

Effect of thermomechanical modification of Scots pine (*Pinus sylvestris* L.) wood on machine sanding efficiency

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Abstract: *Effect of thermomechanical modification of Scots pine (*Pinus sylvestris* L.) wood on machine sanding efficiency.* The aim of this study was to investigate the effect of thermomechanical modification of pine wood (*Pinus sylvestris* L.) on the efficiency of machine sanding. For this purpose, pine wood samples (undensified and densified) were subjected to mechanical sanding. The effect of the modification on the mass loss in the sanding process was investigated and the quality of the obtained surface was examined. Roughness parameters Ra and Rz were used as criteria for the quality of the sanded surface. The study was carried out for three different grit sizes of sanding paper. It was found that the thermomechanical modification of Scots pine wood had a statistically significant effect on the mass loss during sanding and the roughness of the obtained surface. Wood samples subjected to thermomechanical compaction were characterised by lower susceptibility to sanding measured on the basis of weight loss and lower surface roughness.

Keywords: wood densification, sanding, roughness, weight loss,

INTRODUCTION

Solid wood is a relatively easily accessible, inexpensive and natural renewable raw material. It is used in many areas of our life: furniture production, construction, boatbuilding and many others. Wood is an anisotropic material; its physical and mechanical properties depend on factors such as humidity, the presence of natural defects, the proportion of earlywood and latewood, and in particular on the species.

New solutions are constantly sought to improve its properties and increase its functionality. Consequently, wood is subjected to modification during which its components or structure may be changed, and these changes lead for example to improved strength of the material or reduced hygroscopicity. Examples are compression and bending of wood, which have been known to people for years. More recent solutions include thermal modification, acetylation or furfurylation. Such treatments are aimed at changing certain well-defined properties of wood. Wood modification is carried out in order to improve dimensional stability, resistance to weathering and UV radiation, sensitivity to moisture, resistance to biological degradation and increase hardness. In each of the cases mentioned, the modification does not affect dissolved wood or wood fibres and the raw material retains its natural character. According to Jones et al, (2019) a product whose physical, chemical or aesthetic properties have been altered and the material itself has gained new functions is a wood-based material. The processes involved in the above-mentioned modifications of wood are industrial processes that result in wood-based materials that are non-toxic both in use and at the end of their useful life. Wood modified in this way can be disposed of in an environmentally safe way.

Wood modification can be divided into those in which foreign substances are added to the raw material (furfurylation - furfuryl alcohol, acetylation - acetic anhydride) or those based on changing properties through the action of heat, steam, high pressure or a combination of these procedures. We can distinguish between thermo-hydro (TH), thermo-hydromechanical (THM) and thermo-mechanical (TM) modifications.

In THM, by exposing the wood to water and hot steam, the material can be softened sufficiently to enable the intended shaping of the wood. Typically, thermal treatment of wood is in the temperature range 100 - 300°C. As reported by Sandberg et al (2013) treating wood at temperatures above 300°C is of limited value, which is due to the severe degradation of the wood material. According to CEN (2007), thermally modified wood (TMT) is wood that is exposed to temperatures >160°C with limited oxygen availability. It is then so altered that some of its properties have undergone permanent changes across the cross-section.

Wood and wood-based materials are industrially sawn, milled, drilled or sanded. Modified wood is also subjected to the same processing operations as unmodified material. A large number of publications on sanding of wood and wood-based materials can be found in scientific literature. However, little attention is paid to the processing of modified wood, whose physical and mechanical properties differ from natural wood.

Sanding is very important in the furniture industry. It is one of the basic methods of final product finishing. The purpose of sanding is to obtain a high quality surface, and what follows, an assumed surface roughness. This, in turn, is important in the processes of gluing or applying paint and varnish products.

High quality in the sanding process is a combination of several important aspects. Thorpe and Brown (1995) state that the species of wood and its density have a colossal influence on the result obtained, they proved, among others, that in the process of sanding the amount of removed wood irreversibly changed with the density of the wood. As presented in their work by Sydor et al (2021), a faster decrease in machine sanding efficiency is shown by coniferous wood species, i.e., with lower density. The probable reason for this was that in soft coniferous wood, the free spaces (between the abrasive and the wood) become clogged with wood dust much faster. The study also confirmed earlier suspicions about the efficiency of the process in its individual phases. It also proved that lighter deciduous species (walnut, alder) behave similarly to coniferous wood in terms of wood removal efficiency, which has not been compared before. It has been shown that P60-grit bands blunt much faster than higher-grit bands (P180).

Studies evaluating the time required to grind a particular layer of material have shown that the average sanding times for pine are almost half that of spruce, despite the similar hardness of the species.

Očkajová in (2016) subjecting two deciduous species, pedunculate oak (*Quercus robur*) and beech (*Fagus sylvatica*), to a study found that despite a small difference in density (678 and 684 kg/m³, respectively), it had an effect on wood removal rates. On the other hand, Saloni et al (2005) compared the sanding parameters for whitebark pine (*Pinus strobus*) and hard maple (*Acer saccharum*), they proved that the wood species had a significant influence on the sanding results. Miao and Li (2014) conducting a study on two wood species, birch (*Betula sp.*) and Manchurian ash (*Fraxinus mandshurica*), with densities of 470 and 620 kg/m³ respectively, proved that the harder and denser ash material was more difficult to grind.

Wieloch and Sikliena (2004) in their study examined the effect of prolonged sanding on the variation in efficiency for beech wood. The study lasted 8h, abrasive belts with the following gradations were used: P40, P80, P120, and the following belt contact forces: p = 1.0; 1.5; 1.85; 2.0 N/cm². At the lowest of these, a rectilinear decrease in the sanding process efficiency was observed.

In a comparative oak trial, Očkajová et al (2016) found that wood species and sanding direction have a significant effect on contact pressure, which ensures long-lasting abrasive belt efficiency. In their study, the wood species was shown to be more important than the cutting direction and thus had a greater impact on the efficiency of the sanding belt. The examples presented here describe studies in which manual belt sanders were used. The belt speed was vs < 10 m/s and the pressure was relatively high 20000 Pa. In comparison, industrial belt

grinders operate at $v_s > 10$ m/s and pressure $p < 10000$ Pa. Such studies are described in their work by Saloni et al. (2005), where a study comparing industrial sanding of maple and pine wood is presented. It was found that the sanding of pine wood was more efficient and that the influence of contact pressure and sanding paper belt speed affected the efficiency.

It is also important to note that sanding efficiency decreases during the process due to the progressive blunting of the abrasive belt. According to Očkajová et al (2016), the following three phases of sanding belt blunting are distinguished: initial sharpness, working sharpness and sanding belt blunting. In the first phase, there is a very large reduction in efficiency during sanding. The accepted limit between the first two phases is a clear stabilisation of the mentioned decrease in efficiency, ranging from 45-50% in relation to the initial sanding efficiency. In the second phase, where the greatest abrasive wear occurs, a slower decrease in sanding efficiency can be observed, by about 10-20% in relation to the initial value. In the third and final phase, there is a sharp decrease in sanding quality caused by tool (paper) wear.

Issues related to the specific effect of abrasive grains on wood have been studied both from the point of view of abrasive tools such as grain size and type of abrasive paper, but also from the point of view of machine tool design (Vlasev et al., 2019) and the technological parameters used (detailing the speed of the abrasive belt, the pressure, the orientation of the wood fibres at the time of sanding and the size of the sanded surface itself) (Porankiewicz et al., 2010), (Gurau et al., 2005).

In the sanding process other aspects are also important such as, the economic problem of the technology used, this includes: the final quality of the product being as high as possible, and the appropriate number of pieces produced along with its speed. Both problems can be solved by optimal selection of tools and machining parameters (Csanády and Magoss, 2013).

The aim of this study is to investigate the effect of thermomechanical modification of pine (*Pinus sylvestris L.*) wood on machine sanding efficiency.

MATERIALS AND METHODS

The material tested was pine sawn timber (*Pinus sylvestris L.*) with an average density of 476 kg/m^3 and thermo-mechanically compacted pine sawn timber, which was subjected to industrial modification using an Italpress high-pressure press, model GL/260 - PS. Before compaction, the sawn timber was heated between the shelves of the press at 900°C for 20 min to soften the lignin and then pulsed in three stages. In the first pulse the timber was compacted to 22 mm from an average thickness of 24 mm, after which the press was opened (the top shelf of the press was moved away from the timber being pressed). In the second pulse the timber was compacted to 20 mm, after which the top shelf of the press was moved away from the boards being compacted again to allow for stress relaxation. In the third pressing pulse the timber was pressed to 18mm. During the last pressing impulse, the timber was held in the press for 30 seconds and the press shelves were opened. Elastic reformation of the compacted boards was observed after each pressing impulse and after the last impulse the boards were reformed to an average thickness of approx. 20 mm. The sawn timber, which had an initial nominal thickness of 24mm, was compacted to approx. 20 mm, the original average board width of 90 mm was increased to an average of 92 mm (measured as moulded timber). The resulting cross-sections of the boards after pressing were not flat. As a result of thermo-mechanical pressing of the lumber, its average density increased. Density measurements of compacted samples showed an increase to 693 kg/m^3 , i.e., an increase of about 46%. Figure 1 shows a comparative photograph of Scots pine (*Pinus sylvestris L.*) samples - left - and thermo-mechanically compacted Scots pine samples - right.



Fig. 1. Samples of Scots pine (*Pinus sylvestris L.*) and thermomechanically densified Scots pine.

The test material was brought to a constant moisture content of 7.1% and identical dimensions, which were 120 mm x 55 mm x 25 mm for non-compacted pine and 120 mm x 55 mm x 20 mm for compacted pine, respectively. A workshop digital caliper and a moisture meter model HM8-WS25 were used for the measurements.

The basic wood properties, such as static bending strength, modulus of elasticity and Brinnell hardness, were tested according to the standards PN-63/D04117, PN-EN 1534:2011. The averaged test results based on 16 samples for each material batch are presented in Table 1.

Table 1. Selected mechanical and physical properties of undensified pine (UDP) and densified pine wood (DP).

	Density [kg/m ³]	Hardness	MOR [MPa]	MOE [MPa]
Undensified pine	476	15	91	8554
Densified pine	693	43	164	16811

The material for testing was ground on a Houfek Basset Eco 250 belt grinder with movable table, the schematic diagram of that machine is shown in Figure 2. For the tests were used new Klingspor abrasive belts with three different gradations - P80, P120 and P180. The abrasion process for each of the two materials was carried out in five 30-second cycles for each sample using different abrasive belts. After each single cycle, the sample was weighed using a RADWAG electronic balance model WLC 6/12/F1/R with an accuracy of 0.1g. Then the mass loss for the first measurement was calculated in relation to the initial mass, and for the subsequent ones in relation to the previous one.

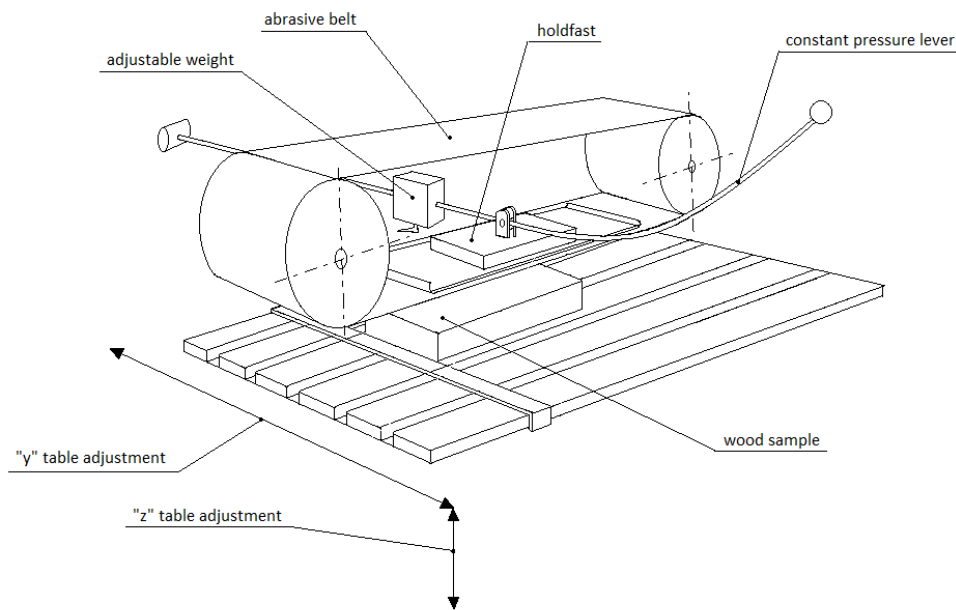


Figure 2. Schematic diagram of a long-belt sander used to sanding samples.

After the last sanding cycles, roughness measurements were made in the direction perpendicular to the course of the fibres. The measurements were carried out with a portable surface roughness measuring device Mitutoyo SJ - 201, which in its measurements ensures compliance with ISO, VDA, ANSI and JIS standards, is equipped with a diamond tip with an angle of 60° , a detector pressure of 0.75 mN, a measuring range of 16 mm, and an operating range of 360 μm : Ra and Rz.

The obtained results were subjected to one-way ANOVA statistical analysis in the Statistica program.

RESULTS

Both static bending strength and modulus of elasticity measurements for densified pine were almost twice as high as for undensified pine. This confirms the assumption of a much higher strength of thermo-mechanically densified wood relative to the natural equivalent species. The Brinell hardness measurement clearly indicated an almost 3-fold higher hardness of densified pine samples in relation to the undensified pine species. This confirmed the assumption of an increase in hardness with increasing material density.

Figures 3, 4 and 5 show the dependence of weight loss on sanding time for three paper grades for non-densified Scots pine (undensified pine) and thermomechanically densified Scots pine (densified pine). The results of the statistical analysis are presented in table Table 2.

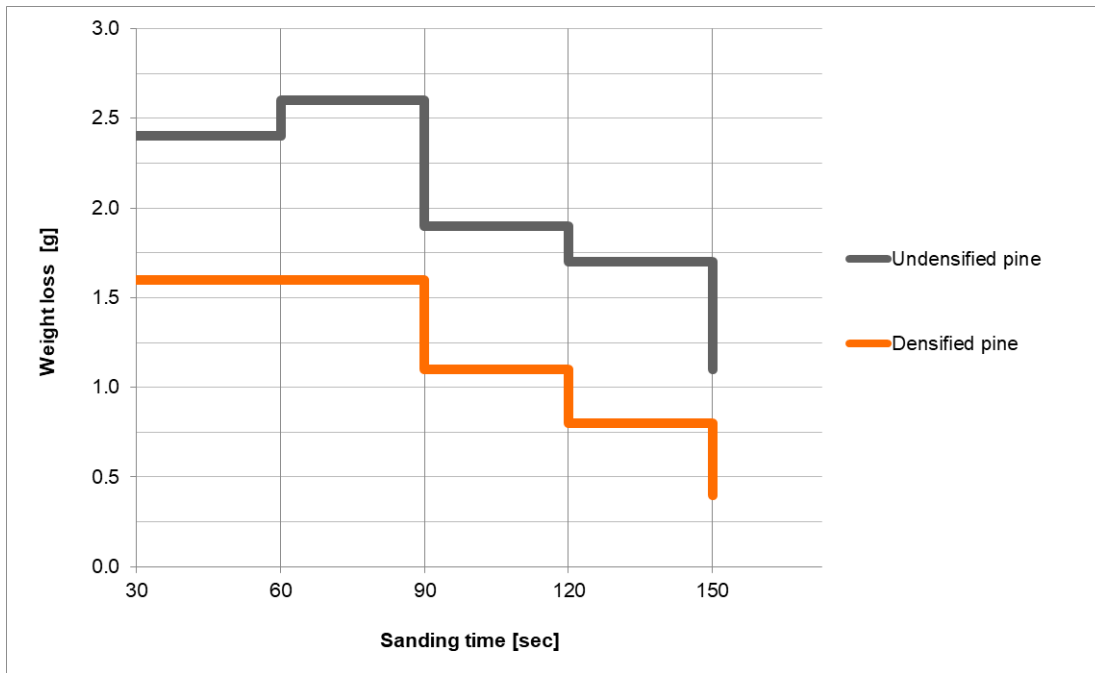


Fig. 3. Dependence of weight loss on sanding time for abrasive belt P80.

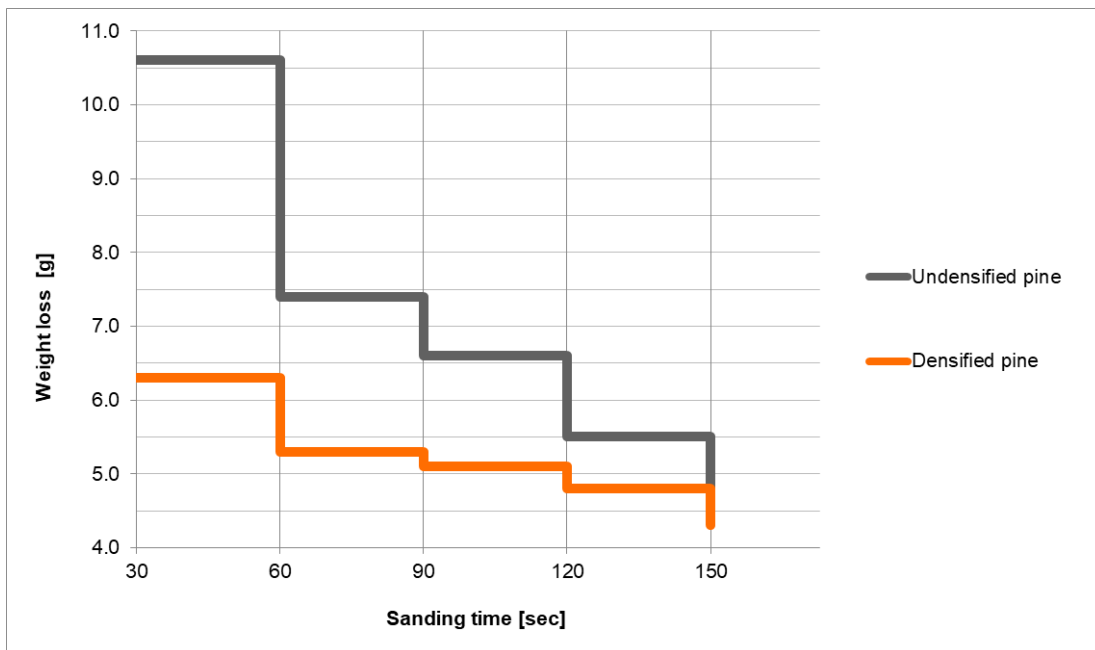


Fig. 4. Dependence of weight loss on sanding time for abrasive belt P120.

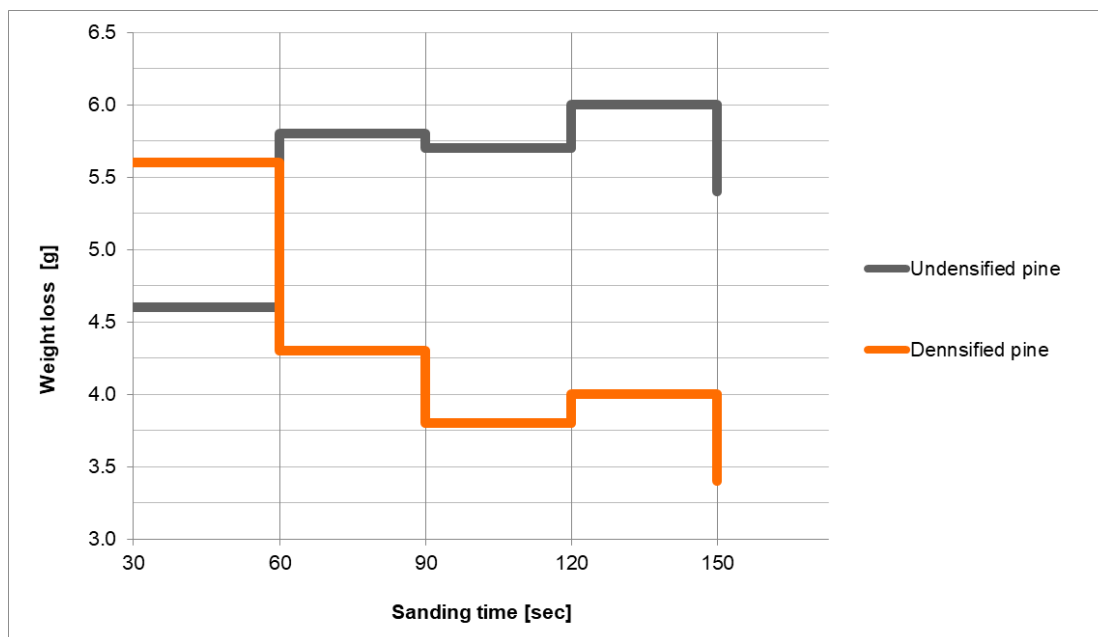


Fig. 5. Dependence of weight loss on sanding time for abrasive belt P180.

Table 2. Analysis of variance for selected factors and interactions between factors affecting the sanding process of pine and thermo-mechanically densified wood.

factors	SS	Df	MS	F	p
Loss 80					
Densify	141,12	1	141,12	63,87	0,0000
Error	66,29	30	2,21		
Loss 120					
Densify	614,25	1	614,25	53,15	0,0000
Error	346,68	30	11,56		
Loss 180					
Densify	345,19	1	345,19	9,74	0,0039
Error	1063,30	30	35,44		

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,

The results presented in the graphs show that for abrasive belt P80 the loss of mass in time is similar for both undensified and thermo-mechanically compacted samples. In the first two cycles, the weight loss remains at a similar level, about 2.5g for Scots pine and 1.6g for modified pine, while in the next cycles it decreases significantly and amounts to 1.1g and 0.4g respectively. This may indicate that in the first stages of sanding the wood we grind off any irregularities resulting from the anatomical structure of the wood. In the later stages, however, due to the increasingly even surface, the loss of mass during sanding decreases quite predictably. When using a P120-graded sanding band, it has been observed that the initial surface quality for pine wood and densified samples clearly differs. This is confirmed by the results in the graph, which show that in the first sanding cycle the compacted wood had a significantly more uneven surface, hence an almost 2 times greater mass loss, which amounts to 10.6g for Scots pine and 6.3g for compacted pine. In later stages, the mass of Scots pine samples decreases quite drastically and several times faster than in densified pine, approaching its value and oscillating within the range of 4.4g, while clearly aiming at 0. When sanding with

an abrasive belt P180, the mass loss of samples in time behaved quite irregularly and quite the opposite comparing the two mentioned wood types. Non-compacted pine loses 4.6 g after the first cycle and 5.8 g, 5.7 g, 6.0 g and 5.4 g after 150s of sanding in the next cycles. In comparison, densified pine loses 5.6g, 4.3g, 3.8g, 4.0g and 3.4g respectively. As can be seen, the trend in weight loss retains similarity only in the last sanding cycle. Figures 6 and 7 show the roughness indices Rz and Rz obtained during sanding. The results of the statistical analysis are presented in Table 3 and 4.

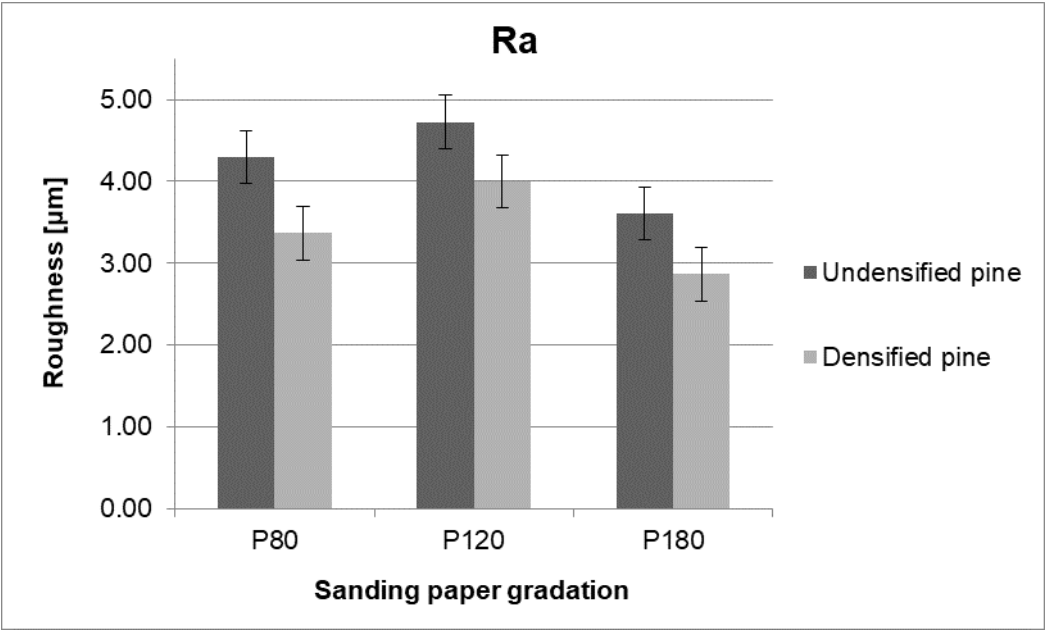


Fig. 6. Surface roughness parameter Ra of Scots pine and thermo-mechanically densified pine.

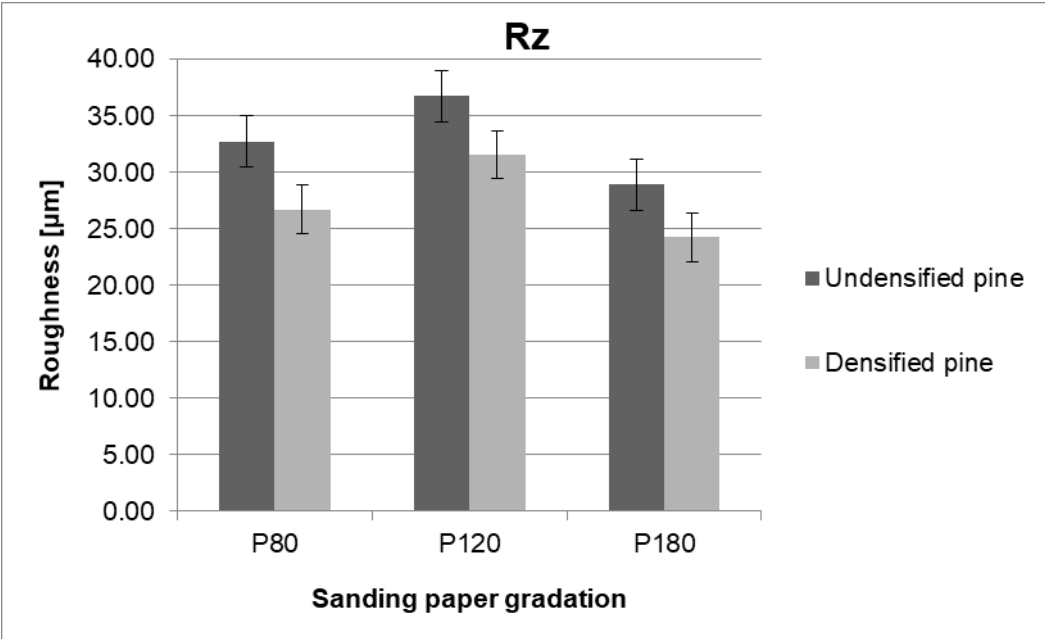


Fig. 7. Surface roughness parameter Rz of Scots pine and thermo-mechanically densified pine.

Table 3. Analysis of variance for selected factors and interactions between factors affecting the sanding process of pine and thermo-mechanically densified wood.

factors	SS	Df	MS	F	p
Ra P80					
Densify	6,93	1	6,93	37,73	0,0000
Error	5,51	30	0,18		
Ra P120					
Densify	4,21	1	4,21	22,74	0,0000
Error	5,56	30	0,18		
Ra P180					
Densify	4,41	1	4,41	46,06	0,0000
Error	2,87	30	0,10		

Table 4. Analysis of variance for selected factors and interactions between factors affecting the sanding process of pine and thermo-mechanically densified wood.

factors	SS	Df	MS	F	p
Rz P80					
Densify	287,22	1	287,22	24,29	0,0000
Error	354,72	30	11,82		
Rz P120					
Densify	218,60	1	218,60	18,85	0,0001
Error	347,94	30	11,60		
Rz P180					
Densify	172,13	1	172,13	28,40	0,0000
Error	181,81	30	6,06		

The comparison of graphs shows that for both roughness parameters Ra and Rz, the surface quality when ground with each of the three gradations of papers is noticeably higher in densified pine. The biggest difference in favour of modified samples was caused by sanding with P80 paper and amounted to 0.93 μ m for Ra parameter and 5.99 μ m for Rz parameter. When using P120 and P180 abrasive belts the difference was 0.73 μ m and 0.74 μ m for Ra and 5.23 μ m and 4.64 μ m for Rz.

CONCLUSIONS

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

1. Thermomechanical modification of Scots pine wood (*Pinus sylvestris L.*) significantly affects the efficiency of sanding and the roughness of the obtained surface.
2. The modified wood samples were less susceptible to sanding, as measured by weight loss.
3. The static bending strength and the modulus of elasticity for the analyzed densified pine are almost twice as high as for the undensified Scots pine.
4. The supposition that hardness increases with increasing material density was confirmed. According to the Brinell method, the hardness of the densified pine in comparison to the non-densified species proved to be almost 3 times higher.
5. Thermomechanical modification of Scots pine wood (*Pinus sylvestris L.*) significantly affects the efficiency of sanding and the roughness of the obtained surface.

6. The modified wood samples were less susceptible to sanding, as measured by weight loss.
7. The thermomechanically modified wood samples were characterised by lower roughness after the sanding process. Such a feature is particularly desirable during the application of paint and varnish coatings.

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Streszczenie: *Wpływ termomechanicznej modyfikacji drewna sosny zwyczajnej (Pinus sylvestris L.) na wydajność szlifowania maszynowego.*

Celem pracy było zbadanie wpływu termomechanicznej modyfikacji drewna sosnowego (*Pinus sylvestris L.*) na wydajność szlifowania maszynowego.

W tym celu próbki drewna sosny zwyczajnej (natywne oraz zagęszczane) poddano szlifowaniu mechanicznemu. Zbadano wpływ modyfikacji na ubytek masy w procesie szlifowania oraz zbadano jakość uzyskanej powierzchni. Jako kryteria jakości szlifowanej powierzchni przyjęto parametry chropowatości Ra i Rz. Badania przeprowadzono dla trzech różnych ziarnistości papieru szlifierskiego. Stwierdzono, że termomechaniczna modyfikacja drewna sosny zwyczajnej wpływa istotnie statystycznie na ubytek masy podczas szlifowania i chropowatość uzyskanej powierzchni. Próbki drewna poddane zagęszczaniu termomechanicznemu charakteryzowały się mniejszą podatnością na szlifowanie mierzoną na podstawie ubytku masy i niższą chropowatością powierzchni.

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