured by feeder Frommia (Fig. 3) with the parameters in Tab. 3. The experiment was performed in a development workshop of Technical University in Zvolen.

Figure 3. Lower spindle mill with feeding mechanism

Table 3. Technical parameters of lower spindle mill FVS and feeding mechanism

Lower spindle milling machine FVS	
Supply voltage	360/220 [V]
Frequency	50 [Hz]
Power	4 [kW]
Feeder Frommia	
Type	ZMD 252 / 137
Feeding range	2,5 / 10 / 15 / 20 / 30 [m.min^{-1}]
Engine	380 [V] / 2 800 [m/min]

3.5 *Milling heads characteristic*

Milling heads for wood with interchangeable cutting plates FH 45 Stanon, produced in SZT - machinery Turany, with parameters in Tab. 4 were used in experimental measurements.

Table 4. Parameters of the cutter body

Diameter of the cutter body	125 [mm]
Diameter of the cutter body with extended knife	130 [mm]
Thickness of the cutter body	45 [mm]
Number of knives	2
Cutting geometry	$\beta = 45°$, $\gamma = 15°, 20°, 30°$

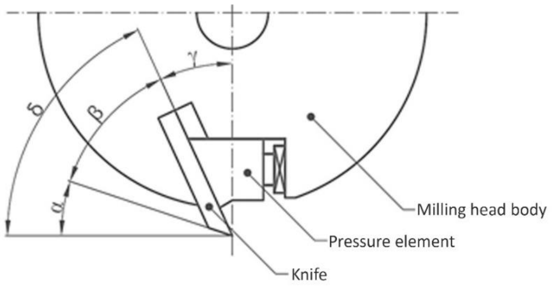


Figure 4. Tool geometry

3.6 Cutting conditions for experimental measurements

Before the measurement sharpening of the replaceable blades of the cutter head was necessary, which was realized in the development workshop of the Technical University in Zvolen. Samples that were intended for experimental measurements were counter-milled along the fiber in various technical parameters and angular geometry of tool, Tab. 5, where there was only one knife in the cut depth of cut of 1 mm.

Table 5. Cutting terms

Cutting terms		Value
Feed speed v_f [m.min^{-1}]		6, 10 , 15
Cutting speed v_c [m.s^{-1}]		20, 40, 60
The angular geometry of tool [°]	Face angle	γ=15 °,20 °,30
	Blade angle	β=45 °
Depth of cut a_p [mm]		1
Thermal treatment of samples T [°C]		Native
		T=160
		T=180
		T=210
		T=240

3.7 Roughness measurements

Measurement of surface roughness of the samples was performed with laser profimeter LPM – 4 (Fig. 5). Digital camera captures images of laser line at a certain angle. The cross-sectional profile of the object is subsequently evaluated on the basis of image acquisition. The measurement of roughness was performed in three places of the sample – on beginning of the sample, on the center of the sample and on its end, for observation changes in surface roughness on entry of tool, after tool stabilization in cutting and at the tool exiting from the cutting process, and three wide zones, on the edges and in the middle of the sample. During the measurement programm LPMWiew was used for the evaluation. Results were processed in program STATISTICA 10 [Siklienka 2007].

Figure 5. Laser profilometer LPM – 4 during the measurement

4 RESULTS

4.1 Influence of heat treatment

From the graph in the Fig. 6 it is clear that the thermal treatment of the material affects the surface roughness. Samples of natural pine wood and samples of thermally modified pine wood are compared with each other. Thermally modified samples have been treated at a temperature 160 °C, 180 °C, 210 °C and 240 °C. Compared to the natural material, surface quality of the thermal treatment wood at 160 °C decreases significantly, with a decrease up to 12% whereby at this temperature occur spillage of amorphous components of wood, what fills the pores after hardening. Increasing the temperature increases the surface roughness, where after thermal treatment at temperature of 240 °C the highest roughness was measured, with an increasing up to 10 %. Thermal treatment at temperatures of 210 °C and 240 °C caused the increase of surface roughness compared to the natural material, what is in accordance with wood degradation by temperature and also increasing the porosity of the wood.

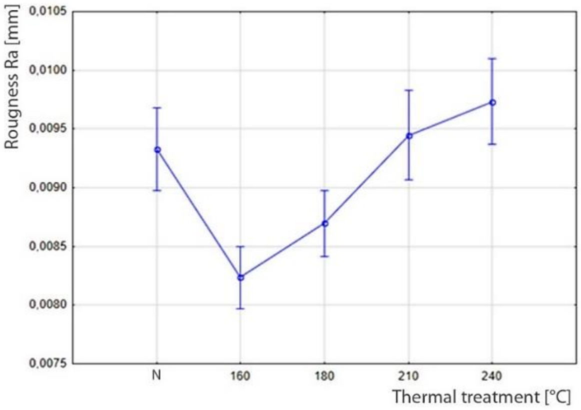


Figure 6. Influence of heat treatment on the material surface roughness

4.2 Influence of feed speed

Another factor affecting the surface roughness of the material is the feed rate. Feed rate was chosen at values of 6, 10 a 15 m.min^{-1}. In the Fig. 7 the multifactorial analysis of variance for the dependence of surface roughness on feed speed is displayed.

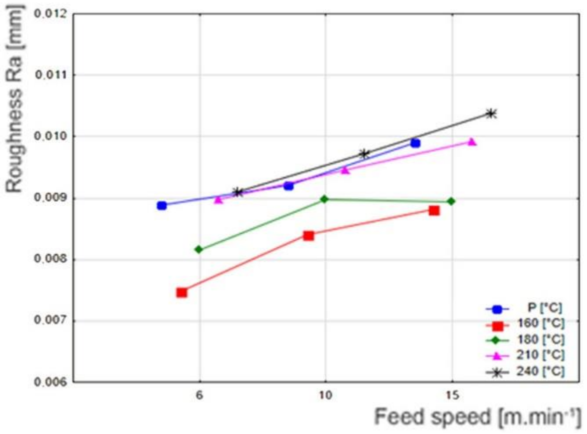
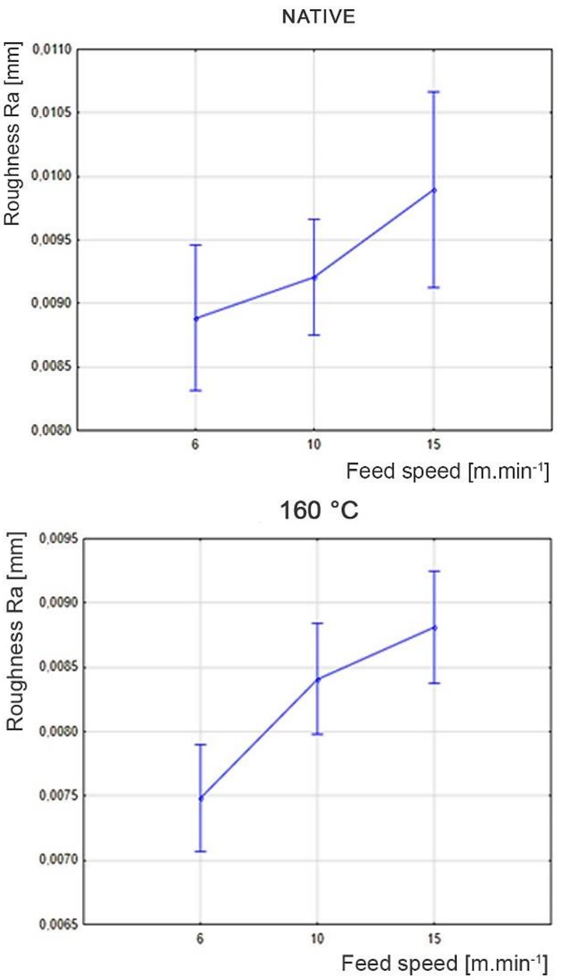


Figure 7. The dependence of surface roughness on feed speed

Based on the analysis of variance (Fig. 8) it is obvious that increasing the feed rate decreases surface quality. In thermal processing at the temperature of 180 °C surface roughness is highest at the feed speed of 10 m.min^{-1}, while for other samples it is the worst surface quality at feed speed 15 m.min^{-1}. The best surface quality is demonstrated in the sample with heat treatment of 160 °C at the lowest feed speed and on the contrary worst quality is demonstrated in the sample with heat treatment 240 °C at the highest feed speed.



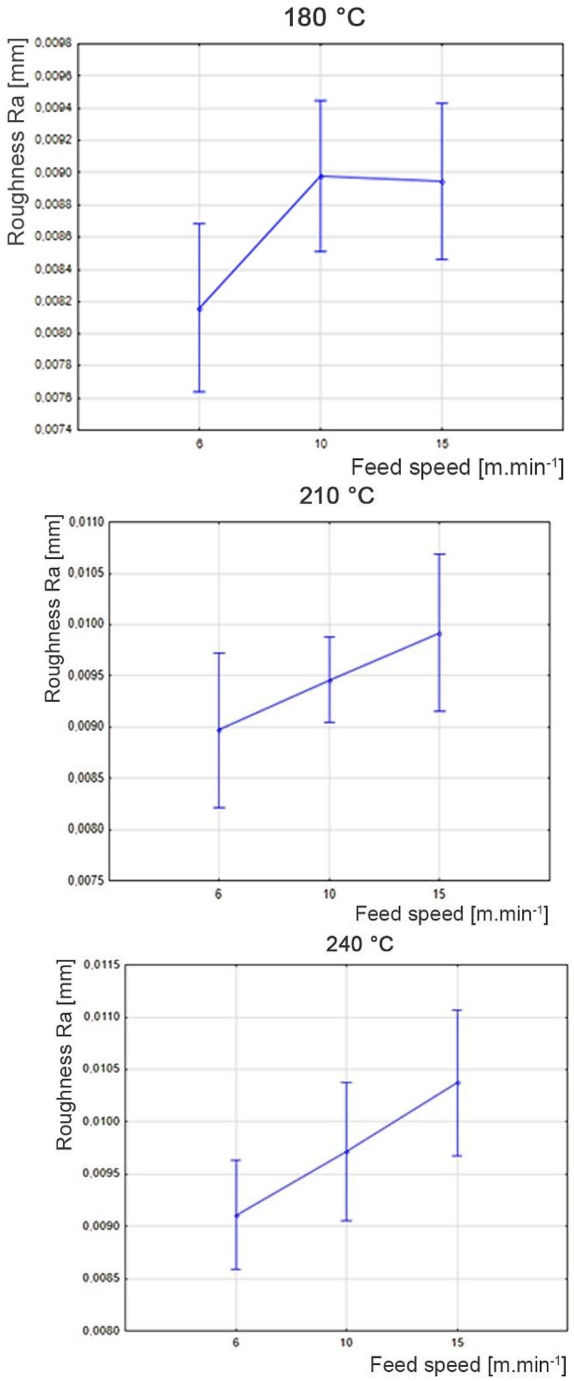


Figure 8. Analysis of variance - the dependence of surface roughness on feed speed

4.3 Influence of cutting speed

Cutting force was monitored at three levels of speed: 20, 40 a 60 m.s^{-1}. On the basis of multifactor analysis in the Fig. 9 it is clear that a sample thermally modified at 160 °C had the best surface quality. With this fact is evident, that for cutting speed 40 a 60 m.s^{-1} it is almost identical surface roughness. On the contrary, the highest surface roughness is in the sample with heat treatment at 240 °C with the cutting speed of 20 m.s^{-1}.

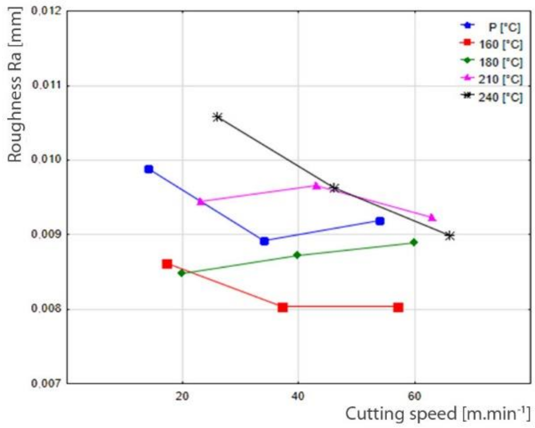
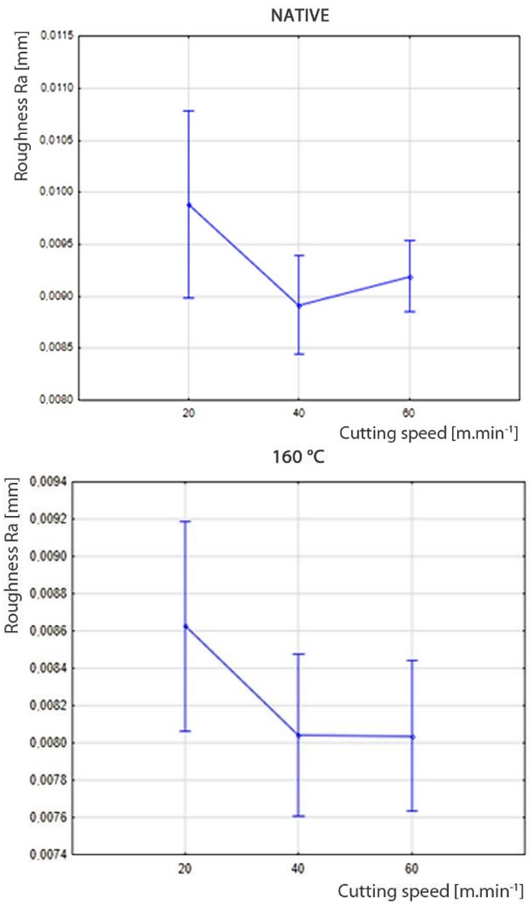


Figure 9. The dependence of surface roughness on cutting speed

By increasing the cutting speed a lower surface roughness was achieved. But this does not definite, the sample with heat treatment at 180 °C had reversed result. Slight fluctuation is seen for samples with heat treatment at 210 °C with the highest roughness at middle cutting speed 40 $m.s^{-1}$. The sample without heat treatment at a cutting speed 40 $m.s^{-1}$ had the best surface quality.



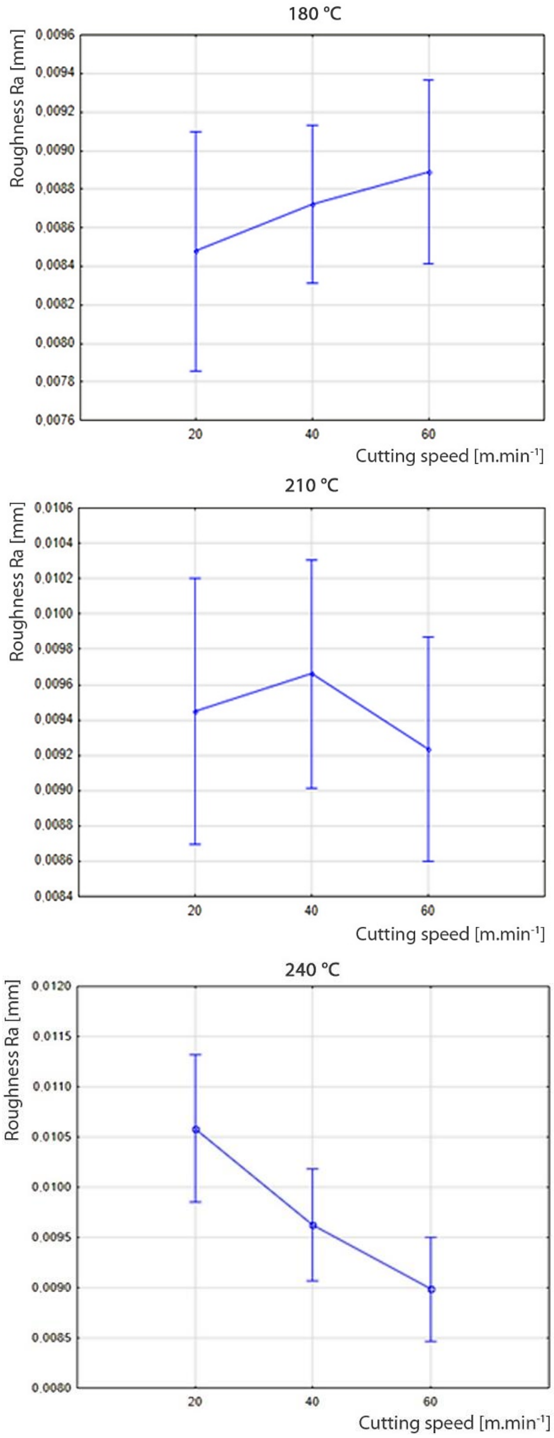


Figure 10. Analysis of variance - the dependence of surface roughness on cutting speed

4.4 Influence of angular geometry

The change of angular geometry was carried out at values of rake angles 15°, 20° and 30°. From the graph in the Fig. 11 is confirmed that the surface quality is getting worse with increasing rake angle.

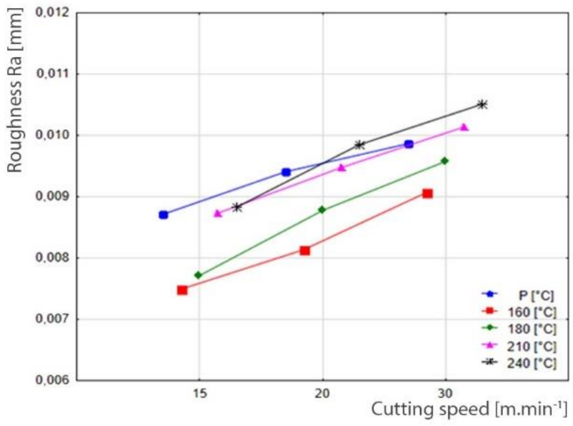
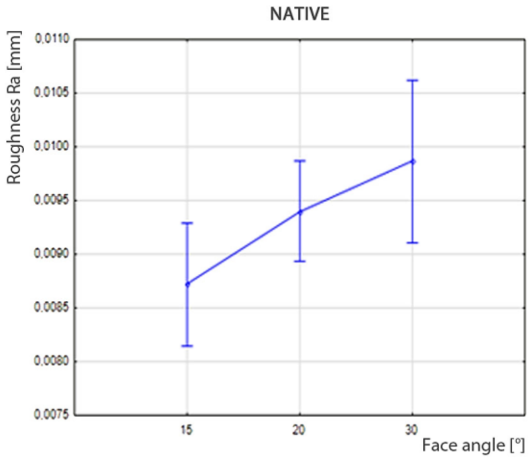
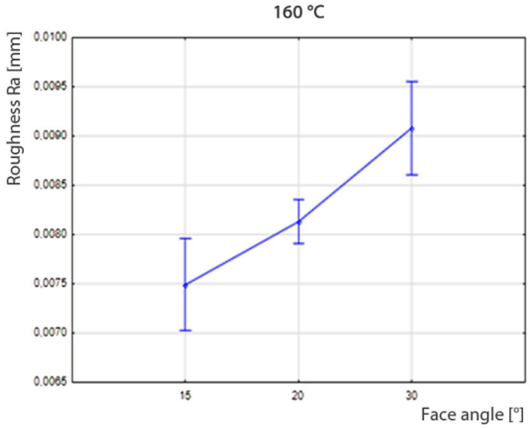
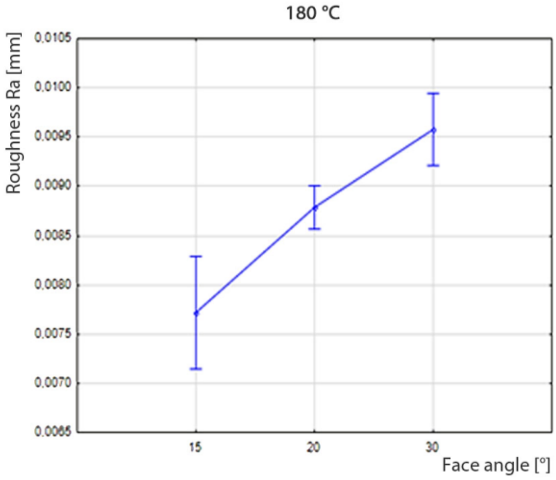


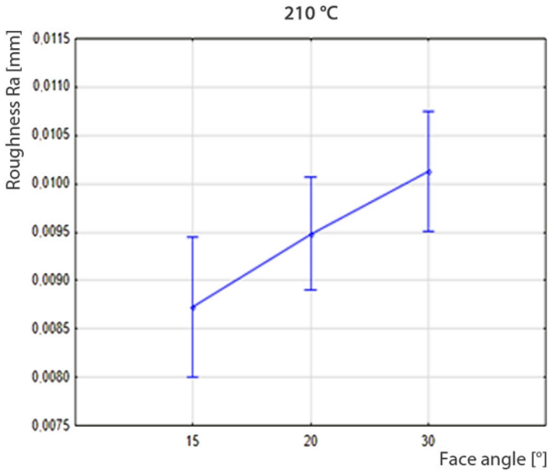
Figure 11. The dependence of surface roughness on rake angle

At a rake angle of 15 ° the best surface roughness is on all samples – in natural wood, as well as for samples with thermal treatment. The sample thermally treated at 160 °C had the best quality. From the point of view of the rake angle the sample heat treated at 160 °C had the best quality using the tool with a rake angle of 15°. The sample heat treated at 240 °C using the tool with a rake angle of 30 ° had the worst quality (Fig. 12).


NATIVE


160 °C


180 °C


210 °C

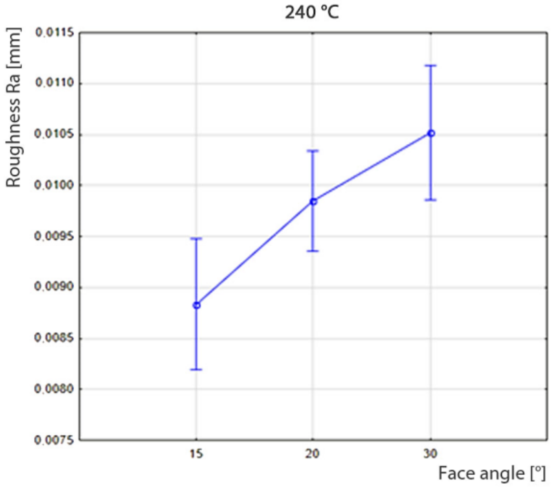

240 °C

Figure 12. Analysis of variance - the dependence of surface roughness on rake angle

5 DISCUSSION

Verification experiments and their results published in the article were aimed at exploring dependent parameters – surface roughness in face milling of natural and thermally modified pine wood on independent factor as thermal treatment, technological and also a tool factors. Research of monitoring of the surface roughness of thermally modified wood of that tree species can now be compared with only partial results of experimental investigation [Barcik 2014]. In this publication, however, the surface roughness was measured using the contact device for measuring roughness. In our case, contactless profilometer LPM was used. In his work samples were thermally modified at the same temperatures as in our experiment, but the resulting surface roughness for each temperature is different. Surface roughness values after thermal treatment were around half the lower and highest surface roughness had the natural material, which is inconsistent with our results. Also in feed speed the maximum surface roughness was observed at temperatures of 210 °C and 240 °C, but the values were approximately lower by 50 %. In examining effect of the cutting speed it had also been confirmed that by increasing of cutting speed surface roughness is reduced, the measured values were again lower by 50 % than our results.

In comparing the angular geometry is need to acknowledge that the angular geometry was in one case the same as the angular geometry of our work (γ= 15°, 20°, 25°). This had the effect on different results in each case, for decreasing the rake angle was the best surface finish.

6 CONCLUSION

The paper presents the results of experimental measurements, where the main objective was to determine the effect of thermal modification of wood surface finish for face milling.

In experiment it was found that thermal modification has a strong influence on surface quality. The sample treated at 160 °C showed the best results in terms of achieved surface quality. Increasing the temperature increases the surface roughness, worst results were after the thermal treatment at 240 °C. Thermal treatment at 210 °C and 240 °C caused the increase of surface roughness compared to the native material.

Feed rate has a significant impact on the quality of the surface. At this factor with increasing feed rate surface quality was worsening. Based on the heat treatment of materials the best quality showed sample with heat treatment at 160 °C and conversely the worst quality sample with heat treatment at 240 °C with the highest feed speed.

Cutting speed had minimal effect at surface finish. From the obtained results it is evident that with increasing cutting speed surface quality is improved, but this is not clear in all samples. With heat treatment at 180 °C it was found reverse course of increasing of the roughness depending on the cutting speed. This effect could be caused by the transition from spring wood to summer wood (or vice versa), which could result in the opposite course.

At angular geometry the most significant change of surface roughness was on the thermally treated material at 160 °C. At this temperature, the surface roughness achieved the best quality properties. With decreasing rake angle the surface quality was the best. The worst surface quality properties are exhibited in the thermal treatment at 240 °C and rake angle of 30°. Generally it can be stated that at 160 °C, the quality indicators show the best results in all studied factors.

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