Zagreb, 7th – 8th December

ICWST 2023

32nd International Conference on Wood Science and Technology

Unleashing The Potential of Wood-based Materials

PROCEEDINGS

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University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology

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UNLEASHING THE POTENTIAL OF WOOD-BASED MATERIALS

PROCEEDINGS

Zagreb, 07th - 08th December 2023

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FOREWORD

Welcome to the 32nd International Conference on Wood Science and Technology – ICWST 2023, themed "Unleashing the Potential of Wood-Based Materials." As we embark on this annual gathering, it is with great excitement that we delve into a rich tradition that has evolved over the years, connecting experts, researchers, and enthusiasts in the field of wood science and technology.

This year marks a significant juncture for ICWST, as we explore the endless possibilities within wood-based materials. Building upon the success of previous conferences, ICWST 2023 is set to be a catalyst for innovative discussions, collaborations, and breakthroughs in the ever-expanding realm of wood science.

Our conference is honoured to be hosted by esteemed institutions such as the Faculty of Forestry, University of Zagreb; Biotechnical Faculty, University of Ljubljana; Faculty of Forest Industry, University of Forestry - Sofia, and InnovaWood. This collaborative effort reflects the commitment of diverse scientific communities to the advancement of wood science and its applications.

In the spirit of tradition and progress, ICWST 2023 seeks to create a multidisciplinary platform where the exchange of ideas transcends borders. We anticipate the convergence of scientists and researchers from a variety of backgrounds, fostering an environment conducive to scientific novelty, industrial applicability, and comprehensive syntheses of high-impact subjects.

As we reflect on the achievements of the past, present, and future, ICWST 2023 is proud to unveil a program that encapsulates the essence of wood science. Distinguished speakers will explore a wide range of topics. We are honoured to host renowned experts who will share their insights, contributing to the rich tapestry of wood science discourse.

In conclusion, ICWST 2023 extends its gratitude to the institutions and companies whose financial support has made this conference possible. This year's conference aims to go beyond the realms of wood science and technology, touching upon interconnected topics such as materials, technologies, design, and more. We aspire to raise awareness about the vital role of wood as a natural resource in the bioeconomy, advocating for its use as a green building material in the fight against climate change.

We look forward to a conference filled with intellectual exchange, collaboration, and the exploration of the untapped potential within wood-based materials. May ICWST 2023 be a stepping stone towards a future where the sustainable utilization of wood contributes to the betterment of our world.

Editors

CONTENTS

increased surface area, did not significantly differ in extractive solubility compared to solid wood samples when both were in an absolutely dry state. This finding could reshape current perceptions regarding the impact of physical state and moisture content on the extraction efficiency of wood. The application of the cold water extraction method proved effective in quantifying the extractive content, which is essential for industries where wood colour consistency and hydrothermal treatment quality are of utmost importance. The results of this research offer valuable insights that can be applied to improve industrial processes, such as drying, steaming, and boiling of oak wood, ensuring better product quality and reducing financial losses due to colour imperfections. This study not only contributes to the fundamental understanding of oak wood's chemical behaviour in the presence of cold water but also provides practical guidance for enhancing the hydrothermal treatment of wood. The findings underline the critical need to consider the unique properties of wood extractives in industrial applications, paving the way for more efficient and cost-effective wood processing techniques

Acknowledgements: *This research paper is a part of Bachelor thesis of student Borno Matišev.*

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The Effect of Thermal Modification on the Quality of the Milled Surface of Beech and Pine Wood

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ABSTRACT

The article deals with the effect of thermal modification on the quality of the created surface during milling on CNC milling cutters. The quality of the created surface is evaluated based on surface roughness, specifically its roughness parameter Ra. The observed surface is created by a shank cutter with a diameter of 20 mm and three cutting edges in a spiral at a standard speed of 18,000. min^{-1}. The article compares thermally modified pine wood and beech wood of at temperatures of 160, 180, 200 and 220 °C with a reference sample of kiln dried wood of the given wood species. The article also monitors the variability of the quality of the created surface due to the change in the feed speed of 2, 4 and 6 $m \cdot min^{-1}$ and the thickness of removal of 1, 3 and 5 mm within the given degree of thermal modification. The article points to the fact that the average value of the arithmetic mean height (Ra) is below 10 µm for both types of wood, regardless of the degree of thermal modification. This meets the general requirements for the surface quality of furniture blanks. The mutual comparison of wood species showed that beech wood forms an average of 1.5 µm higher quality surface than wood pine. Thermal modification within both studied wood species improves the quality indicators of the created surface. In terms of the effect of specific temperatures, the highest quality of the created surface is at 180 °C and deteriorates in the range of 180, 200, 160, 220 °C. From the point of view of the influence of the investigated technological factors, no statistically significant influence of either the feed speed or the thickness of removed layer was demonstrated.

Key words: beech wood, pine wood, thermally modified wood, temperature of thermal modification, quality of the created surface, technological parameters of the process

1. INTRODUCTION

The current trend is to reduce the environmental footprint of the production process. One of the aspects is the minimization of the consumption of chemical substances in the production process, especially in the case of products for children. One of the potential ways is to change the color and increase the resistance of the surfaces due to the thermal treatment of the wood.

In general, thermal treatment can be defined as a process in which high temperatures in the range of 150 to 260 °C are applied to wood in an environment with different types of media (steam, nitrogen, oil, etc.) without chemicals (Sandberg and Kutnar, 2016). As noted by Budakci *et al.* (2013), the effect of these modifications depends on the medium used and its temperature. In Europe, the most commercially used technologies include ThermoWood in Finland, Plato Wood in the Netherlands, oil-heat treatment (OHT) in Germany and Les Bois Perdure and the rectification process (Retiwood) in France (Esteves and Pereira, 2011; Reinprecht and Vidholdova, 2008).

The production process of thermally modified wood is associated with several chemical changes in the structure of the material, in simplified terms it is a change in the proportion of lignin and the degradation of higher cellulose to lower cellulose, and these changes subsequently affect its physical and mechanical properties (Reinprecht and Vidholdová, 2008; Kačíková and Kačík, 2011; ThermoWood Handbook, 2003; Čabalová *et al*., 2016).

The intensity of the change in physical and mechanical properties consequently limits the use of thermally modified material. For this reason, this article was also created, the aim of which is to assess the effect of thermal modification on the quality of the machined surface. At the same time, the article aims to carry out the given assessment not with the help of classic technologies, as is customary, but with the use of CNC technology.

2. MATERIAL AND METHODS

Experimental samples: In the experiment, native and heat-treated blanks of Scots pine (*Pinus sylvestris*) and European Beech (*Fagus sylvatica* L.) with dimensions of 30 × 55 × 500 mm and moisture content 8 ± 1 % were used.

Heat treatment of wood: Samples for the experiment were heat treated with ThermoWood technology at the FLD Arboretum area (ČZU Prague) in Kostelec nad Černými lesy. Thermal treatment was carried out using the chamber S400/03 (LAC Ltd., Czech Republic). The course of the process was controlled by temperature and humidity sensors directly on the processed samples. The course of thermal modification itself was controlled via a computer, using a program from the company Katres spol. Ltd. The treatment process for individual thermal treatments is shown in *Figure 1*.

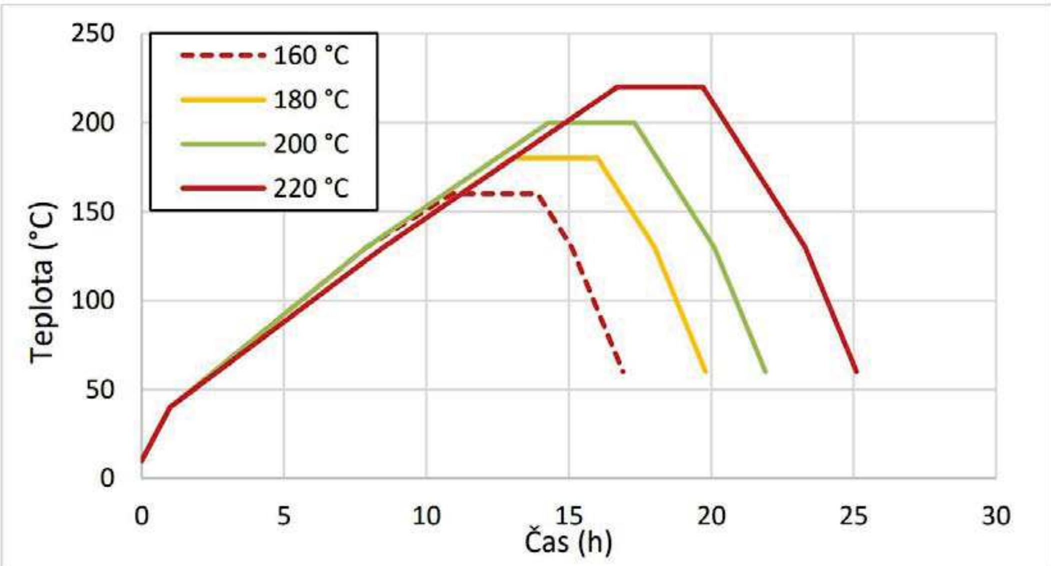

Figure 1. Graphic representation of temperature and time dependence for individual stages of thermal treatment of samples (Korčok et al., 2018).

Machine and tooling: The blanks were milled on a 5-axis CNC machining center SCM Tech Z5 (*Figure 2*) supplied by SCM–group, Rimini, Italy. The basic technical and technological parameters indicated by the manufacturer are listed in *Table 1*. LEUCO VFW 178354 finishers (*Figure 3*) from LEUCO (Beinheim, France) were used for milling. The basic technical and technological parameters indicated by the manufacturer are listed in the *Table. 2*

Figure 2. CNC machining center SCM Tech Z5 (https://www.scmgroup.com/en).

Table 1. Technical and technological parameters of the CNC machining center SCM Tech Z5. (https://www.scmgroup.com/en)

Technical parameters of CNC machining center SCM Tech Z5	
Useful desktop	x = 3,050mm , y = 1,300mm, z =300mm
Speed X axis	0 ÷ 70 m.min^{-1}
Speed Y axis	0 ÷ 40 m.min^{-1}
Speed Z axis	0 ÷ 15 m.min^{-1}
Vector rate	0 ÷ 83 m.min^{-1}

Technical parameters of the main spindle - electric spindle with HSK F63	
Rotation axis C	640°
Rotation axis B	320°
Revolutions	600 ÷ 24,000 ot.min^{-1}
Power	11 kW
Maximum tool diameter	D = 160 mm L = 180 mm

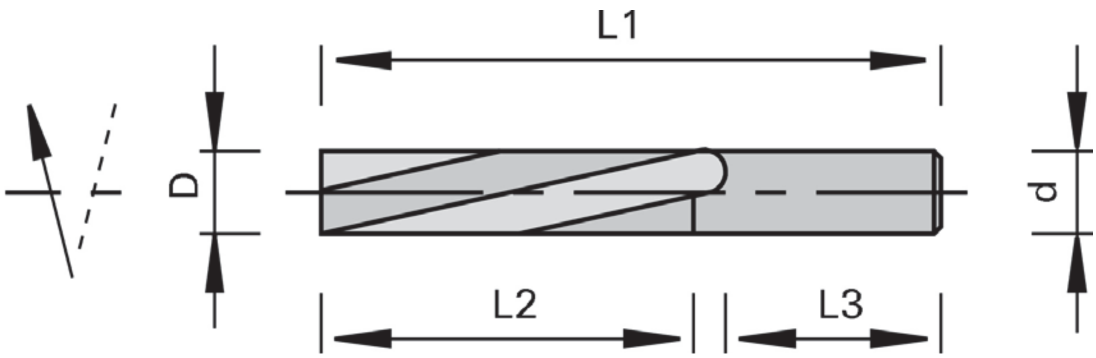

Figure 3. A Finishing cutter LEUCO VFW 178354. (https://www.leuco.com/EN/US/web/home).

Table 2. Technical and technological parameters of finishing cutters LEUCO VFW 178354 (https://www.leuco.com/EN/US/web/home)

Feature	Value
Ø D = Cutting circle diameter	20 [mm]
L2 = Cutting width	55 [mm]
Ø d = Shank diameter	20 [mm]
L3 = Shank length	50 [mm]
L1 = Total length	115 [mm]
Z = No. of teeth	3
Helical direction = Helical direction	negative
n_{max} = maximum RPM	30,000 [min^{-1}]
L/R = cutting direction	R

Milling process: A LEUCO VFW 178354 milling cutter was fitted to a SOBO 302680291 GM 300 HSK 63F hydraulic chuck from Gühring KG Albstadt. The blanks were placed in the CNC machining center so that the longer side was in the X axis and the shorter side was in the Y axis. clamped with mechanical clamps VCMC-S4 145x145x50 12-80 from J. Schmalz GmbH, Glatten, Germany. The milling process took place at a constant milling speed n = 20,000 min-1 and varying thickness of the removal layer a_e = 1, 3 and 5 mm and varying feed speed z vf = 2, 4 and 6 m.min^{-1}.

Determination of surface roughness: The surface roughness of the samples was measured with a laser profilometer LPM-4 (*Figure 4*) from the manufacturer Kvant s.r.o. Slovak Republic. The profilometer uses the triangulation principle of laser profilometry. The image of the laser line is captured at an angle by a digital camera. The cross-sectional profile of the object is then evaluated from the scanned image. The obtained data are mathematically filtered and individual indicators of the primary profile, waviness profile and roughness profile are set (Kminiak and Gaff, 2015)

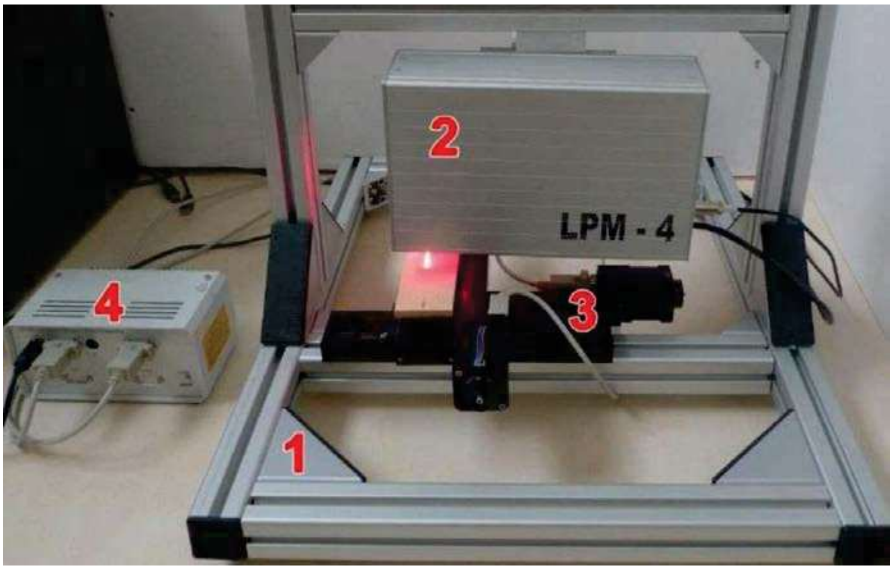

Figure 4. Laser Profilometer LPM - 4 (1 - supporting structure allowing manual setting of working distance and fitting of profilometric head and trolley system, 2 - profilometric head, 3 - feed system of the XZ axis, 4 - control system of working desk shifts) (Kminiak and Gaff 2015).

The methodology of Siklenka and Adamcova (2012) was used to measure the surface roughness, which meets the EN ISO 4287 standard. Within each sample, measurements were made in three traces, located in the center of the sample, evenly distributed over the entire surface of the sample. sample width (5/10/15 mm from the edge of the sample), the traverse length was 60 mm, and the trace was oriented in the direction of spindle displacement in the milling process. The surface roughness was evaluated using the parameter of the arithmetic mean of the deviation of the roughness profile Ra.

3. RESULTS AND DISCUSSION

Background: Changing the quality of the created surface as a result of the thermal modification of wood is not the goal of the thermal modification, but its side effect. The aim of this article is to assess the risks of thermal modification on quality indicators of the surface, whether it is necessary to choose different technical-technological parameters of the process when processing thermally modified wood than when processing wood without thermal modification.

As an objective criterion for assessing the effect of thermal modification on the quality of the created surface, the roughness of the created surface was chosen, specifically its parameter, the „Ra“ mean arithmetic deviation of the roughness profile. The reason for choosing the roughness parameter as the most representative quality parameter is the premise, surface roughness and waviness are interconnected parameters, surface waviness is primarily dependent on machining kinematics, and surface roughness primarily depends on the tool-workpiece interaction. Based on the following premise, roughness reacts more sensitively to material changes, which was also confirmed in the given experiment.

Analysis of the obtained data: The measured data were subjected to analyses in the statistic software STATISTICA 12.

- the effect of the type of wood, the degree of thermal modification and the thickness of the removal layer was shown to be statistically significant, on the other hand, the effect of the feed speed was shown to be statistically insignificant,
- the order of statistical significance of the factors decreases in the order of type of wood, degree of thermal modification and the thickness of the removal layer, all three investigated factors proved to be highly statistically significant
- the roughness of the surface of beech wood ranges from 4.6 µm to 8.2 µm, the roughness of the surface of pine wood ranges from 5.2 to 9.7 µm, the surface of pine wood is 1.4 µm rougher on average like the surface of beech wood (see *Figure 5*).

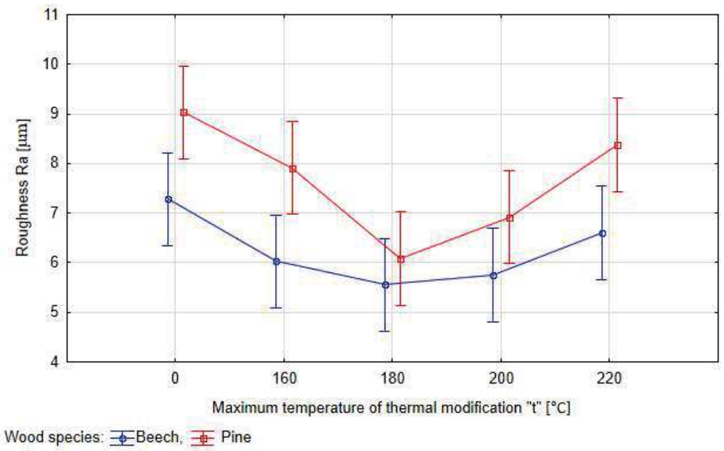

Figure 5. The effect of thermal modification on the quality of the created surface (vertical bars denote 95 % confidence interval for the mean.).

The roughness of the surface of thermally treated beech and pine wood is lower than that of wood without thermal modification, in terms of the influence of specific temperatures, the lowest roughness of the created surface is at 180 °C (on average beech wood 5.6 µm / pine wood 6.1 µm) and deteriorates in the order 180 °C, 200°C (on average beech wood 5.7 µm/ pine wood 6.9 µm), 160 °C (on average beech wood 6.0 µm/ pine wood 7.9 µm), 220 °C (on average beech wood 6.6 µm/ pine wood 8.4 µm) and the reference sample (on average beech wood 7.2 µm/ pine wood 9.0 µm), due to thermal modification there is a decrease in roughness depending on the temperature modifies in the range of 0.7-1.5 µm for beech wood and 0.7-3.0 µm for pine wood.

The statistical significance of the effect of the thickness of the removal layer on the roughness of the created surface was confirmed only within pine wood, in the case of beech wood the given effect is statistically insignificant, in the case of pine wood, as a result of increasing the removal from 1 mm to 3 mm, the roughness of the created surface worsens on average by 1.1 µm, and in the case of an increase in removal from 3 to 5 mm, the roughness will deteriorate by an average of 1.3 µm (see *Figure 6/a)*.

The expected influence of the feed speed on the roughness of the created surface was not confirmed, surface roughness differences due to a change in the feed speed by 2 $m.min^{-1}$, the surface roughness changes on average by 0.3 µm for beech and by 0.7 µm in the case of pine. It is not possible to observe an unequivocal trend of increase or decrease in roughness due to changes in the feed rate (see *Figure 6/b*).

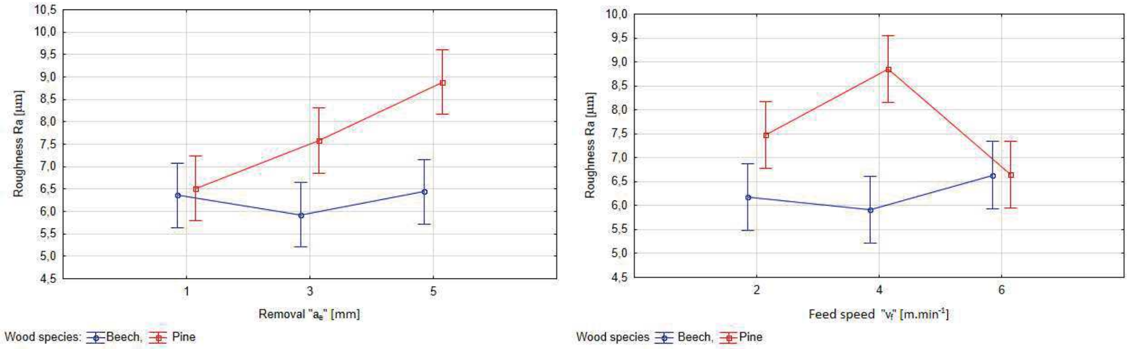

Figure 6. a) The effect of the amount of removal on the quality of the created surface b) the effect of the size of the feed speed on the quality of the created surface (vertical bars denote 95 % confidence interval for the mean.)

Scientific interpretation of the obtained data: For the sake of objectivity, it is necessary to emphasize at the outset the fact that most authors dealing with the given issue use the milling process on the bottom single-spindle cutter and a cutter with a diameter of 120 to 140 mm for surface creation. The experiment carried out by us is carried out on a CNC milling machine with a tool diameter of 20 mm. From a macro point of view, we remove identical layers of material, but from a micro point of view, the chip formation mechanism is not identical. We will use the example of the contact angle, for a tool with a diameter of 120 and a clearance of 1 mm, the contact angle is 10°, and for a tool of 20 mm and a clearance of 1 mm, the contact angle is up to 25°. At the same time, a specific feature of tools for CNC milling machines is the development of the cutting edge into a screw. Both facts significantly influence the vectorization of forces during the creation of new surfaces.

As stated by Škaljič *et al*., (2009), the physical and mechanical properties and anatomical structure of the wood affect the roughness of the surface. The resistance to blade penetration into wood depends on the size and shape of the cells, as well as the thickness and strength of the cell walls. This creates the hypothesis that the denser and more homogeneous the wood, the better the surface it creates. This statement corresponds to our conclusions as well as the conclusions of Malkoçoðlu and Özdemir (2006) and Malkoçoðlu (2007) showed in their research that with the same processing parameters, the surface of conifers is of lower quality than the surface of hardwoods.

The results obtained by us confirm the conclusions of Vančo *et al*., (2017) that the quality of thermally treated wood is higher than the quality of native wood, at the same time we agree with the trend that when the temperature increases to about 200 °C, the quality improves and above this limit it gradually deteriorates. Thermal modification of wood is a process that changes its chemical structure, making the wood more fragile and easier to protect. As stated by (Ispas *et al*., 2016), the brittleness of wood is a consequence of the loss of amorphous polysaccharides.

An explanation of the break and the reverse increase in roughness at a temperature of 200-220 °C is offered by Čabalová *et al*., (2016). A noticeable mass loss (ML) at temperatures above 220 °C suggested there was intensive decomposition of the wood matter. The ML of wood is one of the most important features in heat treatment, and it is commonly referred to as an indicator of quality (Esteves and Pereira, 2009).

Technological interpretation of the results: From a technological point of view, it is necessary to interpret the obtained data regarding the limit value of the surface roughness. Based on our own experience, a milled surface can be considered high-quality if the surface roughness does not exceed the value of Ra = 20 μm. Within the setting of technological parameters, thermal modification will not cause changes in material properties that would relate to quality indicators and limit values. From this point of view, there is no need for a differentiated approach when processing thermally modified wood, and it is possible to use the same technical-technological settings of the machining process. From the point of view of the specific values of the technical-technological parameters, it is appropriate to increase them, this is not prevented by other limiting factors (cutting forces Fc, the ability to evacuate classes S_{zm},...).

4. CONCLUSIONS

Thermal modification, in addition to the targeted change for which it is carried out – a change in color, also brings a change in physical-mechanical properties, which subsequently affect the machinability of the material. From the point of view of the quality of the created surface, specifically the surface roughness parameters, it is possible to state that, under the conditions of machining by means of CNC technology, thermally modified wood shows a higher quality of the created surface than natural wood. As the temperature of the thermal modification increases, the quality of the created surface increases approximately up to a temperature of 200 °C, and above this limit the reverse phenomenon occurs, namely that the quality of the surface decreases with further temperature increases. In absolute terms, the values of the surface roughness in the range of recommended values of the technical-technological parameters usual for the given type of CNC machining are below the limit values, and therefore the quality of the surface created in this way can be considered acceptable.

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