Dimensional Changes of Veneer Layered Materials after Cold Pressing

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Dimensional changes in both non-densified and densified, thin, wooden components and layered materials after external pressing forces were released were evaluated in this work. Densification was carried out using a cold process on a semi-automatic hydraulic pressing machine. The specimens' dimensional stabilities, focusing mainly on their residual plastic deformations, were monitored. The impacts of several factors, such as wood species, material thickness, densification degree, and their combinations, were analyzed. Results showed that, with increased degree of densification, the relative plastic deformations (pressing degree) usually decreased. With regard to the compositions explored, the best combination was a top poplar layer densified by 10% plus a bottom beech layer densified by 20%. The impacts of each of the factors on the pressing degree values proved to be significant; the least significant was the bottom beech layer thickness and degree of densification. The greatest practical benefits can be obtained using the recommended combinations of composite layers.

Keywords: Veneer; Layered material; Densification; Pressing; Dimensional stability; Deformation

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INTRODUCTION

The term "thin-layered materials" includes all kinds of wood layers (veneers, lamellae, flooring components, *etc*.) up to thicknesses of 10 mm (Zemiar *et al*. 2009). Thin-layered materials are basic materials used for decorative and structural purposes when creating various more complex material types. They function either as the main structural element (in plywood and lamellar materials) or as a predominantly decorative covering on a bearing material (usually wood-based). In these cases, the surface veneers are important for the assurance of product/material quality.

In some cases, other properties are required in addition to the aesthetic requirements of the surface veneers. These include hardness, resistance to wear, smoothness, improved mechanical properties, or others (Kvietková *et al*. 2015a,b). Greater hardness than that of natural wood, and other wood properties inherent thereto—such as bending strength, modulus of elasticity, and density—can be achieved by means of pressing.

Pressing is a molding process during which external forces decrease the volume of a work piece; the material is densified (Zemiar *et al*. 2009). Wood pressing can differ in the wood pre-stamping treatment, the direction of the acting force, the output mode, as well as in other features (Nemec *et al*. 1986; Kafka 1989; Fekiač *et al.* 2015). Flat pressing was selected for the veneer pressing.

Neither the dimensional nor the shape changes taking place during pressing are permanent (Gáborík and Dudas 2006; Marko 2010; Gašparík and Barcik 2013). After the external forces are released, wood tends to revert to its initial shape and dimensions (Fig. 1). Unlike when it is placed under the long-term loading, elastic deformations are predominant only under short-term loading that is lower than the limit of elasticity, (Fig. 1). Therefore, under short-term loading, the proportionality limit should not be exceeded. Generally, the purpose of wood pressing is to obtain a product with stable dimensions and shape and higher density than that of natural wood (Lakes 2009).

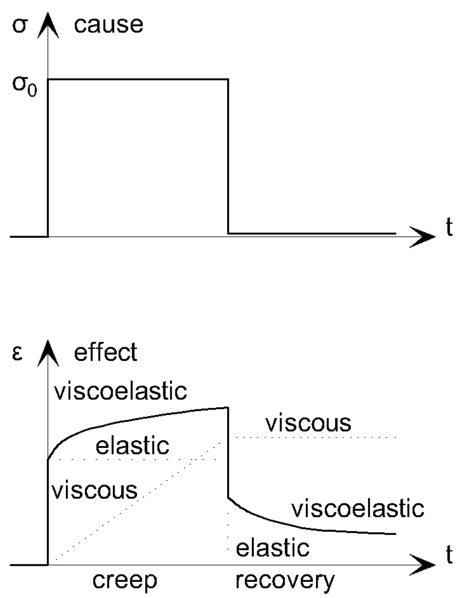

Fig. 1. Creeping course: stress and deformation *vs*. loading/release time curve while not exceeding the proportionality limit

Dimensional stability is also the basis of shape stability. The goal of this research was to determine the dimensional changes occurring after the veneers were pressed under the selected conditions. This goal resulted from the application of the pressed veneers onto the surfaces of layered materials.

EXPERIMENTAL

Materials

Typical domestic representatives of both hard- and softwood species were chosen as the input materials for this study (Požgaj *et al*. 1997; Kurjatko *et al*. 2010): European beech (*Fagus sylvatica* L.) and Eurasian aspen (*Populus tremula* L.), respectively.

A multi-degree choice was used for the preparation of the specimens. The first degree consisted of the selection of suitable beech and aspen roundwood grown in the Sekier forest of the Technical University Forest Enterprise in Zvolen. Circular cutting yielded tangential pieces of timber 10 and 20 mm thick. The cut timber was dried spontaneously in cages such that the moisture was decreased below the fiber saturation point to between 20 and 25%. Subsequently, they were cut to 1-m lengths, the side surfaces were cleaned on a circular saw, and the pieces were divided to dimension stocks. Levelling and thickness equalizing were done. Next, the required number of dimension stocks were cold densified with pressurizing plates at 20 °C in two pressing steps; the thickness was reduced either by 10 or 20%. A polyurethane glue was applied to the selected stocks and groups were assembled (Liptáková and Sedliačik 1989). These groups were pressed with a UT6L (Italpresse, Italy) pressing machine (Fig. 2) under 0.6 MPa (eventually, 0.3 MPa) for 15 s (eventually, 90 min).

Fig. 2. Hydraulic pressing machine model UT6L

After pressing, specimens with dimensions of 60×60 mm were cut (Fig. 3). Subsequently, the specimens were conditioned to approximately 12% moisture in a Binder conditioning chamber (ED, APT Line II; Germany) at 65% relative humidity and 20 °C. The achievement of equilibrium moisture content was verified in accordance with ISO 3130 (1975).

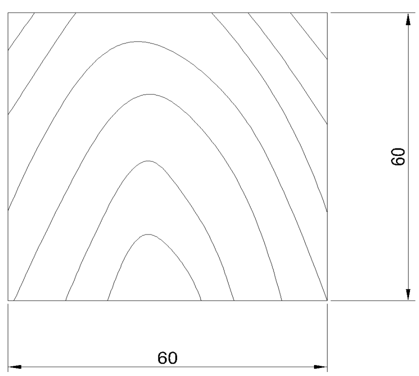

Fig. 3. Test specimen

The experiments were carried out in individual layers (Fig. 4) as well as in various two-layer combinations (Fig. 5), created with densified/non-densified beech/aspen wood layers glued with polyurethane glue. There were a total of 48 groups, each consisting of 10 pieces. The group identification method is shown in Fig. 6. For two-layer groups, the top layer was always aspen.

Methods

The work methodology was based on the experimental verification of the pressed veneer-based materials' dimensional changes. The test pieces were loaded with uniform pressure on their entire surface in the radial direction (Fig. 7). After this test, the deformations created on the test pieces (flexible, temporary flexible, and plastic) were monitored.

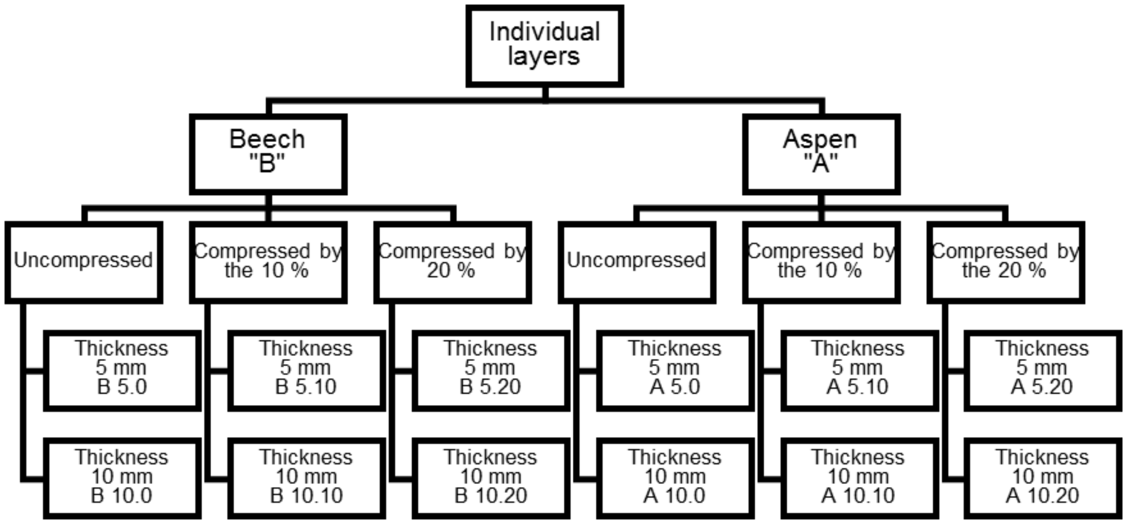

Fig. 4. Flowchart of specimens by the individual layers

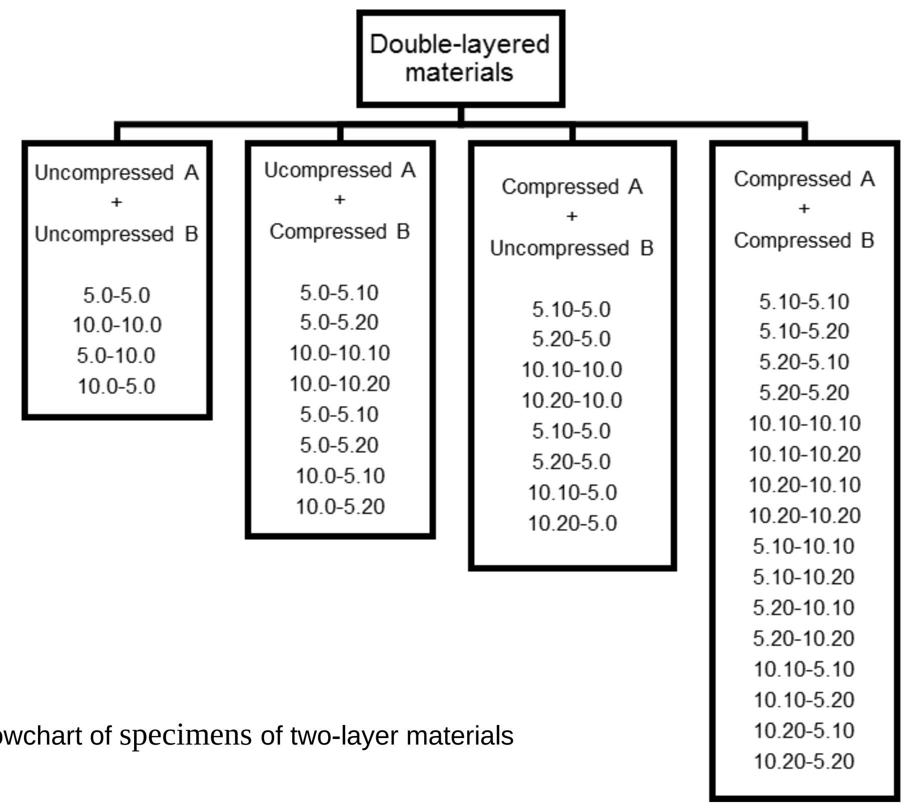

Fig. 5. Flowchart of specimens of two-layer materials

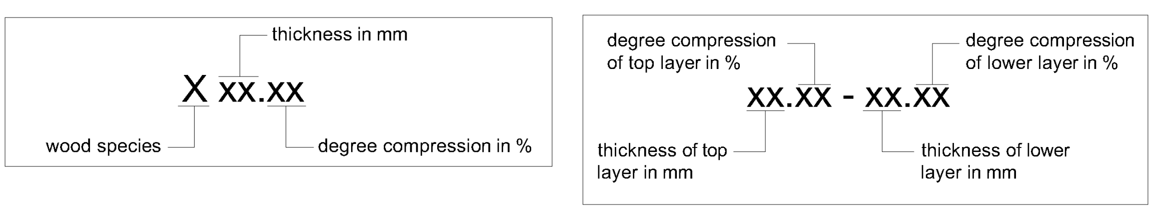

Fig. 6. Group identification method for specimens of both individual layers and two-layer materials

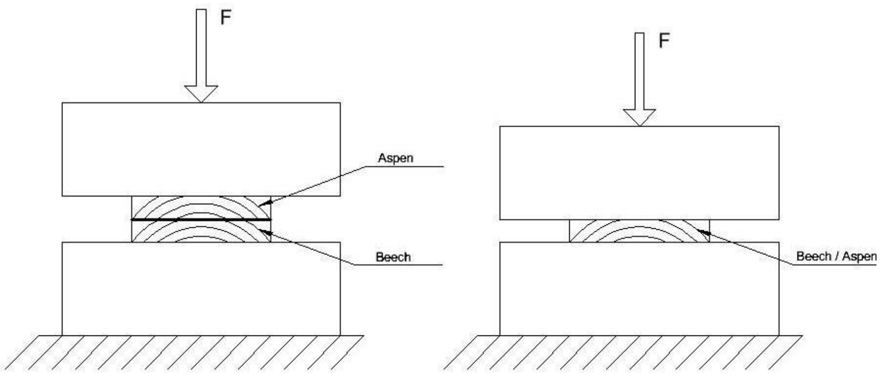

Fig. 7. Test pieces (single- and two-layer) pressing

Testing was carried out on a Rauenstein ZDM 10/90 (Germany) tensile testing machine at pressures up to 60 kN for durations of approximately 2 min. The thickness of the specimens was measured immediately after releasing the pressurizing plates within an accuracy of 0.01 mm. After the test was over, the dimensional changes caused by the pressing were monitored after 0.5, 1, 2, and 24 h (Fig. 9). The thickness was measured at two marked points located 1.5 cm from the test piece margin (Fig. 8). The measured data were graphically illustrated during testing. Curves in the graph were used to identify the different types of deformations. Care was taken to make repeated measurements at the same points.

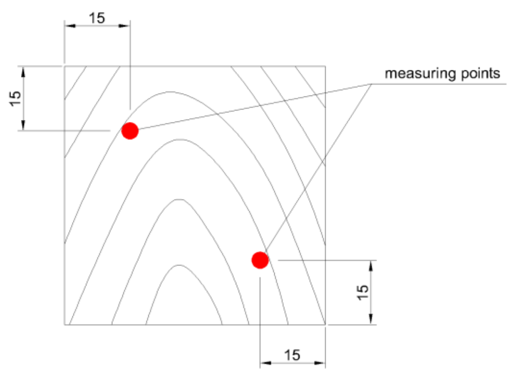

Fig. 8. Test piece with measurement points

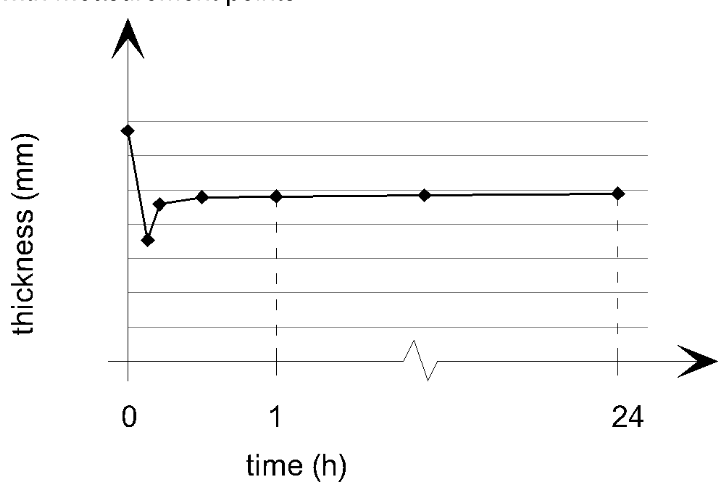

Fig. 9. Deformation curve showing the entire course of thickness change, from compression until dimensional stabilization

Calculations and Evaluation

The moisture content of the specimens was determined using Eq. 1 according to ISO3130 (1975),

$$w = \frac{m_w - m_0}{m_0} * 100 \tag{1}$$

where w is the moisture content of the specimens (%); m_w is the mass (weight) of the test specimens at moisture content w (kg); and m_0 is the mass (weight) of the oven-dry test specimens (kg).

In addition to the individual deformation components of the total deformation, the relative plastic deformation values and the pressing degree were also computed from the measured values (Nemec *et al.* 1986), using Eq. 2,

$$\varepsilon_c = \frac{l_0 - l_{min.}}{l_0} * 100 \tag{2}$$

where ε_c is the deformation (%); l_0 is the original dimension of the specimens in the pressing direction (mm); and $l_{min.}$ is the minimum dimension (length) of the specimens in the pressing direction after loading (mm).

RESULTS AND DISCUSSION

As previously mentioned, neither the dimensional nor the shape changes that take place during pressing are permanent. After the external forces are released, the wood tends to revert to its initial shape and dimensions. The selected force acting on the specimens' surface developed a pressure stress equal to approximately 17 MPa. For the radial pressure on diffuse porous wood species (which both beech and aspen are), this means that the proportionality limit was undoubtedly exceeded. Thus, the proportionality limit, which is conventionally referred to as the breaking limit, was undoubtedly exceeded (Regináč *et al.* 1990). The so-called "elastic-viscoplastic area" was achieved in such cases, as was the goal (Kunesh 1968). For aspen, the conventional breaking limit is approximately 3.1 MPa, and for beech it is approximately 7.0 MPa at 12% moisture content (USDA Forest Service 1999). For this stress type, the radial pressure determines the specific shape of the stress/deformation curve. It consists of three phases. During pressing, the third phase was achieved.

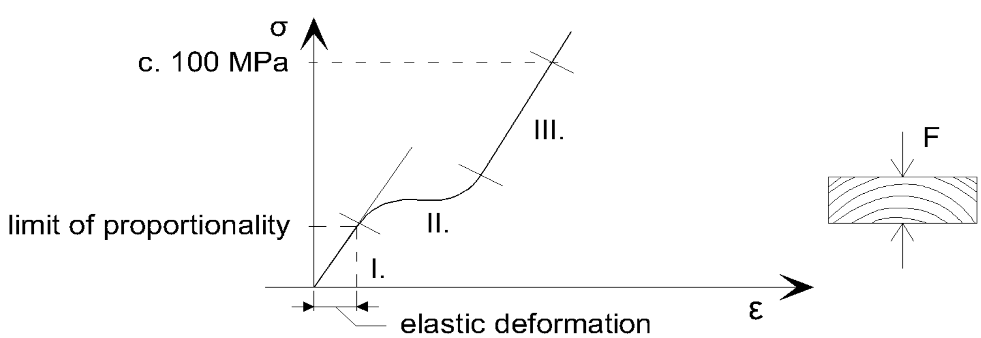

Fig. 10. Three-phase stress/deformation diagram for radial pressure applied to dispersed, porous wood species

The goal was to examine the responses of non-densified and densified thin components of wood and layered materials composed of beech and aspen wood after the pressing forces were released with regard to their deformations. To make correct comparisons, the data obtained from relative plastic deformation are most suitable, as their absolute values are affected by the various thicknesses of the test pieces (Table 1). Likewise, the deformation distribution to flexible and temporary flexible is not perfectly accurate since there is no unambiguous differentiation between reversible deformations, as far as the time line concerns. Therefore, the main feature monitored was the dimensional stability of the test pieces, primarily the residual plastic deformations. Eventually, the pressing degree (relative plastic deformation) was also monitored. The impacts of several factors such as the wood species, material thickness, degree of densification, and layer position were analyzed.

Table 1. Average Values and Portions of Elastic, Temporary Flexible, and Plastic Deformations for Both Individual Layers and All of Their Combinations

Wood	Combination	Deformation (mm)			Proportion of Deformation (%)			Relative Plastic Deformation
		D1	D2	D3	D1	D2	D3	
Aspen	5.0	1.64	0.20	1.54	48	6	45	0.29
Aspen	5.10	1.78	0.12	1.03	61	4	35	0.21
Aspen	5.20	1.57	0.16	0.80	62	6	32	0.17
Beech	5.0	1.48	0.10	0.63	67	4	29	0.13
Beech	5.10	1.29	0.12	0.77	59	6	35	0.16
Beech	5.20	1.29	0.13	0.45	69	7	24	0.10
Aspen	10.0	2.03	0.35	3.46	35	6	59	0.34
Aspen	10.10	2.13	0.37	3.35	36	6	57	0.33
Aspen	10.20	2.03	0.26	2.77	40	5	55	0.28
Beech	10.0	1.73	0.22	1.82	46	6	48	0.18
Beech	10.10	1.71	0.22	1.31	53	7	40	0.14
Beech	10.20	1.83	0.24	1.21	56	7	37	0.13
Aspen + Beech	5.0-5.0	1.89	0.30	2.23	43	7	50	0.22
Aspen + Beech	5.10-5.0	1.64	0.17	1.03	58	6	36	0.11
Aspen + Beech	5.20-5.0	2.24	0.26	1.39	58	7	36	0.15
Aspen + Beech	5.0-5.10	1.96	0.24	1.95	47	6	47	0.20
Aspen + Beech	5.10-5.10	2.11	0.25	2.05	48	6	46	0.21
Aspen + Beech	5.20-5.10	1.96	0.18	1.63	52	5	43	0.17
Aspen + Beech	5.0-5.20	1.91	0.16	1.54	53	4	43	0.16
Aspen + Beech	5.10-5.20	2.29	0.28	1.80	52	6	41	0.19
Aspen + Beech	5.20-5.20	2.15	0.17	1.46	57	5	39	0.16
Aspen + Beech	10.0-10.0	3.20	0.69	5.47	34	7	58	0.27

Aspen + Beech	10.10-10.0	2.64	0.66	4.72	33	8	59	0.24
Aspen + Beech	10.20-10.0	3.58	0.56	4.44	42	7	52	0.22
Aspen + Beech	10.0-10.10	3.44	0.57	5.21	37	6	57	0.26
Aspen + Beech	10.10-10.10	3.32	0.71	4.42	39	8	52	0.23
Aspen + Beech	10.20-10.10	3.70	0.60	4.35	43	7	50	0.22
Aspen + Beech	10.0-10.20	3.66	0.56	4.11	44	7	49	0.21
Aspen + Beech	10.10-10.20	3.23	0.56	3.10	47	8	45	0.16
Aspen + Beech	10.20-10.20	3.26	0.62	3.88	42	8	50	0.21
Aspen + Beech	5.0-10.0	2.64	0.47	2.48	47	8	44	0.17
Aspen + Beech	5.10-10.0	2.22	0.32	2.77	42	6	52	0.19
Aspen + Beech	5.20-10.0	2.17	0.53	2.09	45	11	44	0.14
Aspen + Beech	5.0-10.10	2.22	0.32	2.08	48	7	45	0.14
Aspen + Beech	5.10-10.10	2.75	0.73	1.57	54	14	31	0.11
Aspen + Beech	5.20-10.10	1.82	0.30	1.56	49	8	42	0.11
Aspen + Beech	5.0-10.20	2.22	0.44	2.42	44	9	48	0.17
Aspen + Beech	5.10-10.20	2.02	0.35	1.04	59	10	30	0.08
Aspen + Beech	5.20-10.20	2.32	0.19	1.65	56	5	40	0.12
Aspen + Beech	10.0-5.0	2.80	0.42	3.47	42	6	52	0.23
Aspen + Beech	10.10-5.0	2.64	0.57	3.81	38	8	54	0.26
Aspen + Beech	10.20-5.0	2.50	0.62	3.28	39	10	51	0.22
Aspen + Beech	10.0-5.10	2.89	0.55	3.37	42	8	49	0.22
Aspen + Beech	10.10-5.10	2.33	0.48	3.47	37	8	55	0.24
Aspen + Beech	10.20-5.10	2.71	0.49	3.24	42	8	50	0.23
Aspen + Beech	10.0-5.20	2.75	0.57	3.65	39	8	52	0.25
Aspen + Beech	10.10-5.20	2.89	0.56	2.95	45	9	46	0.21
Aspen + Beech	10.20-5.20	2.30	0.49	3.39	37	8	55	0.24

(D1 = flexible deformation; D2 = temporary flexible deformation; D3 = plastic deformation)

When comparing the layer thicknesses, the smallest absolute deformations were obviously found in the single layers, mostly those of beech with 5-mm thickness. For composite layers, the smallest absolute deformations were found in test pieces 5.10 to 5.0 and 5.10 to 10.20 mm. With increasing degree of densification, the relative plastic deformations decreased. In terms of the layer composition, the best combination was a top layer (aspen) densified by 10% and a bottom layer (beech) densified by 20%. The impact of each of the factors on the pressing degree was significant. The least significant was the impact of the bottom beech layer thickness and densification, as shown in Table 3 and in the graphic illustrations in Figs. 11 to 16. A similar impact was also demonstrated in terms of the factor's contribution to the plastic deformation share of the total deformation (Table 4). The impact of each of the factors on the absolute plastic deformation was unambiguously significant (Table 2).

Some paradoxical results, mainly following the 10% densification of the bottom layer, may have been caused by the cold densification process.

Table 2. Impact of Factors on Absolute Plastic Deformation

Monitored Factor	Sum of Squares	Degree of Freedom	Variance	Fisher's F-test	Significance Level, p
Intercept	506.888	1	506.888	393.101	0.000001
1 - wood species	91.281	2	45.640	35.395	0.000001
Error	305.602	237	1.290		
Intercept	1003.260	1	1003.260	3675.368	0.000001
2 - top layer thickness	223.349	1	223.349	818.223	0.000001
3 - compressed top layer	10.701	2	5.350	19.601	0.000001
4 - bottom layer thickness	86.807	2	43.403	159.005	0.000001
5 - compressed bottom layer	8.215	2	4.107	15.047	0.000001
Error	63.329	232	0.273		
2-3-4-5	4.927	4	1.232	8.479	0.000002
Error	28.764	198	0.145		

Table 3. Impact of Factors on Relative Plastic Deformation

Monitored factor	Sum of Squares	Degree of Freedom	Variance	Fisher's F-test	Significance Level, p
Intercept	5.033	1	5.033	2022.148	0.000001
1 - wood species	0.262	2	0.131	52.624	0.000001
Error	0.590	237	0.002		
Intercept	6.750	1	6.750	3429.011	0.000001
2 - top layer thickness	0.295	1	0.295	150.065	0.000001
3 - compressed top layer	0.054	2	0.027	13.627	0.000003
4 - bottom layer thickness	0.023	2	0.012	5.874	0.003246
5 - compressed bottom layer	0.016	2	0.008	4.017	0.019281
Error	0.457	232	0.002		
2-3-4-5	0.033	4	0.008	5.169	0.000556
Error	0.315	198	0.002		

As shown in Fig. 11, the aspen wood (A) plastic deformation was the greatest, while that of the beech wood (B) was the lowest.

The relative plastic deformation values increased with increasing thickness of the growth top layer (Fig. 12).

Table 4. Impact of Factors on Plastic Deformation Share in Total Deformation

Monitored factor	Sum of Squares	Degree of Freedom	Variance	Fisher's F-test	Significance Level, p
2-3-4-5	526.296	4	131.574	5.901	0.000166
Error	4415.019	198	22.298		

(for the meaning of 2-3-4-5, see Tables 2 and 3)

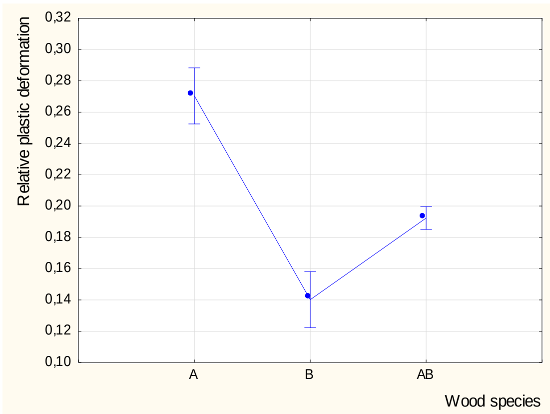

Fig. 11. Wood species' effect on relative plastic deformation. A - Aspen, B - Beech, AB - Aspen and Beech. Data reported as mean ± SD

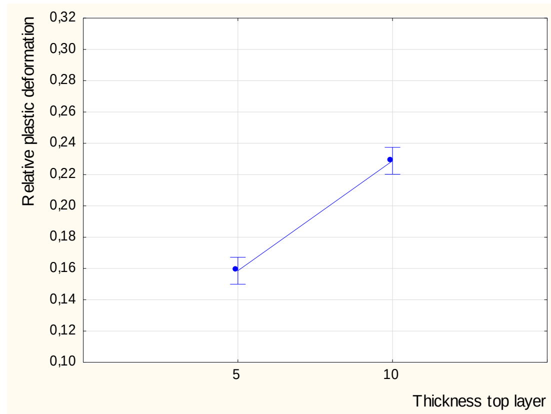

Fig. 12. Effect of thickness of top layer on relative plastic deformation. Data reported as mean ± SD

Statistically significant decreases in the relative plastic deformation values were found with increasing top layer densification (Fig. 13).

As shown in Fig. 14, the lowest values of the monitored features were measured for bottom layer thickness equal to 10 mm.

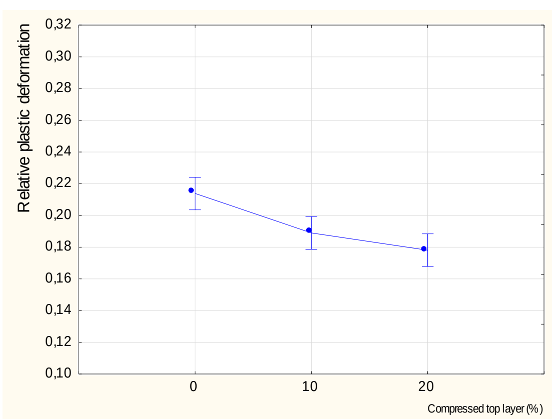

Fig. 13. Effect of compression of top layer on relative plastic deformation. Data reported as mean ±SD

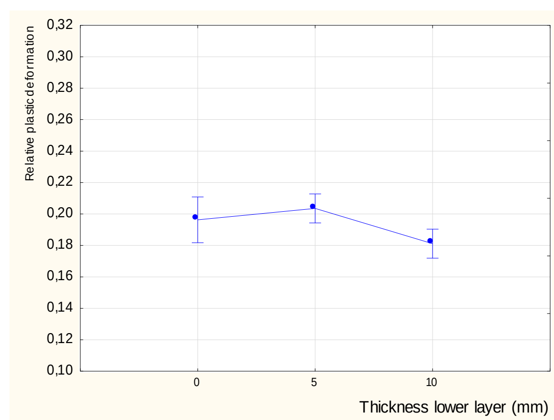

Fig. 14. Effect of thickness of lower layer on relative plastic deformation. Data reported as mean ±SD

While the bottom layer densification increased, the relative plastic deformation values decreased in a statistically significant manner (Fig. 15). As shown in Fig. 16, a statistically significant decrease in the relative plastic deformation value took place with test piece densification. On the other hand, the monitored feature value increased in a statistically significant manner for the non-densified pieces.

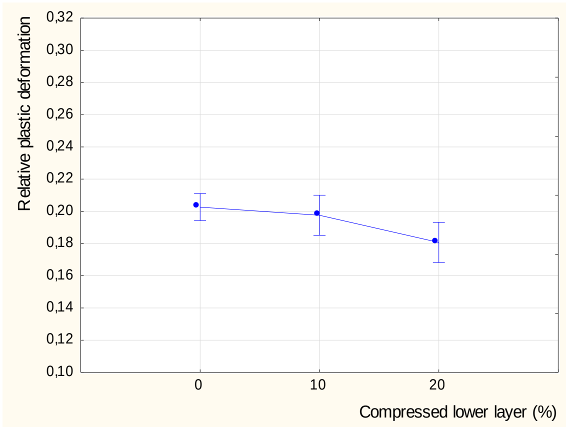

Fig. 15. Effect of compression of lower layer on relative plastic deformation. Data reported as mean ± SD

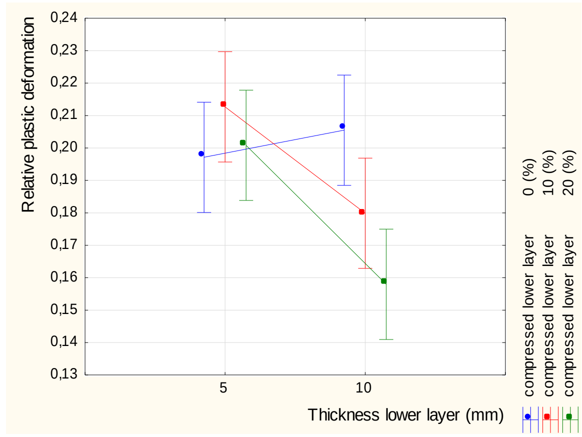

Fig. 16. Effect of compression and thickness of lower layer on relative plastic deformation. Data reported as mean ± SD

CONCLUSIONS

1. When comparing the layer thicknesses, the smallest absolute deformations were found for single layers, mostly of beech with 5 mm thickness.
2. For the composite layers, the smallest absolute deformations were in specimens 5.10-5.0 and 5.10-10.20.
3. With increasing degree of densification, the relative plastic deformation decreased; as far as the layer composition is concerned, the best combination was of a top layer (aspen) densified by 10% and a bottom layer (beech) densified by 20%.
4. The impact of each of the factors on the pressing degree value proved significant; the least significant was the bottom beech layer thickness and densification.
5. The combinations 10-10 and 10-5 appeared unsuitable due to deformations reaching high values. This was caused by the aspen’s thicknesses and low degree of densification.
6. The use of combinations of layers 5.10-5.0 and 5.10-10.20 is recommended. The top layer (aspen) was densified by 10%, while the bottom layer (beech) was either not densified or densified by 20%.
7. One further recommendation is to carry out similar research using the same wood species but at densification rates from 30 to 50%.

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REFERENCES CITED

Fekiač, J., Zemiar, J., Gaff, M., Gáborík, J., Gašparík, M., and Marušák, R. (2015). "3D-moldability of veneers plasticized with water and ammonia," *BioResources* 10(1), 866-876. DOI: 10.15376/biores.10.1.866-876

Gáborík, J., and Dudas, J. (2006). "The change of properties of aspen wood by mechanical treatment - By pressing," *Electronic Journal of Polish Agricultural Universities* 9(3), #15. ISSN: 1505-0297.

Gašparík, M., and Barcik, Š. (2013). "Impact of plasticization by microwave heating on the total deformation of beech wood," *BioResources* 8(4), 6297-6308. DOI: 10.15376/biores.8.4.6297-6308

ISO 3130 (1975). "Wood-determination of moisture content for physical and mechanical tests," International Organization for Standardization, Geneva, Switzerland.

Kafka, E. (1989). *Wood Guide I.*, SNTL, Praha, 484 pp. ISBN: 80-03-00009-2.

Kunesh, R. H. (1968). "Strength and elastic properties of wood in transverse compression," *Forest Products Journal* 18(1), 36-40.

Kurjatko, S., Čunderlík, I., Dananajová, J., Dibdiaková, J., Dudas, J., Gáborík, J., Gaff, M., Hrčka, R., Hudec, J., Kačík, F., Kúdela, J., Lagaňa, R., Laurová, M., Mamoň, M., Mišíková, O., Račko, V., Rohanová, A., and Solár, R. (2010). "Parametre kvality dreva určujúce jeho finálne použitie (Wood quality parameters determining its end use)," Ivan Makovíny, Štefan Šteller (eds), Technical University in Zvolen, 352 pp.

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), 137-146.

Kvietková, M., Gaff, M., Gašparík, M., Kminiak, R., and Kriš, A. (2015b). "Effect of number of saw blade teeth on noise level and wear of blade edges during cutting of wood," *BioResources* 10(1), 1657-1666. DOI: 10.15376/biores.10.1.1657-1666

Lakes, R. (2009). *Viscoelastic Materials*, Cambridge University Press, New York, 461 pp. ISBN: 978-0-521-88568-3.

Liptáková, E., and Sedliačik, M. (1989). *Chémia a aplikácia pomocných látok v drevárskom priemysle*, ALFA Bratislava, 519 pp.

Marko, M. (2010). *Deformácie dyhových vrstvovitých materiálov v závislosti na ich štruktúre* (Deformation venner laminar materials in relation to their structure), M.S. thesis, Technical University in Zvolen, Zvolen, Slovakia.

Nemec, Ľ., Šulán, E., and Zemiar, J. (1986). *Technológia Výroby Nábytku*, SNTL Praha, ALFA Bratislava, 520 pp.

Požgaj, A., Chovanec, D., Kurjatko, S., and Babiak, M. (1997). *Štruktúra a Vlastnosti Dreva* [*Structure and Properties of Wood*], Príroda a. s., Bratislava, 486 pp.

Regináč, L., Babiak, M., Beničák, J., Dubovský, B. Kuriatko, S., Ladomerský, J., Makovíny I., and Požgaj, A. (1990). *Wood Science II.*, Editačné stredisko, VŠLD Zvolen, 424 pp.
USDA Forest Service. (1999). *Wood Handbook: Wood as an Engineering Material*, Madison, Wisconsin, 508 pp. ISBN: 978-1-59124-170-6.
Zemiar, J. Gáborík, J., Muzikař, Z., Navrátil V., and Ružinská, E. (2009). *Technology of Furniture*, TU Zvolen, 287 pp. ISBN 978-80-228-2064-6.

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