Quality of the Surface of Aspen Wood after Pressing

Jozef Gáborík,[a] and Milan Gaff, [b]* Daniel Ruman,[b] Miroslav Gašparík,[b]
Tomáš Svoboda,[b] Vojtech Vokaty,[b] and Adam Síkora [b]

This paper explores changes in the quality of the surface of aspen wood after pressing. Pressing, a type of processing, facilitates changes in surface quality and smoothness, thereby producing wood suitable for the furniture industry. The results obtained for the pressed wood surface were compared with those obtained for wood surfaces that were not subjected to pressing. Attention was paid to the impact of moisture, the degree of compression, and plasticizing by steam. The change in smoothness/ roughness was monitored in both the longitudinal and transverse directions (relative to the grain). The contact method was used to measure the roughness both before and after pressing. The independent variables of moisture content and degree of compression had the greatest impact on the smoothness/roughness. Plasticizing by steam had no greater impact. Therefore, the non-plasticized aspen wood was determined to be more suitable for the given purpose.

Keywords: Smoothness; Roughness; Roughness reduction; Plane milling; Cyclic pressing; Steaming; Aspen; Surface quality

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

INTRODUCTION

Wood is a renewable raw material with properties that place it in competition with other materials. Wood-processing companies must therefore search for new processes to reduce the adverse properties of wood and widen its scope of applications in non-traditional areas. As a natural material, wood has unique properties based on its natural vague. However, these properties are not always sufficient for the manufacture of modern and future products. Therefore, the wood can be treated by various processes in order to change its properties as required.

Targeted modification, mainly of soft deciduous wood species of less frequent application, may allow these species to be used in the furniture industry. For this reason, we have focused on aspen wood. Its longer fibers, lower density, and pale (white) color make it appealing for molded furniture production.

Pressing enables the modification of numerous wood properties, such as density, hardness, stability, bendability, surface smoothness, *etc*. Wood pressing may only be carried out mechanically, with eventual joint action of the heat; this case is more frequent. Densification improves the mechanical properties of all wood species. Due to the effect of heat and moisture, the substances constituting wood cellulose structure are softened. Pressed wood mechanical properties change as a function of the pressing degree and the position of pith rays (Blomberg 2006).

Under compressive stress perpendicular to the grain in the radial direction, authors (Dubovský *et al.* 1998) present a three-phase diagram (Fig.1), which occurs mainly in coniferous wood species and deciduous ring-porous wood species, as well as in a number of other deciduous wood species.

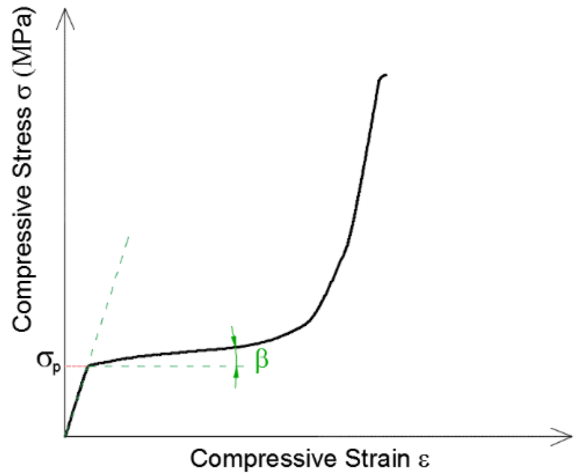

Fig. 1. Compression parallel to grain in radial direction

The process of densifying wood material perpendicular to the grain can be explained in Fig. 1, where the first part of the stress-strain diagram reflects the mechanical condition of the springwood in its elastic region, and only partially the mechanical condition of the summerwood. Up to the limit of proportionality σ_p, only elastic deformation occurs in the wood subjected to stress. Above the limit of proportionality σ_p, elastic deformation over time and plastic deformation also occurs, which gradually develop in the second stage, where cell walls and their density are disturbed. In the second stage, the stress only increases slightly, while the deformation increases significantly. The end of the second stage captures the mechanical condition of the summerwood and the condition of the springwood in its hardened form. This stage can also be referred to as linear plastic strain hardening, described by angle β, which represents the intensity of the strain hardening. In the third stage, the cell walls collapse and come into contact with secondary cell walls. The wood densification process begins, where the stress increases dramatically. The yield strength in stress perpendicular to the grain in the stress-strain diagram is completely insignifcant; during the loading, the wood is gradually compressed without visible failure of the wood. Under this type of stress, the wood does not tend to break into separate parts (Požgaj 1997; Nairn 2006).

In order to complete the final product, the wood can be processed using various methods. Each product has different surface quality requirements given by its function and appearance. Each surface of the product represents the output of a certain fabrication process.

Each process step leaves expected irregularities on the surface. These irregularities may affect the required function of such surfaces. The irregularities can be evaluated with respect to both their macro- and microgeometry concerns (Dubovská 2000). Both macro- and microscopic irregularities appearing on the wood surface mean very small deviations from the optimum flat surface. The wood surface is the area separating the wood substance from its environment (Požgaj 1997). For real wood surfaces, the effects of the working tool on the surface geometry shall always be taken into account (Liptáková and Kúdela 2000). The wood surface geometry results from its anatomic structure and treatment method (Barcík and Gašparík 2014).

As far as the process is concerned, major attention should be paid to veneer surface roughness. Sawn and milled surfaces of pieces are subjected to further surface treatments within the manufacturing process (varnishing, polishing, *etc*.) (Schulz *et al.* 2012), and such operations are affected by roughness. Surface roughness monitoring is the most usual method for the surface quality evaluation. Surface roughness is a geometric feature given by the material type and its treatment method. Suitable features and parameters of surface roughness criteria are measured as follows:

- R_a = arithmetic mean deviation of the evaluated profile;
- R_z = profile maximum height.

Surface quality is achieved by treatment with appropriate tools, thereby removing wood surface irregularities (Kvietková *et al*. 2015a, 2015b). The most usual wood finishing methods are grinding and, to a lesser extent, milling. The disadvantages of grinding are its lengthiness and dust generation. Therefore, new methods of wood surface roughness reduction are found within mechanical and/or thermomechanical smoothing (*e.g.*, pressing), which eliminate these disadvantages (Gáborík and Dudas 2008; Gáborík and Žitný 2010). The grinding process can be improved by moistening the surface between the grinding steps, using water with approximately 10% urea-formaldehyde based glue.

Uniform pressing of the whole area of the wood modifies the surface, thereby changing its smoothness. Pressing densifies the surface and reduces wood roughness. Smoothing by pressing is therefore an alternative to grinding, when the wood surface should be pre-treated before finishing. Several factors such as material, density, temperature, moisture, compression degree, smoothing speed and others, influence the smoothing process.

Various authors (Vorreiter 1949; Wagenführ and Buchelt 2005) cover the increase in smoothness of material surfaces by thermomechanical methods. They mainly reported on wood surface treatments such as thermal smoothing by rolling and pressing, used as wood surface finishing methods. Under both heat and pressure, the so-called thermo-effect takes place. This causes the surface fibers to plasticize, resulting in an indenture in the surface. As the melting lignin levels the wood's irregularities, the treated surface becomes smoother and brighter.

The goal here was to detect wood surface quality changes resulting from aspen wood mechanical and thermomechanical treatments. Wood treatment by pressing is carried out either with or without stabilization, but this work was aimed at pressing without stabilization, which allows the simulation of such processes based on continuous pressing, such as rolling. The targeted thermomechanical treatment of the wood is most challenging in the case of softwood species, in which the density significantly increases, thereby improving mechanical properties. This study focused on the qualitative change of smoothness/roughness. An emphasis was put on the wood in its natural state after pressing, with no previous treatment, and after pressing with previous plasticizing. Plasticizing by steam was done to determine its necessity for aspen wood within the given purpose.

EXPERIMENTAL

Materials

Test pieces from aspen (*Populus tremula* L.) wood were used for the experiment. Aspen woods originated from the Poľana region of central Slovakia. Logs were cut to planks. Planks were cut into samples with the dimensions 55 x 55 x 55 mm.

The pressing was carried out in single-cycle and multi-cycle procedures without stabilization, in order to simulate rolling by continuous pressing. The following methodology was chosen in order to determine the impact of the pressing treatment on the surface smoothness.

First, two groups of test pieces, non-plasticized wood and wood plasticized by steam, were prepared. Both groups of test pieces were further divided into three subgroups based on their initial moisture content: 16%, 30%, and wet. Moisture contents 16% and 30% were conditioned in the HCP 108 humidity chamber (Memmert, Schwabach, Germany). Wet samples were prepared from freshly cut wood. For both the plasticized and non-plasticized wood groups, each of the moisture subgroups was further divided into sub-subgroups based on a particular pressing method or cycle, those being with: single-, two-, three-, and four-cycle pressing. The groups were then compressed to various degrees.

Due to the moisture changes during testing, the density of the test pieces was measured at several points throughout the procedure: before the testing within the range of the required moisture contents, before the plasticizing, after the pressing, and after the conditioning to 8% moisture content. After all the tests had been performed, the pieces were dried in the lab drier KBC-G-100/250 (Premed; Warszawa; Poland) at 103 ± 2 °C, in order to achieve zero moisture content.

Methods

Smoothness was evaluated by measuring the roughness of wood at 8% moisture content.

The compression degree within the selected pressing cycles was determined in relation to the original dimensions of the test piece and was expressed in percentage. It was calculated using the formula (1),

$$\delta = \frac{h_0 - h_S}{h_0} * 100 \tag{1}$$

where δ is the compression degree (%), h_0 is the original dimension in pressing direction (mm), and h_s is the evaluated dimension in pressing direction (after the pressing in the press) (mm).

One pressing cycle was defined as compression to the required value (compression degree) and complete release in the press (single-cycle procedure).

The multi-cycle procedure included compression to the first defined value, complete release, and compression to another value, then repetition in accordance with the established number of cycles. The samples were pressed in the one-story pressing machine JU 60 (Paul Ott GmbH, Lambach, Austria).

The test pieces were compressed in a single direction, radially (Fig. 1). The plasticized test pieces were pressed in heated pressing plates at 100 °C, while the non-plasticized test pieces were pressed between cold (20 °C) pressing plates. The pieces were placed between the pressing plates as shown in Fig. 2. Before pressing, the surfaces were adjusted by milling.

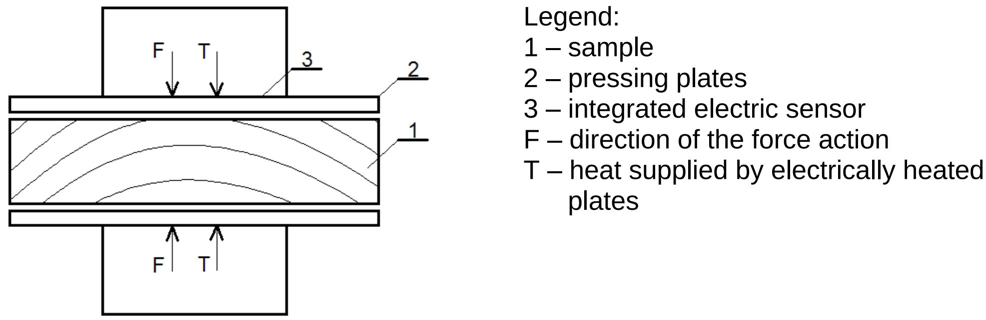

Fig. 2. The principle of thermo-mechanical pressing of wood

The smoothing by pressing was carried out at several compression modes and at three moisture contents: 16%, 30%, and wet. The pressing was carried out for between 1 and 4 cycles, and with various compression degrees as follows:

- **1 cycle:** 20%, 30%, 40%, 50%, 60%
- **2 cycles:** 20-30%; 20-40%; 30-40%; 30-50%,
- **3 cycles:** 10-20-30%; 20-30-40%; 30-40-50%; 10-30-50%,
- **4 cycles:** 10-20-30-40%; 20-30-40-50 %.

After the pressing, the samples were removed from the press and their dimensions and weights were measured with regard to their moisture content.

After the pressing, the test pieces were conditioned to the final moisture content of 8%. In test pieces that underwent the above procedure, changes in wood surface quality, *i.e.*, changes in smoothness were evaluated, which was determined on the basis of the measurements of surface roughness.

A Mahr Pocket Surf (Rapp Industrial Sales, Pennsylvania, United States) profile metering instrument connected to a PC was used to measure the surface roughness. The results were evaluated using the DRSNOSŤ software.

The arithmetical mean deviation was calculated for the evaluated profile (R_a), which is defined under STN EN ISO 4287 (1999) as bilateral roughness irregularity related to the mean line in the evaluated length (L) (Fig. 3).

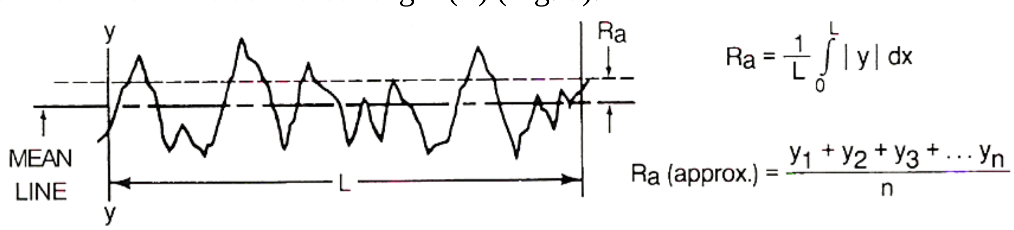

Fig. 3. Arithmetic mean deviation of the profile Ra (STN EN ISO 4287 1999)

The surface quality of the aspen wood was evaluated on the basis of the roughness mean value, R_a (μm), measured along the evaluated length, L =4.0 mm, in two directions, transverse (⊥) and longitudinal (//) with relation to the grain, at five measurement points. Non-plasticized and plasticized materials were evaluated separately.

Plasticizing by steam was carried out in a device designed for this research. Before the steaming of the wood, water in the bottom of the device was heated to 100 °C. Subsequently, the sample was placed on a metal grate and plasticized for 50 min. During heating, the temperature in the device was kept at about 95 ºC. After the plasticizing, the temperature, density, and evaluated dimensions were determined, in order to discover the changes in moisture and dimensions.

The changes in roughness/smoothness of the surfaces of the test pieces were evaluated based on the difference between the roughness (R_a) values measured before and after the pressing.

The reduction in roughness of the pressed surface in comparison with the milled surface was expressed in percentage, according to the following formula (2),

$$\Delta r = \frac{R_a(m) - R_a(p)}{R_a(m)} \times 100\% \tag{2}$$

where Δr is the roughness reduction (%), R_a (m) is the roughness value after the milling (μm), and R_a (p) is the roughness value after the pressing (μm).

RESULTS AND DISCUSSION

Thermomechanical treatment of wood by pressing is challenging for softwood species, in which the density significantly increases and thus improves the mechanical properties. This work was aimed at achieving qualitative improvement in the surface smoothness of aspen wood. Aspen wood typically has an irregular, rough surface, which is affected by the grain direction, wood moisture, pressing method, and treatment. The efforts of this study were aimed at tangential surface smoothing, which means that the pieces were pressed in the radial direction. Before smoothing, the surfaces were treated by milling.

The roughness values corresponded with the milled surfaces of the aspen wood achieved in the longitudinal direction (along the grain), an average value of R_a = 2.94 μm, and in the transverse direction (perpendicular to the grain), an average value of R_a = 5.47 μm. Pivolusková (2008) found the longitudinal roughness to be R_a = 5.3 to 10.7 μm, whereas Kminiak (2007) and Barcík *et al.* (2009) found R_a = 5.57 to 10.33 μm, and Žitný (2010) found R_a = 2.49 μm for the longitudinal direction and R_a = 4.70 μm for transverse directions. Kvietková *at al*. (2015), working with beech wood, found that R_a = 3.32 μm for the transverse direction.

Provided that the moisture content and pressing methods are taken into account, it was possible to conclude that for non-plasticized aspen wood pressed at an initial moisture content of 16%, the highest surface smoothness could be achieved in wood pressed in the longitudinal direction under single-cycle pressing and compressed at 50% of the original thickness. The surface roughness, under these conditions, was equal to R_a = 2.05 μm. From the other monitored pressing methods, good results were achieved with the 2-cycle procedures with compression degrees of 20% to 40% and 30% to 40%, as well as with the 3-cycle procedures with compression degrees of 10% to 20% to 30%, and 20% to 30% to 40%, which produced surface roughness values equal to R_a = 2.11 to 2.29 μm. Similar results were found with pressing conducted in the transverse direction, with roughness values ranging between R_a = 3.98 to 4.92 μm (Table 1).

For 30% moisture content, the lowest roughness value, R_a = 2.18 μm, was achieved at the compression degree of 20% to 40% in the longitudinal direction. The second lowest value, R_a = 2.40 μm, was found with the 3-cycle procedure at the compression degrees of 20% to 30% to 40%.

The results were more balanced for "wet" wood. Smoother surfaces were found in wood pressed with 2 cycles at the compression degree of 30% to 50% (R_a = 3.04 μm), and for wood pressed with 3 cycles at the compression degree of 20% to 30% to 40% (R_a = 3.05 μm) in the longitudinal direction. For this moisture content, good results were also achieved with single-cycle pressing at a compression degree of 30%, which produced a roughness of R_a = 3.14 μm (Table 1).

Table 1. Roughness of Untreated Aspen Wood Treated by Different Pressing Styles in Longitudinal and Transverse Direction According to Wood Grain

Pressing style	Roughness (average value taken from 10 measurements) R_a (μm)					
	Non-plasticized aspen wood					
	Moisture content, w_v					
	16%		30%		Wet	
	Along fibers	Perpendicular to grain	Along grain	Perpendicula r to grain	Along grain	Perpendicular to grain
1 cycle, 20%	3.48	5.06	2.59	4.52	3.24	5.64
1 cycle, 30%	2.56	4.48	2.49	4.40	3.14	5.59
1 cycle, 40%	2.17	4.16	2.66	4.35	3.61	5.69
1 cycle, 50%	2.05	3.98	3.12	4.75	3.73	5.64
1 cycle, 60%	2.32	3.94	3.10	4.34	3.58	5.38
2 cycles, 20% to 30%	2.35	4.35	2.60	4.59	3.58	5.64
2 cycles, 20% to 40%	2.16	4.59	2.18	4.06	3.40	5.35
2 cycles, 30% to 40%	2.11	4.07	2.48	4.27	3.27	5.47
2 cycles, 30% to 50%	2.40	4.13	2.42	4.30	3.04	4.94
3 cycles, 10% to 20% to 30%	2.15	4.07	2.84	4.32	3.35	5.28
3 cycles, 20% to 30% to 40%	2.29	4.25	2.40	4.70	3.05	5.62
3 cycles, 30% to 40% to 50%	2.59	4.92	2.61	4.26	3.65	5.31
3 cycles, 10% to 30% to 50%	2.61	4.58	2.42	4.39	3.14	5.31
4 cycles, 10% to 20% to 30% to 40%	2.29	4.45	2.84	4.62	3.89	5.63
4 cycles, 20%-30%-40%-50%	2.42	4.92	2.67	4.65	4.03	5.53
Average	*2.39*	*4.40*	*2.63*	*4.43*	*3.44*	*5.47*

For the wood plasticized by steam, the results were similar to those for non-plasticized wood. Regarding roughness/smoothness in the longitudinal direction, the lowest roughness, R_a = 2.04 μm, was found with the three-cycle pressing procedure applied at the moisture content of 16%, and with the compression degree of 30% to 40% to 50%; the next lowest roughness values, R_a = 2.36 μm and R_a = 2.23 μm, were found with the two-cycle and single-cycle pressing procedures, respectively, when the wood was compressed to the degrees of 30% to 50% and 50%, respectively. For higher moisture contents, better smoothness was achieved with the two-cycle and three-cycle pressing treatments, which produced minimum roughness values of R_a = 2.39 to 2.55 µm (Table 2).

For tests in the transverse direction, the results were similar, with the lowest roughness values of R_a = 3.04 to 4.82 µm occurring following the two- and three-cycle pressing procedures.

It was observed that the aspen wood plasticized by steam was not improved significantly in terms of smoothness. In contrast to non-plasticized wood, lower values of roughness were recorded in only five cases.

Table 2. Roughness of Plasticized (Steamed) Aspen Wood Treated by Different Pressing Styles

Pressing style	Roughness (average value taken from 10 measurements) R_a (µm)					
	Plasticized aspen wood					
	Moisture content, w_v					
	16%		30%		Wet	
	Along grain	Perpendicular to grain	Along grain	Perpendicular to grain	Along grain	Perpendicular to grain
1 cycle, 20%	3.72	4.87	2.77	4.67	3.41	4.95
1 cycle, 30%	2.69	4.70	3.11	4.74	3.43	5.37
1 cycle, 40%	2.45	4.53	2.93	4.82	3.37	5.05
1 cycle, 50%	2.23	4.24	2.84	4.92	2.94	4.97
1 cycle, 60%	2.63	3.82	3.00	4.71	2.84	4.34
2 cycles, 20% to 30%	2.39	4.27	3.23	5.05	3.32	4.94
2 cycles, 20% to 40%	2.63	4.14	2.98	4.85	3.45	5.40
2 cycles, 30% to 40%	2.76	4.19	2.54	4.69	2.55	5.01
2 cycles, 30% to 50%	2.36	3.70	2.61	4.45	2.90	4.82
3 cycles, 10% to 20% to 30%	2.08	4.27	3.36	5.36	3.42	4.92
3 cycles, 20% to 30% to 40%	2.05	3.04	3.26	5.10	3.31	5.60
3 cycles, 30% to 40% to 50%	2.04	3.29	2.39	4.45	3.59	5.50
3 cycles, 10% to 30% to 50%	2.58	3.50	2.98	4.57	3.62	5.67
4 cycles, 10% to 20% to 30% to 40%	2.41	3.90	3.06	4.77	3.90	5.55
4 cycles, 20% to 30% to 40% to 50%	2.45	3.66	2.81	5.01	4.09	5.52
Average	*2.50*	*4.01*	*2.92*	*4.78*	*3.34*	*5.17*

Similar results were achieved for beech veneer smoothing by rolling, achieving a surface roughness of R_a = 2.3 μm. When pressing the tangential surfaces of beech wood, Kamenská (2009) achieved roughness values of R_a = 2.09 to 2.21 μm in the longitudinal direction and of R_a = 3.32 to 4.07 μm in the transverse direction. After rotational smoothing of tangential surfaces of aspen, Kiššák (2009) achieved roughness values of R_a = 1.57 to 1.61 μm in the longitudinal direction, and R_a = 2.75 to 3.67 μm in the transverse direction. When pressing aspen, Žitný (2010) achieved a roughness value of R_a = 2.24 μm in the longitudinal direction, and R_a = 4.18 μm in the transverse direction.

After surface smoothing by pressing, an aspen moisture content of 16% has proven to be the most suitable in the case of non-plasticized wood (Table 3). With increasing moisture input, the smoothness decreased as the wood roughness values increased. In the longitudinal direction, when compared with the roughness of wood with an initial moisture content of 16%, the roughness of wood with 30% moisture content was 9.7% higher, and the roughness of wet wood was as much as 43.89% higher. In the transverse direction, the roughness increased by 0.68% at 30% moisture content, and by 24.26% in wet wood. Similar results were achieved for the wood plasticized by steam: the roughness was increased by 17.07% and by 33.79% in the longitudinal direction, and by 18.39% and by 29% in transverse direction, for moisture contents of 30% and wet wood, respectively. It was determined that the initial moisture content was better for achieving a smooth wood surface by pressing. In this case, plasticizing did not have an improving effect. Plasticization with steam demonstrated a positive result when measuring the roughness of wet wood, where wet plasticized specimens had 3% lower roughness in the longitudinal direction and 5.5% lower roughness in the perpendicular direction than non-plasticized specimens (Tab. 3).

Wood is a complex polymeric composition, which consists of a lignin-carbohydrate network structure matrix. These networks are mutually overlapping and are linked by various bonds (hydrogen, valence, *etc.*), which are disturbed during plasticization. This results in a change in the physico-mechanial properties of the wood. The degree of their disturbance depends on the plasticizing medium used and the technology of its application. During the plasticization of the wood, the deepest changes occur in the middle lamella and the secondary layer of the cell wall (Trebula 1989; Zemiar 2007).

Table 3. Smoothed Surface Roughness as a Function of the Wood's Initial Moisture Content and Grain Direction

Treatment	Moisture content (%)	Longitudinal direction R_a (μm)	Transverse direction R_a (μm)
Non-plasticized	16	2.39	4.40
	30	2.63	4.43
	Wet	3.44	5.47
	Average	2.82	4.77
Plasticized	16	2.50	4.01
	30	2.92	4.74
	Wet	3.34	5.17
	Average	2.92	4.64

The reason why plasticization did not demonstrate a more positive result under compression (at various stages of the compression) was probably due to the poor thermal conductivity of the wood (the permeation of heat from the surface zones to the interior zones). Another reason why the plasticization did not show a positive result could be the initial moisture content of the specimens. The optimal initial moisture content in plasticization by steaming is in the range of 25 to 30%. At a lower initial moisture content (16% in our case), the plasticization by steaming may be less effective (Vaněk 1952).

As far as the impact of the cold compression method (pressing method) was concerned, the quality of the treated aspen wood was compared between single-cycle and multi-cycle compressions. The R_a roughness values found in the longitudinal and transverse directions are shown in Table 4. The roughness values of the transverse direction were almost double those of the longitudinal direction.

Overall, the two- and three-cycle pressing methods proved to be the best ones, followed by the single-cycle methods (Table 4). In our specific conditions, these constituted the pressing cycles having the compression degrees of 20% to 40%, 30% to 40%, 30% to 50%, 10% to 20% to 30%, 20% to 30% to 40%, and 20% to 30% to 50% (Tables 1, 2, and 4).

It was possible to conclude that the single-cycle pressing methods to 50% and 60% of the original thickness showed good results in some cases; however, the pieces were often damaged, presenting with inner cracks. About 10% of the samples were damaged at the wood compression degree of 50%, and about 30% were damaged at the compression degree of 60%. Therefore, these parameters would not be recommended for the purpose of the wood surface smoothing.

Table 4. Average Surface Roughness as a Function of Studied Factors

Treatment	Pressing style	Roughness, R_a (µm)							
		Moisture content, w_v						Average	
		16%		30%		Wet			
		Along grain	Perpendicular to grain	Along grain	Perpendicular to grain	Along grain	Perpendicular to grain	Along-side grain	Perpendicular to grain
Non-plasticized	1-cycle	2.51	4.35	2.79	4.47	3.46	5.59	2.92	4.80
	2-cycle	2.25	4.28	2.42	4.27	3.32	5.35	2.66	4.63
	3-cycle	2.41	4.52	2.57	4.42	3.29	5.38	2.76	4.77
	4-cycle	2.35	4.69	2.75	4.64	3.96	5.58	3.02	4.97
Plasticized	1-cycle	2.75	4.43	2.93	4.77	3.20	4.94	2.96	4.71
	2-cycle	2.53	4.08	2.84	4.76	3.05	5.04	2.91	4.63
	3-cycle	2.19	3.53	3.00	4.73	3.49	5.42	2.89	4.56
	4-cycle	2.43	3.78	2.93	4.89	3.99	5.53	3.12	4.73

The extent of increase in wood smoothness was evaluated by comparing the roughness before and after the pressing according to formula (2). The cold pressing of non-plasticized aspen wood resulted in increased smoothness, *i.e.*, a reduction in roughness by 6.12 to 9.52% in comparison to the milled surface. The two- and three-cycle pressing styles gave the best roughness values in the longitudinal direction. Better results were achieved in the transverse direction, reducing the roughness by 12.8 to 15.36%. For plasticized wood pressed in the longitudinal direction, the roughness was only improved by 1%. However, in the perpendicular direction, the improvement was as great as by 12.80 to 15.36%. Kvietková *et al*. (2015) improved beech smoothness by 31% through thermal rotation smoothing. Žitný (2010) reduced the roughness of aspen by 11% in the longitudinal direction, and by 21% in the transverse direction, by means of pressing. Kiššák (2009) achieved significant improvement in the surface smoothness of aspen, by 30% in the longitudinal direction and by 70% in the transverse direction. The results demonstrate that the thermal smoothing of aspen wood by means of either pressing or a rotating tool improved the surface in the direction perpendicular to the grain more significantly than it improved the longitudinal surface.

CONCLUSIONS

1. The results have proven that for cold pressing at 20 °C without non-plasticized aspen wood stabilization in the press, single-cycle pressing is not sufficient to smooth the surface. This is proven by the inconvenient values of roughness. Multi-cycle pressing is more advantageous. In the experiments, the required wood surface quality was achieved by means of two- and three-cycle pressing methods. In comparison with the milled surface, the roughness was reduced.
2. While monitoring the moisture impact on the surface quality, the following was concluded: increased smoothness of the aspen wood surface was achieved by decreasing the moisture content during cyclic pressing.
3. Growth direction perpendicular to the grain provided higher roughness values than the longitudinal direction. The direction perpendicular to the grain was 1.69-times rougher than the longitudinal one.
4. Based on the obtained results, it is recommended that non-plasticized aspen wood be used with a lower moisture content for densification, smoothing and similar processes, *i.e.*, with 8% or 16%, in multi-cycle pressing (not exceeding 50%). Plasticizing did not contribute to the achievement of more favorable smoothness results.
5. Based on the results, we recommend using the pressing by smoothing method at elevated temperatures (above 100 °C), with stabilization in the press.
6. The improved properties of aspen wood make it suitable for combining with other wood species, *e.g.*, with beech, for the manufacture of furniture-molded layered pieces.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Internal Grant Agency (IGA) of the Faculty of Forestry and Wood Sciences, project No. B04/16.

REFERENCES CITED

Barcík, Š. Pivolusková, E., Kminiak, R. and Wieloch, G. (2009). "The influence of cutting speed and feed speed on surface quality at plane milling of poplar wood," *Wood research* 54(2), p. 109-116.

Barcík, Š., and Gašparík, M. (2014). "Effect of tool and milling parameters on the size distribution of splinters of planed native and thermally modified beech wood," *BioResources* 9(1), 1346-1360, DOI: 10.15376/biores.9.1.1346-1360.

Blomberg, J. (2006). "Mechanical and physical properties of semi-isostatically densified wood," Ph.D. thesis, Luleå Tekniska Universitet, pp. 170.

Dubovská, R. (2000). "Niektoré poznatky o kvantifikácii drsnosti pri obrábaní dreva, [Some knowledge of quantifying roughness in woodcutting]," *Procesy Trieskového A Beztrieskového Obrábania Dreva*, Zvolen, Slovakia, pp. 43-47 (in Slovak).

Dubovský, J., Babiak, M., and Čunderlík, I. (1998). *Textúra, štruktúra a úžitkové vlastnosti dreva* [Texture, structure and performance characteristics of wood]," Technical university of Zvolen, (in Slovak), 106 p.

Gáborík, J., and Dudas, J. (2008). "Thermo-mechanical smoothing of wood," *Annals of Warsaw University of Life Sciences –SGGW, Forestry and Wood Technology* 65, 49-54.

Gáborík, J., and Žitný, M. (2010). "Quality changes of aspen and beech surface after smoothing by rotary tool," *Acta facultatis xylologiae Zvolen,* TU vo Zolene, pp. 41-46.

Kamenská, K. (2009). "Effect of different kinds of mechanical processing of beech on selected properties of the coating," M.S. Thesis, Technical University of Zvolen, Zvolen, Slovakia (in Slovak).

Kiššák, P. (2009). "The effect of the rotation for surface smoothing of aspen wood," M.S. Thesis, Technical University of Zvolen, Zvolen, Slovakia (in Slovak).

Kminiak, R. (2007). "The influence of selected technical and technological factors on the energy and quality indicators for plane milling of juvenile poplar wood," M.S. Thesis, Technical University of Zvolen, Slovakia (in Slovak).

Kvietková, M., Barcík, Š., and Aláč, P. (2015a). "Impact of angle geometry of tool on granulometric composition of particles during the flat milling of thermally modified beech," *Wood Research* 60(1), pp. 137-146.

Kvietková, M., Gašparík, M., and Gaff, M. (2015b). "Effect of thermal treatment on surface quality of beech wood after plane milling," *BioResources* 10(3), 4226-4238, DOI: 10.15376/biores.10.3.4226-4238.

Liptáková, E., and Kúdela, J. (2000). "The surface properties of beech wood in different ways mechanical machining," *Procesy trieskového a beztrieskového obrábania dreva*, TU Zvolen, pp. 107-115.

Nairn, J. (2006). "Numerical simulations of transverse compression and densification in wood," *Wood and Fiber Science* 38(4), 576-591.

Pivolusková, E. (2008). "The influence of selected technical and technological factors on the formation of wood chips and surface quality in plane milling of juvenile poplar wood," PhD. thesis, Technical University of Zvolen, Slovakia, 128 p., (in Slovak).

Požgaj, A. (1997). *Štruktúra a Vlastnosti Dreva* [*Wood Structure and Properties*], Príroda, Bratislava, Slovakia, 486 p. (in Slovak).

Schulz, T., Scheiding, W., and Fischer, M. (2012). "Sperrholz und Sperrholzformteile aus thermisch modifizierten Furnieren," *Holztechnologie* 53, 14-24.

STN EN ISO 4287 (490147). (1999). “Geometrické špecifikácie výrobkov (GPS). Charakter povrchu: Profilová metóda - Termíny, definície a parametre charakteru povrchu. [Geometrical product specifications (GPS)-Surface texture: Profile method - Terms, definitions and parameters of surface texture],” Slovak Office of Standards, Metrology and Testing, Bratislava, Slovakia (in Slovak).

Trebula, P. (1989). *Hydrotermická úprava a ochrana dreva : časť Hydrotermická úprava dreva* [*Hydrothermal treatment and wood protection : Part Hydrothermal treatment of wood*], Technical University of Zvolen, Zvolen, Slovakia, 301 p. (in Slovak).

Vaněk, J. (1952). *Ohýbaný nábytek* [*Bentwood furniture*], Praha, průmyslové vydavatelství, 112 p., (in Czech).

Vorreiter, L. (1949). *Holztechnologisches Handbuch, Band 1: Allgemeines, Holzkunde, Holzschutz und Holzvergütung*, Verlag Georg Fromme & Co., Vienna, Austria.

Wagenführ, A., and Buchelt, B. (2005). “Untersuchungen zum materialverhalten beim dreidimensionalen Formen von Furnier,” *Holztechnologie* 46(1), 13-19.

Zemiar, J. (2007). *Technólogia druhostupňového spracovania dreva. Časť I*. [*Second level of wood processing technology*. *Part I*]”, Technical University of Zvolen, Zvolen, Slovakia, 144 p. (in Slovak).

Žitný, M. (2010). “Thermo smoothing wood surface,” M.S. Thesis, Technical University of Zvolen, Zvolen, Slovakia (in Slovak).

Article submitted: June 29, 2015; Peer review completed: September 6, 2015; Revised version received and accepted: November 3, 2016; Published: November 8, 2016.
DOI: 10.15376/biores.12.1.82-94