The Influence of Thermomechanical Smoothing on Beech Wood Surface Roughness

Jozef Gáborík,[a] Milan Gaff, [b]* Daniel Ruman,[b] Marek Šomšák,[a] Zuzana Gaffová,[b] Tomáš Svoboda,[b] Vojtech Vokaty,[b] and Adam Síkora [b]

This paper deals with the change of roughness of compressed beech wood. Effects of temperature, pressure, and time on the results of pressing were examined. The surface roughness of beech wood in longitudinal and transversal directions was evaluated. Roughness was described by R_a. A contact method was applied. The results show that by increasing pressure, time, or temperature, the surface roughness of beech wood decreases. The highest roughness reduction occurred at the temperature of 150 °C, pressure 4 MPa, and time 20 min.

Keywords: Beech; Roughness; Temperature; Pressure; Time

*Contact information: a: Department of Furniture and Wood Products, Technical University in Zvolen, T. G. Masaryka 24, Zvolen, 96053, Slovakia; b: Department of Wood Products and Wood Constructions, Czech University of Life Sciences in Prague, Kamýcká 1176, Praha 6 - Suchdol, 16521, Czech Republic; * Corresponding author: gaffmilan@gmail.com*

INTRODUCTION

Wood is a material that can be treated using various technologies to create altered and improved final products. Every product has different surface quality requirements, when considering its function and aesthetic appearance. The quality of an individual product surface represents the output of certain production technology.

Each technological operation leaves characteristic irregularities on the surface, affecting the integrity and usage of the treated surface of the specimen. It is necessary to regard these irregularities both in their macrogeometric and microgeometric aspects (Kvietkova *et al.* 2015a).

Macroscopic and microscopic irregularities are very minor deviations from an ideal flat surface, which form on the wood surface (Prokeš 1982). The wood surface is a border region which divides the wood substance from the surrounding environment (Požgaj *et al.* 1997). To obtain a more complete idea of wood surfaces, it is necessary to know information regarding many of its properties, such as morphology, chemical composition, optical properties, thermodynamic properties, *etc*. (Kurjatko *et al*. 2010). It is also necessary to be familiar with the effects of a whole range of factors on the surface properties. These factors include methods of wood surface treatment, moisture, temperature, *etc*.

With real wood surfaces, it is always necessary to take into account the effect of the operating instrument on the geometry of the surface (Liptáková *et al*. 1995).

The geometry of the wood surface results from a combination of its anatomical structure and the selected treatment method. The principle of evaluating the surface geometry of solid materials lies in the classification and quantification of deviations, corresponding to the actual surface from the base surface.

In technological practice, researchers differentiate between three deviations of geometric surfaces, which consider the range of rough irregularities:

- Order 1: Deviation represents major macrogeometric defects on the whole surface. This deviation is mostly considered a deviation from the geometrical shape.
- Order 2: Deviation is a waviness. It is given mainly by the method of treatment and by technological operations.
- Order 3: Deviation of higher orders, included in the common name of roughness (Liptáková and Sedliačik 1989; Liptáková and Kudela 2000).

Surface roughness is a geometric property that is determined by the material type, and also by the method of treatment (Kvietkova *et al.* 2015b). During evaluation, the same criteria are used for solid materials with a certain degree of irregularity. The examination of surface roughness is the most utilized method of surface quality evaluation.

Roughness can be expressed by several parameters (*e.g.*, R_a - arithmetical mean deviation of the assessed profile, R_z - maximum height of the profile, R_p - maximum profile peak height, R_v - maximum profile valley depth). According to the norm STN EN ISO 4287 (1997), the R_a characteristic is considered one of the main evaluation criteria for evaluating roughness, and it is appropriate to supplement the characteristic with the other aforementioned parameters.

Roughness and waviness are determined either by contact or optical profilometers. It is necessary to correctly choose the sampling length, as the (*R*) and (*W*) parameters of roughness are established (Kúdela 2010). The treated surface quality is determined by treatment with an appropriate instrument, by which the irregularities on the wood surface are removed. The most utilized method of final wood surface treatment is sanding, and to a lesser extent, milling. The slowness and dustiness of the sanding process poses many problems. That is why new methods of decreasing the roughness of a wood surface utilizing mechanical, or more precisely, thermomechanical treatment are being researched (Gáborík and Dudas 2008; Gáborík and Žitný 2010).

Several authors have attempted to increase the smoothness of a sample's material surfaces in their works (Sandig 1998; Kneist and Raatz 2001; Raatz 2002; Wieloch 2004; Rehm and Raatz 2005). The authors engaged in a thermomechanical method of wood surface treatment, namely thermal-smoothing by rolling and hot pressing. Thermal-smoothing is considered a final treatment for the wood surface. By the use of temperature and pressure, a so called thermo-effect develops, which plasticizes the surface fibers, pressing them into the surface. As a result of lignin melting, which floods the irregularities of wood, the treated surface becomes smoother and shinier (Mýtny 1995; Wieloch 2004).

During this work, the researchers focused on wood surface treatment by hot pressing (thermal-smoothing). This study investigated the effect of pressing factors (*i.e.*, temperature, pressure and duration) on the roughness of the wood surface, in relation to the direction of the wood fibers. The purpose of this paper was to evaluate the effect of the examined factors on the surface roughness of the beech wood, *i.e.*, the increase in surface smoothness by thermal-smoothing.

EXPERIMENTAL

Materials

Beech wood (*Fagus sylvatica* L.) originated from the Poľana region of central Slovakia. Logs were cut into planks. Heartwood planks were cut into samples with dimensions of 16 x 60 x 100 mm. The number of samples was 10 for each measurement. They were cut from the same batch of material. The samples were conditioned in a HCP 108 humidity chamber (Memmert, Schwabach, Germany) to a moisture content of 7%, which was determined using the weighting method in accordance with STN 490103 (1979). This moisture content corresponds to the equilibrium moisture content of furniture elements according to EN 942 (2007) and STN 91 0001/Z3 (1998).

After all the tests the samples were dried in a lab drier KBC-G-100/250 (Premed; Warsaw; Poland) at 103 ± 2 °C in order to achieve zero moisture content. The density of beech wood at its absolute driest state was ρ_0 = 650 kg/m^{-3}. The surface of the samples before hot compression was treated *via* milling. Hot pressing with stabilization (thermal-smoothing) was conducted in the radial direction, *i.e.*, the tangential surfaces of the samples were treated. The researchers evaluated the quality of the surface based on roughness observations. The roughness was determined using the Mahr Pocket Surf (Rapp Industrial Sales, Pennsylvania, United States) contact profile meter, with a sampling length of L = 5 mm. The roughness was measured in 5 areas, parallel to the wood fibers and perpendicular to the fibers (Fig. 1).

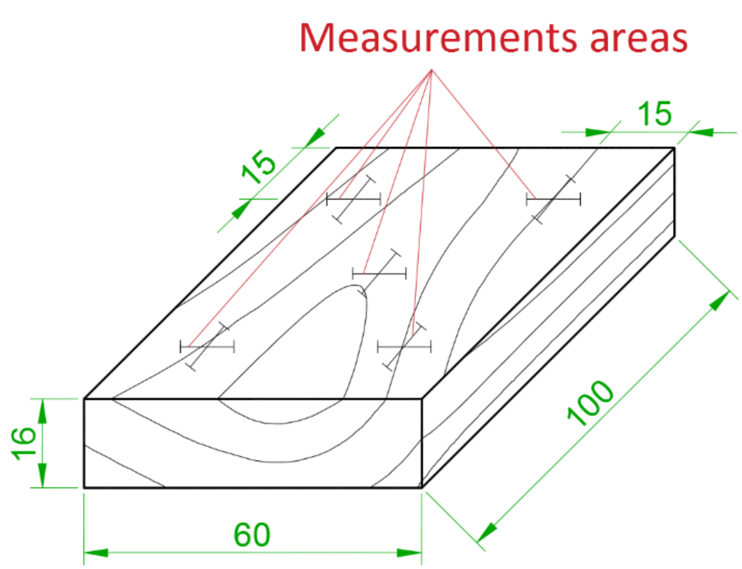

Fig. 1. Measurements areas of roughness by contact method

Methods

The researchers measured the arithmetic mean deviation of the evaluated profile (R_a). This is defined by STN EN ISO 4287 (1999) as a bidirectional roughness irregularity relating to the mean line on a sampling length, denoted as L (Fig. 2). For the purpose of scanning the surface irregularities, a scanning stylus with a 5 microns tip radius was mounted in the instrument. The measurement range of the instrument, for the arithmetical mean deviation – R_a, was 0.03 μm to 6.35 μm.

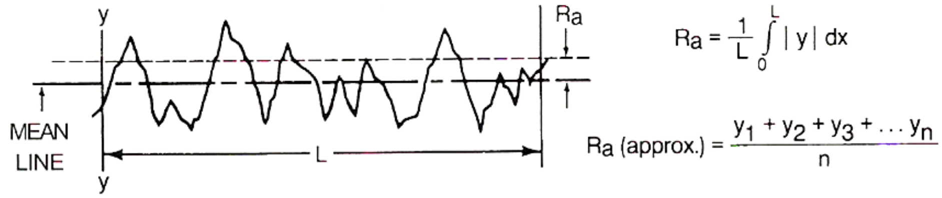

Fig. 2. Arithmetical mean deviation of the assessed profile Ra STN EN ISO 4287 (1999)

The samples were molded and planed between heated plates in a ZD 10/90 (VEB TIR RAUENSTEIN; Germany) tensile testing machine. There were polished steel sheets on the surface of the plates. The plates were heated resistively, with their own temperature regulators. Two temperatures and three pressures (each pressure with its own duration) of hot pressing were selected. The actual pressing parameters are listed in Table 1.

Table 1. Pressing Parameters

Temperature (°C)	Pressure (MPa)	Duration of compression – stabilization (min)
120	1	5
	2	10
	4	20
150	1	5
	2	10
	4	20

Based on the values of roughness (Ra) measured before and after compression, the changes in surface roughness were evaluated.

Illustrated below is the decrease of roughness, on the molded – planed surface, as opposed to the milled surface, expressed as a percentage, according to Eq. 1,

$$R_x = \frac{R_a(F) - R_a(L)}{R_a(F)} \times 100 \quad (1)$$

where R_x is the roughness change (%), $R_a(F)$ is the value of roughness after the milling (μm), and $R_a(L)$ is the value of roughness after the hot compression (μm).

RESULTS AND DISCUSSION

At the chosen thermal-smoothing conditions, the beech wood was pressed by 2.5% of its thickness. The determined values of roughness (the arithmetic mean deviation of the evaluated profile (R_a) of the wood before and after pressing) are listed in Tables 2 to 6. The input roughness achieved by plane milling reached an average value of 1.62 μm along the length of the fibers, and 2.73 μm crosswise against the fibers. Based on the ascertained data, the researchers concluded that the roughness of the milled wood surface varies depending on the fibers' direction. Extrapolating from the data, it can be concluded that the direction perpendicular to the wood fibers was 71% rougher than the direction parallel to the fiber for the beech wood. Žitný (2010) achieved similar results, listing a roughness equal to 2.86 μm lengthwise and 5.06 μm crosswise (this is 77% rougher than the direction parallel to the fiber), and 2.4 μm lengthwise and 4.7 μm crosswise (96 % rougher). After milling the radial surfaces, Rešetka (2013) found the roughness along the length of the fibers was 3.78 μm and 7.54 μm when oriented crosswise against the fibers (99.5% rougher). Wieloch (2004) found that roughness oriented crosswise across the fibers of beech wood was 3.32 μm.

After the process of thermal-smoothing by hot pressing, the roughness decreased and the average value of roughness was 1.3 μm for the lengthwise orientation, and 2.15 μm for the crosswise orientation (Table 2). Even after hot pressing, the wood roughness measured perpendicular to the fibers was 65% higher than the parallel direction. By thermal-smoothing, this difference decreased by only 6%.

Table 2. Mean Values of Roughness Before and After Hot Pressing

Surface treatment	Roughness * R_a (μm)	
	Parallel to the fibers	Perpendicular to the fibers
Milling before hot pressing	1.62	2.73
After hot pressing	1.30	2.15

Note: * the value represents the average of all values measured on the samples

The effects of the factors, *i.e.*, a temperature of 120 °C, the pressure, and the duration of hot pressing, are listed in the Tables 3 and 4. From the results, it can be extrapolated that by the gradual increasing of the pressure and the duration of stabilization in the press, a 17 to 31% decrease in the wood surface roughness in the direction parallel to the fibers, and a 15 to 40% decrease in the direction perpendicular to the fibers, can be expected.

More distinct improvements in the surface smoothness were exhibited in the direction perpendicular to the wood fibers (Table 4). A similar tendency of decreasing roughness was also exhibited on the surface of wood molded at a temperature of 150 °C. From the data in Tables 3 and 4, it can be deduced that a decrease in wood surface roughness of 20 to 39% in the direction parallel to the fibers, and 15 to 43% in the direction perpendicular to the fibers, had occurred. The increase of temperature by 30 °C yielded only a slight improvement in the examined surfaces' smoothness.

It can be concluded that a 30 °C increase in temperature (considering the marginal difference from 120 °C) did not significantly decrease the surface roughness. The contribution to the roughness decrease was only 3 to 8%.

A higher temperature, pressure, and duration of thermal-smoothing improved the smoothness of the wood surface. The improvement of wood smoothness by thermal-smoothing is also evident in the works of other authors. For example, Žitný (2010) achieved a surface improvement of 11 to 23%, Wieloch (2004) by 31%, and Kiššák (2009) by 30 to 70%. Rešetka (2013) found an improvement of the surface quality (*i.e. a* decrease of roughness) of beech wood hot pressed at 160 °C, 40% compression and 6 minutes duration. He found an average roughness 1.75 μm (a 54% decrease) in the direction parallel to the fibers and 3.25 μm (a 57% decrease) perpendicular to the fibers. It can be concluded that in these conditions, almost the same surface smoothness improvement was achieved for both directions.

Table 3. Influence of Pressing Temperature 120 °C and 150 °C, Pressure, and Time on Roughness

Temperature (°C)	Pressure (MPa)	Duration of hot pressing (min)	Roughness before hot pressing $R_a(F)$ (µm)		Roughness after hot pressing $R_a(L)$ (µm)	
			‖	⊥	‖	⊥
120	1	5	1.72	2.73	1.26	2.31
		10	1.81	2.99	1.48	2.53
		20	1.57	2.68	1.31	2.11
	2	5	1.55	2.65	1.28	2.17
		10	1.72	2.70	1.29	2.19
		20	1.69	2.84	1.14	2.08
	4	5	1.44	2.81	1.04	1.67
		10	1.59	2.62	1.17	1.91
		20	1.72	2.89	1.19	1.93
	Average		**1.65**	**2.77**	**1.24**	**2.10**
150	1	5	1.55	2.65	1.28	2.17
		10	1.72	2.70	1.29	2.19
		20	1.69	2.84	1.14	2.08
	2	5	1.51	2.73	0.98	1.83
		10	1.60	2.60	1.28	2.02
		20	1.66	2.63	1.22	2.03
	4	5	1.79	2.88	1.34	2.16
		10	1.55	2.67	1.23	1.87
		20	1.63	2.87	1.00	1.64
	Average		**1.63**	**2.73**	**1.20**	**2.00**

Wieloch (2004) and Móza (2010) decreased the roughness by 12.5% to a value of 2.1 µm, by hot pressure with the parameters of 140 °C temperature and stabilization 2 min. During the surface treatment by gradual sanding, the researchers achieved a 33.3% decrease in the R_a value, resulting in a roughness value of 1.6 µm. In this case, the moistening of the surface by water, with the addition of urea-formaldehyde glue, facilitated a better smoothness. Moistening was conducted between the first and second sanding. Gurau *et al.* (2004) achieved a surface roughness of 1.8 to 2.1 µm by sanding beech.

The mentioned data corresponds with the results of Wieloch (2004) and Žitný (2010).

Table 4. Influence of Pressing Temperature 120 °C and 150 °C, Pressure, and Time on Decrease of Roughness

Temperature (°C)	Pressure (MPa)	Duration of hot pressing (min)	Decrease in roughness R_x (%)	
			Parallel to the fibers (‖)	Perpendicular to the fibers (┴)
120	1	5	26.9	15.4
		10	18.2	15.1
		20	16.6	21.3
	2	5	16.8	18.1
		10	25.0	18.6
		20	30.7	26.8
	4	5	27.3	40.6
		10	25.9	27.1
		20	30.9	33.2
150	1	5	19.7	15.0
		10	21.5	18.5
		20	22.8	15.9
	2	5	35.1	32.7
		10	20.1	22.7
		20	26.5	22.8
	4	5	24.7	25.0
		10	20.1	30.1
		20	38.6	43.2

CONCLUSIONS

1. Many different technologies can be used to treat wood and achieve the desired quality on all surfaces. Thermal-smoothing by hot pressing can be considered a viable method of wood surface treatment. The main factors of hot pressing affecting the result of planing are pressure, temperature, and duration of stabilization in the press. During the observation of these parameters, this study found that their mutual interaction has an effect on the change in roughness (R_a (μm) - arithmetical mean deviation of the assessed profile), or more precisely, the increase in the surface smoothness of beech wood.
2. Based on the achieved results, one can conclude that after beech wood pressing, a decrease in roughness occurred in both directions, considering the structure of the wood fibers. In the direction parallel to the fibers, the roughness decreased by 15 to 40 %, and in the direction perpendicular to the wood fibers it decreased by 15 to 43 %.
3. An increase in temperature of 30 °C did not produce significant changes in the surface roughness measured by the Ra parameter.
4. The increase of the pressure and the increase of duration showed positive effects on the surface smoothness of the tangential planes of beech wood.
5. By pressing the wood, some technological operations can be excluded from the wood surface preparations, *e.g.* sanding. Surfaces treated in a better way by thermal-

smoothing undergo shorter surface treatment processes by excluding inter-operational sanding for water-soluble coating substances or by excluding the filling of the pores during treating into a closed surface. This means a decrease in coating substance usage can be achieved.

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