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Effect of thermomechanical densification of pine wood (*Pinus sylvestris* L.) on cutting forces and roughness during milling

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Abstract: *Effect of thermomechanical densification of pine wood (Pinus sylvestris L.) on cutting forces and roughness during milling.* The paper presents the results of research concerning the assessment of machinability of pine wood thermomechanically compacted. The assessment was made on the basis of the cutting forces and surface roughness after the milling process. Selected properties of native and modified wood were examined. Based on the research, it was found that compacted wood is characterized by higher cutting forces during milling. The surface quality after milling was examined and the roughness index Ra values were determined. The research shows that the modified wood is characterized by a lower Ra value both along and across the grain. Statistical analysis showed that the modification had a statistically significant effect on the values of cutting forces and the physical and mechanical properties of the tested wood.

Keywords: pine, densified, milling, roughness

INTRODUCTION

For years, various modifications of wood have been used to improve selected wood properties, such as: hardness, dimensional stability, hygroscopicity and resistance to insects. Among many available methods of wood modification: chemical, thermo-hydro-mechanical, biological, using electromagnetic radiation or plasma, and thermo-mechanical treatment can be distinguished (Sandberg et al.2017).

Each of the above-mentioned modifications changes the properties of wood in a different way. Chemical modification based on the injection of substances such as furfuryl alcohol or styrene into the wood and their polymerization in appropriate conditions. This treatment increases the dimensional stability of wood, resistance to bio-corrosion and many mechanical properties (Li Y et al. 2011; Esteves et al. 2013).

Thermal modification occurs using only heat. It allows for the reduction of wood hygroscopicity (Akyildiz and Ateş 2008; Brito et al. 2018). As a result, it has a significant impact on the elastic properties of wood and the type of structural damage (Kozakiewicz 2010). The use of a temperature of 215 °C to a reduction in the amount of hemicellulose, the fungi are deprived of the nutrient solution, making the wood more resistant to fungal attack. In addition it improves dimensional stability - shrinkage and swelling of wood are about 50% lower than that of unmodified wood moreover application of this temperature improves thermal insulation properties and color changes to brown (Adamczyk-Królak 2013)

In recent years, there has been a growing interest in thermo-mechanical treatment, otherwise known as densification.

Thermo-mechanical treatment of wood is a process of increasing the density of wood using heat and mechanical compression. Wood compaction improves its properties, increases hardness up to 300%, resistance to fire, thermal conductivity and reduces abrasion (Versal.com 2017). Wood compaction is carried out using various parameters. (Nguyen et al. 2012) compacted bamboo wood at 130, 150 and 220 °C. The obtained wood was characterized by a lower equilibrium moisture content than the native wood of Vietnamese bamboo and a clear change of color. These changes were more intense when the process was carried out at higher temperatures.

Laskowska (2020) carried out the compaction of 3 wood species: beech, oak and pine, at a temperature of 100ºC and showed that the density of selected species increased by 25%, 26%, and 41%, respectively, and their hardness compared to native wood almost doubled.

Ulker et al. (2012), when compacting pine wood at temperatures of 120, 140, and 160°C, showed that the best improvement of selected properties of pine wood was obtained by modifying them at 120 and 140°C, while compaction at 160°C turned out to be ineffective (the same bending values as for unmodified wood). Hardness also improved significantly across the range of temperatures tested. Laine et al. (2016), by conducting the process of thickening the sapwood of Scots pine at the temperature of 200°C for 2h, 4h and 6h, obtained pine wood which hardness was 2 times higher than native wood.

Changing the properties of wood through the above-mentioned modifications leads to change in the physical and mechanical properties and thus affects the forces generated during the cutting process of modified wood. Hlaskova et al. (2020) showed that modified beech wood under such trade names as: Bendywood, Lignamon, Belmadur statistically significantly influences the change of cutting forces during sawing with circular saws.

Thermo-mechanical modification significantly influences the change of wood density and hardness. It is known that high-density wood species have high mechanical properties. These characteristics significantly influence the machinability of the wood based on the cutting forces. The differentiation of the density resulting from the diversity of the wood species leads to a divergence of cutting resistance at the level of 300% (Eymaa et al. 2002), which results in the fact that different types of wood require an individual processing technique and even within one species the technique must be changed.

One of the indicators for assessing the quality of solid wood processing is the roughness of the surface after machining. The roughness of the wood is related to its density. High density species are more compact and has a lower roughness (Tanaka 1991; Lavery et al. 1995; Hecker and Becker 1995; Thoma et al. 2014). It is an important feature, especially when finishing the surface of wood, because the service life of the surface, durability of the coating and the consumption of paint and varnish products depend on the hardness of the wood. It has been proved (Bekhta et al. 2014) that thermomechanical compaction of wood veneers improves the surface quality.

The above-mentioned publications relate to the improvement of selected properties of wood of various species. Wood compaction directly increases the density of wood, which results in change of its mechanical properties, but there is no reliable information on the impact of compaction on the quality of machining after machining or the value of the cutting force occurring during machining.]

The aim of the study is to assess the quality of the surface after the milling process of thermomechanically compacted pine wood, as well as to test.

MATERIALS AND METHODS

Wood samples of Scots pine (*Pinus sylvestris* L.) were used for the research. For the thermo-mechanical compaction of sawn timber in industrial conditions, a high pressure press from Italpress, model GL / 260 - PS, was used, which enables flat pressing of boards up to 2.5 m long. Before compacting, the sawn timber was heated between the press shelves at a temperature of 900°C for 20 minutes in order to soften the lignin, and then it was pulsed compacted in three stages. In the first pressing impulse, the sawn timber was compacted from an average thickness of 24 mm to a thickness of 22 mm, then the press was opened (the upper press shelf was moved away from the pressed piece of sawn timber), in the second impulse the sawn timber was compacted to 20 mm, and then the upper presser shelf was removed for a while from the compacted planks to allow stress relaxation. In the third impulse, the sawn timber was pressed to 18mm. At the last pressing impulse, the sawn timber was held in the press for 30 seconds. then the press shelves were opened. The phenomenon of elastic redeformation of the compacted boards was observed after each pressing impulse, and after the last impulse a redeformation to an average thickness of approx. 20 mm. The lumber, which had an initial nominal thickness of 24 mm, was compacted to approx. 20 mm, the original average width of the boards of 90 mm was increased to an average of 92 mm (measurement of lumber with protuberances). The obtained cross-sections of the boards after pressing were not flat.

The entire modification process consists in squeezing heated wood in a hydraulic press with a unit pressure of 80MPa, and the temperature of the plate is 100C, 150°C and 200°C. The initial stage consisted in heating the samples for 180 seconds, without applying pressure, then pressing for 180 seconds, and finally cooling the samples until reaching the temperature of 70°C without pressure and in an unheated press. The modified material has a higher density, which influence on greater hardness, utility properties and greater use.

Samples with dimensions 90x150mm (width, length) were randomly selected and cut. 20 thermomechanical and 20 native wood samples were used for the tests. The average thickness of the native samples was 24mm, the thickness of the samples after the compaction process was lower than that of the native samples and was on average 20 mm.

The wood was tested for selected properties and the results are presented in Table 1. Bending strength was carried out based on the standard (EN 310:1993), modulus of elasticity (EN 310:1994, hardness (EN 1534:2010), density (ISO 13061-2:2014).

Table 1. The results of selected average mechanical and physical properties

	Bending strength [MPa]	Modulus elasticity [MPa]	Brinell hardness[N/mm^2]	Density[kg/m^3]
Native Wood	86,6	9000	19,0	508
Densified wood	131,0	13000	40,2	651

The milling process was successfully passed through parameters by the milling operator, using the milling cutter, Busselato Jet 130 milling (Thiene, 2004). Shoulder of 20mm wide and6mm depth were milled. Figure 1 shows samples after the milling process (on the left a native sample, on the right - densified wood).

Figure 1. Example samples of milled wood

The surface roughness was measured using a Mitutoyo SJ-201 contact profilometer. During the tests, the Ra parameter was measured. A total of eight, four along the fiber and four across the fiber measurements were taken from the surface of each solid wood sample.

To measure the cutting force, a piezoelectric sensor mounted on the moving beam of the Busselato Jet 130 machining center was used. This sensor measured the forces during milling in two axes X and Y. The signal passed through the Kistler 5036 amplifier. Then the signal was transferred to a data acquisition card (National Instruments PCI- 6111), which was controlled by a PC. The signal was in mV and was calculated to N. The result of the experiment was the resultant force. This means that based on the values of the cutting forces in the x and y direction, the arithmetic mean was determined. Signals were analyzed in the LabView environment (Austin, USA). Statistical analysis was performed in the Statistica computer program. Figure 2 shows an example of the signal recorded during milling.

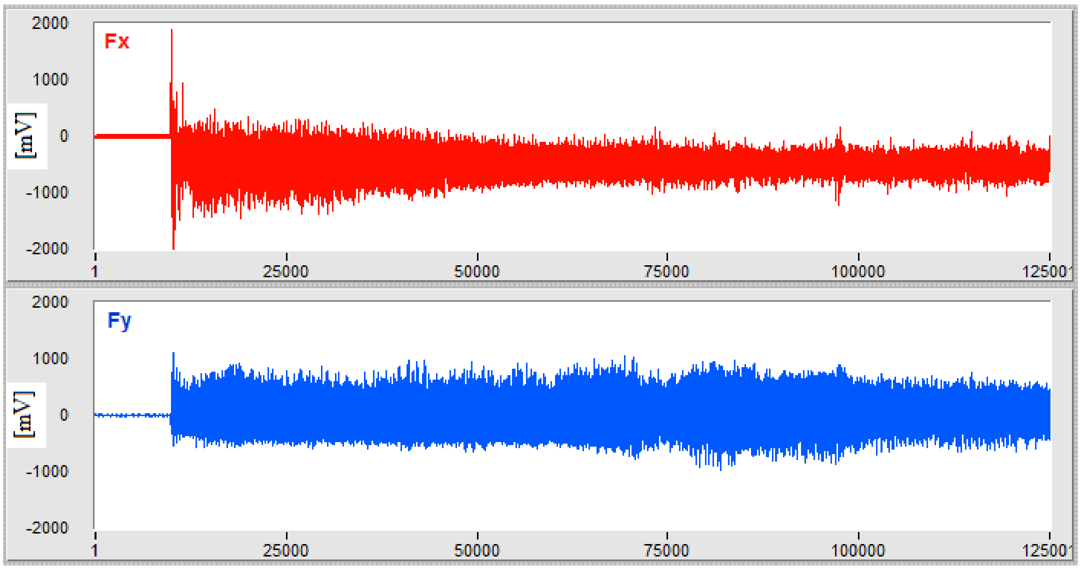

Figure 2. Example of typical signal waveform

RESULTS AND DISCUSSION

Figure 3 shows the results of research on resultant cutting forces for native wood and compacted wood. The average value of the cutting forces for native wood was 34.36 N, while for compacted wood it was 51.61 N. Figure 4 shows the average roughness results. The analysis of variance (Table 2) showed that the compaction process had a statistically significant impact on all the examined characteristics of the tested material (cutting force, MOR, MOE, density and hardness).

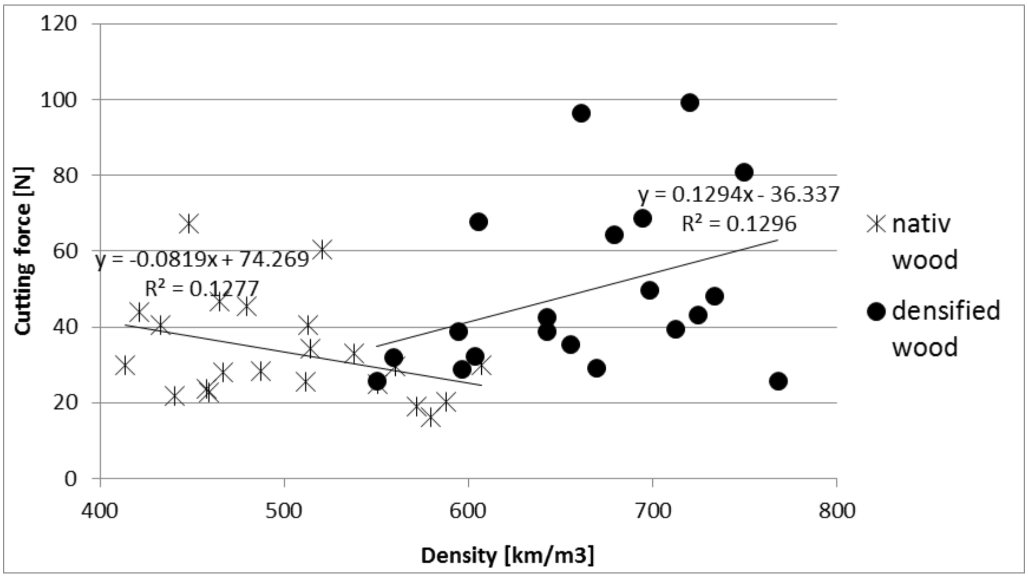

Figure 3. Influence of wood density on cutting forces for native wood and densified wood

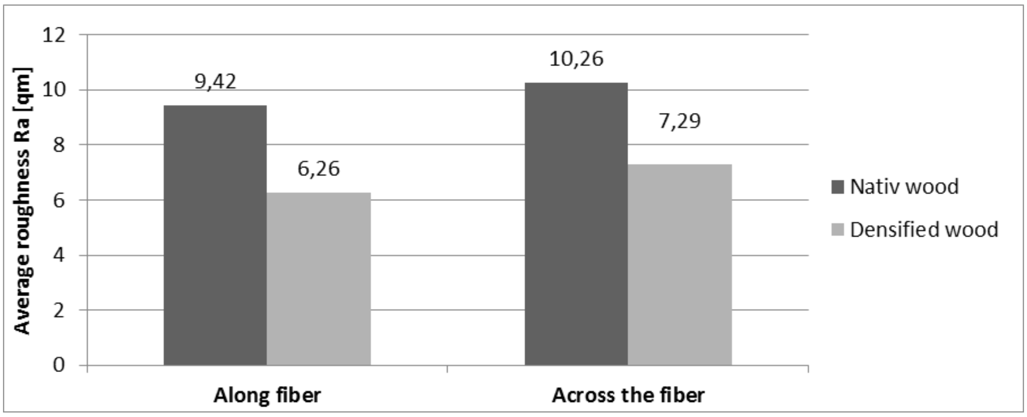

Figure 4. Average roughness values of the native wood and densified wood specimens along and across fiber orientations.

Table2. Analysis of variance for the tested material

	SS	Df	MS	F	p
		Force			
Factor	416470	1	416470	6,9562	0,0121
Error	2215200	37	59870		
		MOR			
Factor	39383	1	39383	13,044	0,0008
Error	111707	37	3019		
		MOE			
Factor	519917900	1	519917900	6,9912	0,0119
Error	2751603000	37	74367640		
		Density			
Factor	264078	1	264078	70,087	0,0000
Error	139410	37	3768		
		Hardness			
Factor	4686,67	1	4686,67	42,366	0,0000
Error	4093,05	37	110,62		

SS–sum of the squares of deviations from the average value, Df–number of degrees of discretion, MS – average square of deviations (MS=SS/Df), F – test value, p – probability of error,

CONCLUSION

Based on the performed analyzes the following conclusions can be drawn:

1. Thermomechanical wood compaction has a statistically significant effect on the increase of cutting forces during milling. With the increase in the density of wood by 150 kg/m^3, the value of the cutting forces increased by 66%.
2. Compacted wood is characterized by a lower roughness of the treated surface as measured by the Ra index measured both along and across the fibers.
3. Wood compaction increases the values of bending strength, modulus of elasticity, hardness and density.

Thermomechanical compaction of Scots pine wood significantly increases the cutting forces simultaneously increasing the quality of the treated surface. The observed decrease in roughness is the desired effect of the modification process, both during gluing and finishing wood with paint and varnish coatings.

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REFERENCES

1. ADAMCZYK-KRÓLAK IZABELA 2013: Drewno modyfikowane termicznie. Budownictwo o zoptymalizowanym potencjale energetycznym 1(11) 2013, s. 7-13
2. BEKHTA P., PROSZYK S., KRYSTOFIAK T., MAMONOVA M., PINKOWSKI G., LIS B. 2014: Effect of thermomechanical densification on surface roughness of wood veneers, "Wood Material Science and Engineering" Publisher: Taylor & Francis Pages 233-245
3. ESTEVES B., NUNES L., PEREIRA H.,2011: Properties of furfurylated wood (Pinus pinaster), European Journal of Wood and Wood Products, 69, 521-525
4. EYMAA F., MÉAUSOONEB P.J., MARTINC P.2004: Study of the properties of thirteen tropical wood species to improve the prediction of cutting forces in mode B Annals of Forest Science 61 (2004) 55–64
5. HECKERM.; BECKERG. 1995: Surface roughness of Douglas fir veneer as a result of silviculture management. Paper presented in the IUFRO XX World Congress. Tampere, Finland. August 6–12, p 352.
6. HLÁSKOVÁ L., KOPECKÝ Z., NOVÁK V. 2020: Influence of wood modification on cutting force, specific cutting resistance and fracture parameters during the sawing process using circular sawing machine, European Journal of Wood and Wood Products 78:1173–1182
7. KOLLMAN E.P., KUENZI E.W., STAMM A.J. 1975: Principles of wood science and technology Wood Based Materials, vol. II, Springer-Verlag, New York, Heidelberg, Berlin pp. 139-149
8. KOZAKIEWICZ P. 2010: Effect of Temperature and Moisture Content on Compression Strength Parallel to the Grain of Selected Species of Wood with Variable Density and Anatomical Structures], Treatises and Monographs series of Publishing WULS- SGGW, Warsaw, Poland.
9. LAINE K., SEGERHOLMK., WÅLINDERM., RAUTKARIL., HUGHESM. 2016: Wood densification and thermal modification: Hardness, set-recovery and micromorphology. Wood Science and Technology 50 [5]: 883-894
10. LASKOWSKA A. 2020: Density profile and hardness of thermo-mechanically modified Beech, Oak and Pine wood. Drewno 2020, Vol. 63, 25-41.

11. LASKOWSKA A. 2020: The influence of ultraviolet radiation on the colour of thermo-mechanically modified beech and oak wood Maderas. Ciencia y tecnología 22(1): 55 - 68, 2020
12. LAVERYD.J., MCLARNONTUL D., TAYLOR J.M., MOLONEY S., ATANACKOVICA. 1995: Parameters affecting the surface finish of planed Sitka spruce. Forest Products Journal 45:45–50.
13. LI Y., LIU Z., DONG X., FU Y., LIU Y., 2013: Comparison of decay resistance of wood and wood-polymer composite prepared by in situ polymerization of monomers, International Biodeterioration and Biodegradation, 84, 401-406.
14. NGUYEN, C. T., WAGENFÜHR, A., PHUONG, L. X., DAI, V. H., BREMER, M., AND FISCHER, S., 2012: The effects of thermal modification on the properties of two Vietnamese bamboo species, Part I: Effects on physical properties, BioResources. 7(4), 5355-5366.
15. TANAKA, C.,1991: Relationship between surface finish quality and acoustic emission count 239 rate in circular sawing. Paper presented in the Tenth International Wood Machining Seminar. October 21–23, University of California, Forest Products Laboratory, Richmond, CA, pp 308–316
16. THOMA H., L PERILEONIDHA PERIENTELA LATOENTELA LATOMADERAS CIENCIA., 2014: Evaluation of wood surface roughness depending on species characteristics. Maderas-Cienc Tecnol 17(3):
17. ÜLKER O., İMIRZI Ö., BURDURLU E., 2012: The effect of densification temperature on somephysical and mechanical properties of Scots pine (Pinus sylvestris L.)”. BioResources 7: 5581-5592
18. www.versal.com.pl/zagęszczanie-drewna ,2017

Streszczenie: *Wpływ zagęszczania termomechanicznego drewna sosny (Pinus sylvestris L.) na siły skrawania oraz jakość obróbki podczas frezowania.* W pracy przedstawiono wyniki badań dotyczące oceny skrawalności drewna sosny zwyczajnej zagęszczanej termomechanicznie. Oceny dokonano na podstawie sił skrawania oraz chropowatości powierzchni po procesie frezowania. Zbadano wybrane właściwości drewna natywnego i modyfikowanego. Na podstawie przeprowadzonych badań stwierdzono, że drewno zagęszczane charakteryzuje się wyższymi siłami skrawania podczas frezowania. Zbadano, jakość powierzchni po frezowaniu i określono wartości wskaźnika chropowatości Ra. Z przeprowadzonych badań wynika, że drewno modyfikowane charakteryzuje się niższą wartością wskaźnika Ra zarówno wzdłuż jak i w poprzek włókien. Analiza statystyczna wykazała, że modyfikacja wpływa w sposób istotny statystycznie na wartości sił skrawania oraz właściwości fizykomechaniczne badanego drewna.

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