Modification of Veneers by Lamination and Steaming for the Purpose of Increasing 3D Moldability

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The focus of this work was to determine the 3D moldability of veneers on circular test pieces treated with steam plastification. These results were compared with results acquired from pieces laminated with three different types of laminating foils with thicknesses of 80, 100, and 125 µm before proper 3D molding. The purpose of test piece lamination was to change the degree of pre-stress and move the neutral plane into the laminating foil, which actually works as a flange. Results acquired from sets of test pieces modified by steam plastification and lamination were compared with the results acquired for the set of test pieces without any treatment. To determine the effects of wood type, the results obtained with beech wood of 0.5-mm thickness were compared with the results acquired from birch wood of 0.5-mm thickness using two types of spherical stamping tools with 20-mm and 40-mm diameters for molding the test pieces. The final examined characteristics were the means of attachment of the test pieces; *i.e.,* the effect of loose attachment and attachment with a hold. The characteristic of maximum deflections was examined during 3D-molding. To measure the listed results, a testing appliance was specially designed and constructed.

Keywords: Veneer; 3D-molding; Plasticizing; Erichsen deep-drawing test; Moldability

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INTRODUCTION

There has been an interest in wood (veneer) three-dimensional molding for many years. As early as 1949, Vorreiter discussed some options for increasing veneer moldability by means of multi-layered material production, veneer production from comprimed wood, or modification by chemical plastification. Recently, the issue of veneer moldability and modification has been discussed in several works (Wagenführ and Buchelt 2005; Wagenführ *et al.* 2006; Huber and Reinhard 2007; Yamashita *et al.* 2009; Schulz *et al.* 2012).

Modification by plastification is a traditional type of wood modification carried out primarily for the purpose of bending (2D molding). There are several known methods of plastification, such as hydrothermic, electromagnetic, and chemical (Zemiar *et al.* 1999), of which only the first two are generally used for the given purpose. Chemical methods have found their application mostly in the compression (press molding) of wood, carried out for the purpose of compensating for low-performance hardwood species or for the purpose of surface relief (Lábsky 1974; Schellberg 2012). During the molding process, the highest degree of wood plasticity with the lowest amount of damage to the lignin-polysaccharide components of the matrix must be achieved (Antti 1999; Hansson 2007). This also depends on plastification method. Steaming is one of the oldest and most widely used methods of plastification. The advantage of this method is the resulting high plasticity of wood with only minor degeneration caused by longer plastification times.

The state in which wood reaches the highest degree of plasticity is convenient for molding technologies, but the compounds of the lignin-polysaccharide matrix of wood are damaged as little as possible. The primary purpose of wood plastification before molding is the temporary change in physical and mechanical characteristics, with which the optimal conditions for molding are reached (Gaff and Zemiar 2008).

Regardless of wood structure and applied technology, the molding process is complicated for the following reasons (Sandberg and Navi 2007): (1) Wood is a viscous-elastic material with an indistinctive yield point, which is highly dependent on the speed of deformation in every case; (2) The yield points for drawing and pressure are numerically diverse, and the difference increases with increasing humidity content, as well as with increasing temperature; and (3) The tension at which rupture occurs is much higher for pressure than for drawing.

Another method of wood molding that complements the effects of plastification and provides increased deflections is the use of a flange. To better utilize a material’s plasticity, the neutral plane must be moved further in the direction of the drawing zone. It is possible to achieve this with axial pre-loading (axial pressure). Both in theory and in practice, it turns out that even though wood had been plastified, damage occurred in the drawing zone. However, this can be compensated for with axial pre-loading, which can be achieved by inserting a metal elastic band alongside the convex side of the treated piece and by anchoring the wood with the flange terminal stops. Because of the change in pre-loading degree, the neutral plane is moved into the flange (Sandberg 2012). The neutral line is moved into the flange by the use of flange and terminal stops, and the drawing ruptures on the drawing side are eliminated.

The purpose of this research was to assess the effect of steam plastification and veneer lamination with a foil on the 3D molding of beech and birch veneers based on the method developed by Zemiar and Fekiač (2014).

EXPERIMENTAL

Materials

For evaluation, the 3D moldability circular test pieces were used. Specimens with diameters of 60 mm were radially cut from beech (*Fagus sylvatica* L.) veneers and birch veneers (*Betula pendula* L.) with an average thickness of 0.51 mm. Beech and birch trees came from Poľana, near Zvolen, Slovakia and were manufactured by Drevonaexport s.r.o. (Slovakia).

The test pieces were created from veneer sheets by cutting, while ensuring the test pieces did not have any faults. The initial moisture content of all sets of test pieces was 16%. To achieve the required moisture levels, the test samples were placed in a Binder climate chamber (ED, APT Line II; Germany), under the conditions 60% relative humidity and 20 °C temperature.

Based on the aforementioned knowledge, a method of veneer lamination was designed in which the wooden veneer was laminated bilaterally with a foil (Fig. 1). The laminating effect can be seen in the change of pre-loading degree and in the movement of the neutral plane into the used foil, which actually works as a flange with stops.

Fig. 1. Specimen after foil lamination

This veneer modification consolidates the functions of the flange and terminal stops and therefore creates the best conditions for veneer 3D molding. The scheme of veneer insertion into the foil used for laminating veneers is shown in Fig. 2.

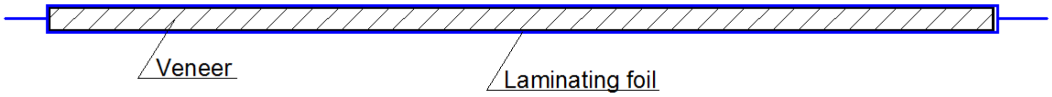

Fig. 2. Scheme of veneer insertion into a foil

Furthermore, the sets of test pieces were split according to their treatment method. The set of test pieces plastified with steam was compared with the set of test pieces modified by lamination. These results were compared with the results acquired from the set of untreated test pieces (controls).

Plastification of the samples by steam was carried out within a thermal chamber (ED, APT Line II, Germany) (*t* = 95 °C). The sets of test pieces were laminated with three different thicknesses of foil (*i.e.*, 80, 100, and 125 µm) from the Peach® Co. (Slovakia). The foil was comprised of polyethylene terephthalate (PET), polyethylene (PE), and ethylene-vinyl acetate (EVA) at ratios of 6:1.6:2.4, respectively. Untreated test pieces were used as the basic comparison criteria for the acquired results. The set of untreated test pieces was conditioned to 16% moisture content, the same as the test pieces.

Methods

There is currently no official method for assessing the 3D moldability of veneers, unlike for metals (metal sheets). As a result of low veneer moldability compared with metallic materials, Erichsen's method (Veles 1989) for assessing the moldability of metal sheets, was modified and used in this study.

During the 3D molding of veneers, pressure tensions act in the tangential plane and drawing tensions act in the radial plane of the test piece. Considering this, curls occur on the veneer margins, and ruptures form in the center of the veneer. According to Wagenfurer (2006), it is possible to avoid curling on the veneer margin by the application of a steady attachment appliance during bending. In this work, it was decided to observe the attachment of pieces with a hold in the appliance (Fig. 3) during the stressing of veneer 3D molding. The results acquired this way were compared with the results measured on test pieces without the hold in which the veneer was laid in the appliance (Fig. 3a). The pre-loading system (attachment of test pieces with a hold), developed to prevent possible curling on the perimeter of the circular test piece, was held by the peripheral thrust force F´ during molding (Fig. 3b).

The 3D moldability was based on the maximal caving size of the veneer pressed by the stamping tool (either 20 mm or 40 mm diameter) into the matrix before its rupture (Fig. 3).

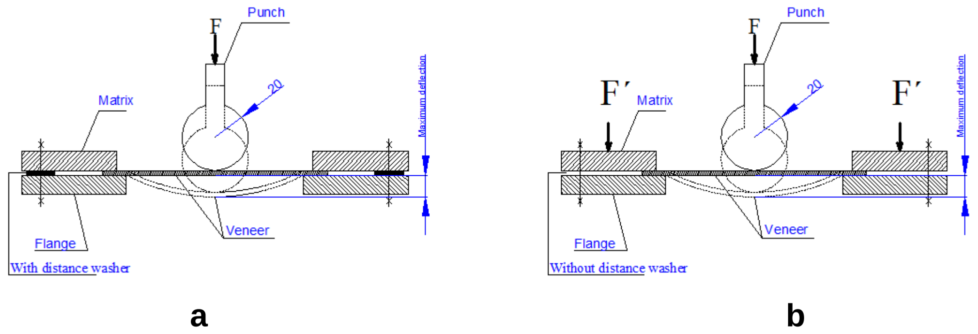

Fig. 3. Schematic of principle and molding framework. (a) no pressure on the edge of the veneer piece; and (b) pressure on the edge of the veneer piece. F = molding force; F´ = thrust force

In Fig. 4, a flow chart provides the experimental design of individual examined sets of test pieces.

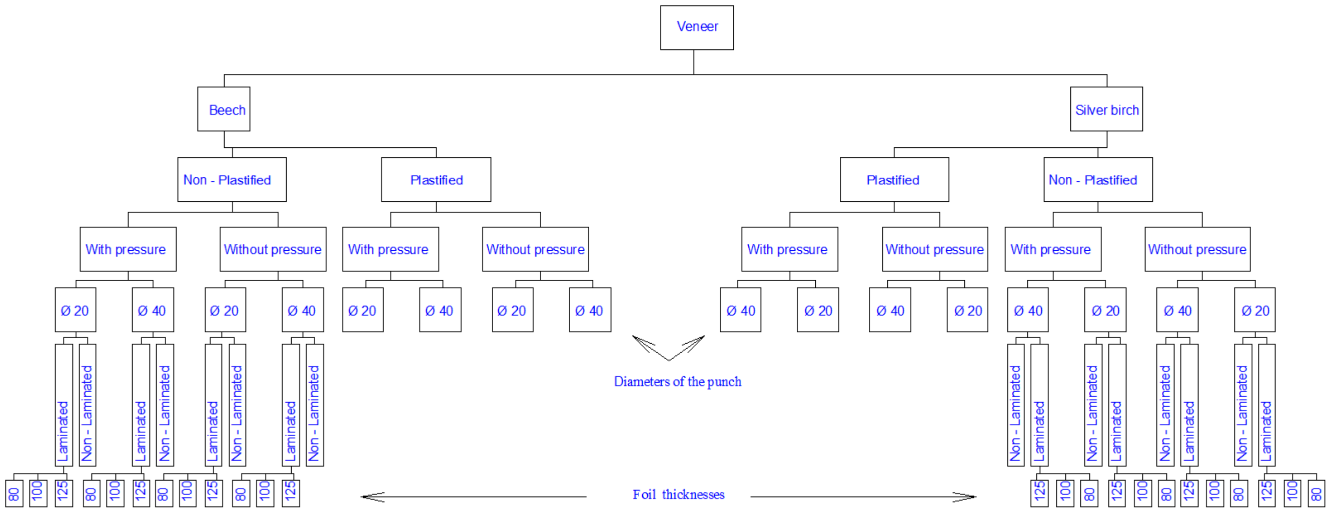

Fig. 4. Categorization of test pieces

STASTICA 7 software (StatSoft Inc.; Tulsa, OK) and a six-factor analysis were used to statistically assess the measured results. The effect of individual factors as well as the interactions was determined. The term "mixed factor" included factors of lamination, type of foil used for lamination, and plastification. The mixed factor approach was used due to the difference in the numbers of test piece sets. The degree of curling on the margins of test pieces were visually assessed as "did form" or "did not form".

RESULTS AND DISCUSSION

The six-factor analysis results for variance assessing the effect of individual factors, as well as the effect of two- to six-factor interactions on veneer deflections during 3D molding are listed in Table 1. From these results, it is apparent that the effect of individual factors and their interaction can be considered statistically significant ($P<0.05$) in all of the examined cases.

Based on the data in the table, the effects of the other examined three- to six-factor interactions can be considered combinations whose synergistic effect on the values of the examined characteristics is statistically significant ($P<0.05$).

Table 1. Influence of Individual Factors and Its Interactions on Deflection

Monitored Factor	**Sum of Squares**	**Degrees of Freedom**	**Variance**	**Fisher's F-test**	**Significance Level P**
Overall diameter	13078.74	1	13078.74	4638.674	0.000001
{1} Wood specie	185.84	1	185.84	65.911	0.000001
{2} Size of stamping tool	198.31	1	198.31	70.335	0.000001
{3} Attachment	54.38	1	54.38	19.286	0.000015
{4} Mixed factor	1061.56	4	265.39	94.127	0.000001
1*2*3*4	45.06	4	11.26	3.995	0.003489

It is evident from the graph in Fig. 5 and from the statistical analysis in Table 1 at a 95% interval of reliability, assessing the effect of wood species on maximal deflections during the 3D molding of wood, generally higher deflections during the molding of birch veneers was achieved. An average deflection of almost 6.9 mm was found for birch veneers, while for beech veneers; the average deflection was 5.5 mm.

It is possible to assert that generally, with increasing stamping tool diameter, deflections also increased (Fig. 6).

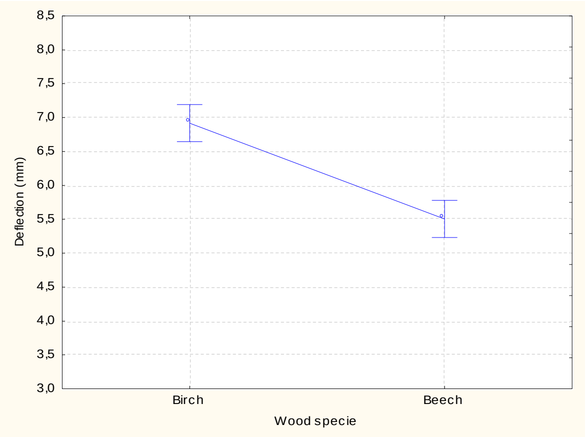

Fig. 5. Effect of wood species type on deflections

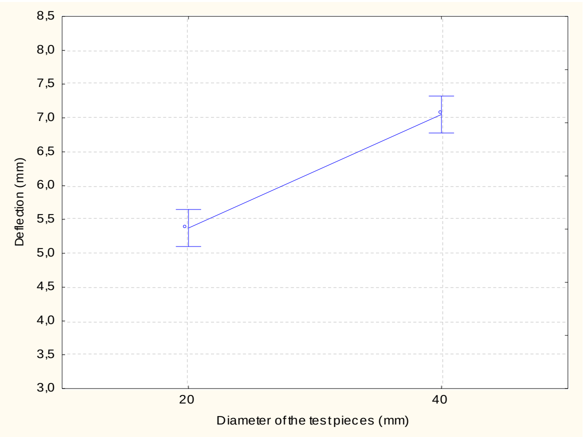

Fig. 6. Effect of stamping tool size on deflections

From Fig. 7, which depicts the effects of attachment, it can be seen that higher deflections were achieved during 3D-molding with loose attachment of test pieces in the appliance. In comparison with the listed results with those measured for steady attachment, it is evident that based on the difference in average values, the difference can be considered statistically significant ($P<0.05$).

Figure 8 depicts the effect of type of laminating foil on the plastification of test pieces, and also compares the results of the aforementioned sets with the results measured for the set of untreated test pieces. From the graph, it can be seen that the highest maximal deflections were observed during 3D-molding for the set of test pieces that were laminated with a foil of 80-µm thickness, though the difference was on the verge of statistical significance. Furthermore, it is apparent from the diagram that a slight increase in deflections with plastification was achieved in comparison with values measured for the set of untreated test pieces. However, a significant ($P<0.05$) decrease in deflections was observed in the set of plastified test pieces by comparing the set of untreated test pieces with the sets that were laminated.

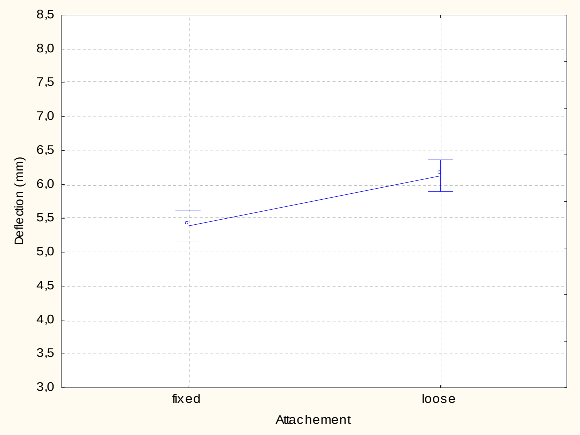

Fig. 7. Effect of attachment on deflections

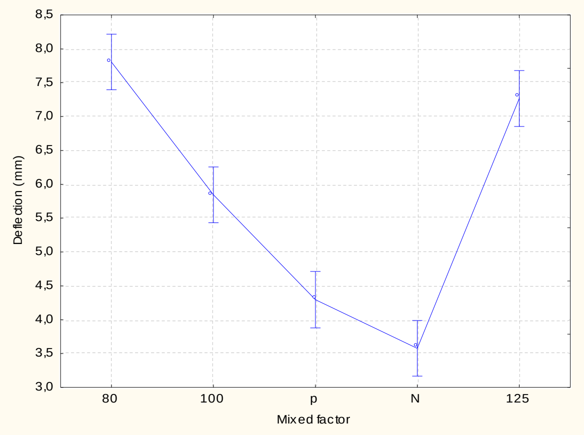

Fig. 8. Effect of treatment type on deflections. 80, lamination with foil of 80-µm thickness; 100, lamination with foil of 100-µm thickness; 125, lamination with foil of 125-µm thickness; P, plastified – non laminated; N, non plastified, without treatment

Because of the wide range of results, the analysis of results was focused on assessing the effects of all the examined factors concurrently. Figure 9 depicts the synergistic effect of the examined factors, namely the diameter of the stamping tool, type of wood species, and method of treatment for steadily attached test pieces. Based on the comparison of the individual sets of test pieces, it is possible to assert that lower deflections of test pieces were measured for the beech wood for all examined sets.

The increased diameter of the stamping tool was also manifested by an increase in deflections in all examined cases. The effect of plastification on the values of examined characteristics can be considered a statistically significant contribution. With plastification, an increase in deflections was observed for both types of wood species, compared with untreated pieces. The greatest increase was found in the values of examined characteristics in all cases of laminated test pieces. The most significant ($P<0.05$) increase in maximal deflections occurred with the use of 80-µm and 125-µm thick foils (Table 1).

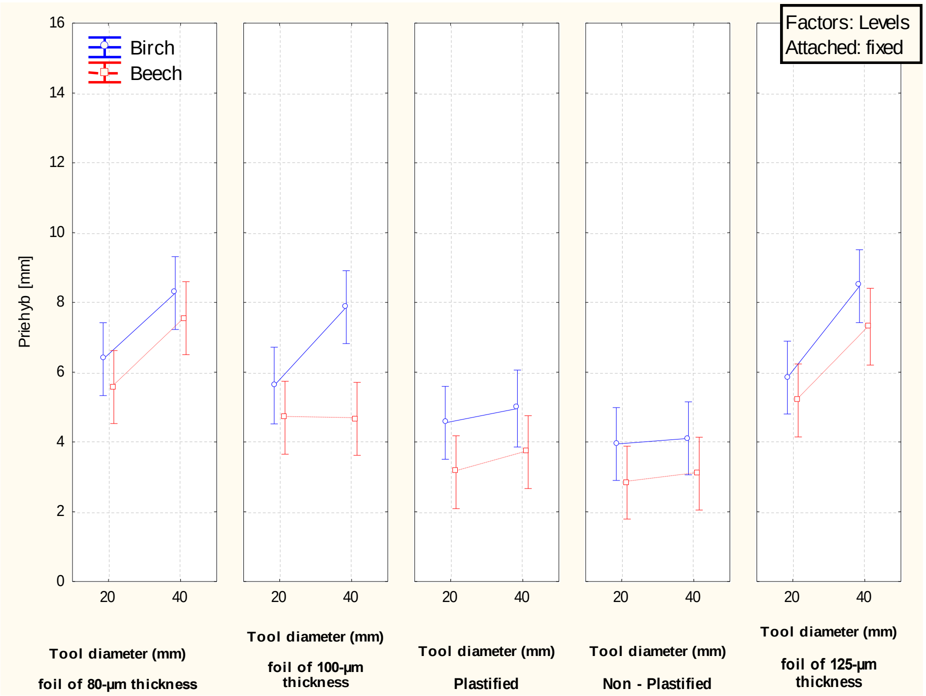

Fig. 9. Effects of foil thickness and plastification on deflections on attached test pieces. Diagram legend: 80, lamination with foil of 80-µm thickness; 100, lamination with foil of 100-µm thickness; p, plastified test pieces; N, non-plastified test pieces; 125, lamination with foil of 125-µm thickness

Figure 10 depicts the interaction of factors such as stamping tool diameter, type of wood species, and method of modification with loose attachment of test pieces.

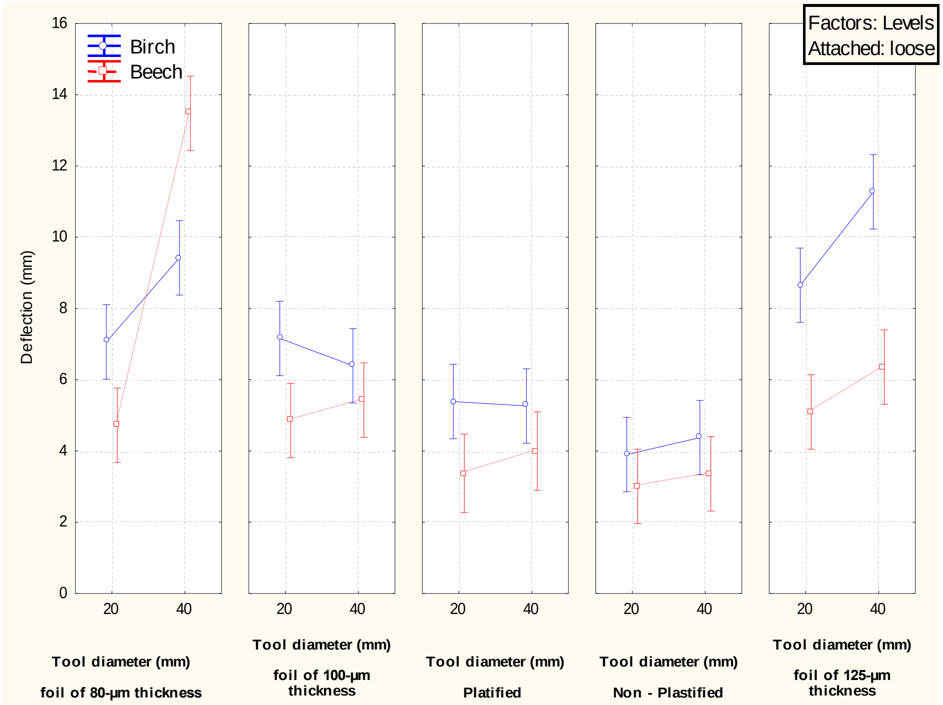

Fig. 10. Effects of foil thickness and plastification on deflections on non-attached test pieces. diagram legend: 80, lamination with foil of 80-µm thickness; 100, lamination with foil of 100-µm thickness; p, plastified test pieces; N, non-plastified test pieces; 125, lamination with foil of 125-µm thickness

Similiar to the results in Fig. 9, higher deflections of test pieces were observed for birch wood. The positive effect of plastification in comparison with sets of untreated test pieces was evident from the comparison of the results for individual modifications. With lamination, multiple increases in veneer deflections were achieved during molding, and the highest values were with the use of 80-mm and 125-mm-thick foil.

The set of beech test pieces stressed by a spherical stamping tool of 40-mm diameter and laminated with foil of 80-mm thickness was an interesting group. The test piece deflection was 13.5 mm, which was much higher than that found in any other group. This was not due to a failure of the test piece, since no defects, such as ruptures in the center of the test piece or curls on the margins of the test piece, were found.

It is apparent from the comparison of Figs. 9 and 10 that higher deflections were achieved with the loose attachment than for the sets of test pieces with attachment. The results assess the formation of undesirable defects, such as curling on the margins of test pieces (Tables 2 and 3). From the results listed, it is evident that for most cases of loose attachment, higher deflections were achieved; however, curls occurred on the margins of the test pieces.

For the sets of test pieces that were subject to attachment with hold in the appliance during the stressing, the average values were lower; however, fewer curls occurred on the margins of the test pieces than for sets of test pieces with loose attachment.

Table 2. Average Deflection Values for Stamping Tool Diameter 20 µm

Wood Species	Modification	Foil Thickness (µm)	Stamping Tool Diameter (µm)	Attachment Method	Average Deflection Values (mm)	Undulation
Beech	Laminated	80	20	Loose	4.8	No
	Laminated	100	20	Loose	5.9	Yes
	Laminated	125	20	Loose	5.0	Yes
	Plastified	-	20	Loose	3.2	No
	Untreated	-	20	Loose	3.0	No
	Laminated	80	20	Steady	5.5	Yes
	Laminated	100	20	Steady	4.7	No
	Laminated	125	20	Steady	5.2	Yes
	Plastified	-	20	Steady	3.0	No
	Untreated	-	20	Steady	2.8	No
Birch	Laminated	80	20	Loose	7.0	Yes
	Laminated	100	20	Loose	7.1	Yes
	Laminated	125	20	Loose	9.0	Yes
	Plastified	-	20	Loose	6.5	Yes
	Untreated	-	20	Loose	4.0	No
	Laminated	80	20	Steady	6.4	Yes
	Laminated	100	20	Steady	5.7	Yes
	Laminated	125	20	Steady	5.9	Yes
	Plastified	-	20	Steady	4.7	No
	Untreated	-	20	Steady	4.0	No

The occurrence of curls was found for test pieces with deflection greater than 5 mm. The exception was the set of beech test pieces laminated with 80-µm foil, stressed by a spherical stamping tool with a 40-mm diameter and loose attachment in the appliance. For these test pieces, the highest deflections of test pieces, and no curls on the margins of the test pieces occurred. Hence, the author will plan to investigate these test parameters in the future.

Table 3. Average Deflection Values for Stamping Tool Diameter 40 µm

Wood Species	Modification	Foil Thickness (µm)	Stamping Tool Diameter (µm)	Attachment Method	Average Deflection Values (mm)	Undulation
Beech	Laminated	80	40	Loose	13.5	No
	Laminated	100	40	Loose	6.5	Yes
	Laminated	125	40	Loose	6.2	Yes
	Plastified	-	40	Loose	4.0	No
	Untreated	-	40	Loose	3.4	No
	Laminated	80	40	Steady	7.5	Yes
	Laminated	100	40	Steady	4.6	No
	Laminated	125	40	Steady	7.2	Yes
	Plastified	-	40	Steady	3.7	No
	Untreated	-	40	Steady	3.0	No
Birch	Laminated	80	40	Loose	9.5	Yes
	Laminated	100	40	Loose	6.5	Yes
	Laminated	125	40	Loose	11.3	Yes
	Plastified	-	40	Loose	6.4	Yes
	Untreated	-	40	Loose	4.5	Yes
	Laminated	80	40	Steady	8.3	Yes
	Laminated	100	40	Steady	7.8	Yes
	Laminated	125	40	Steady	8.5	Yes
	Plastified	-	40	Steady	4.9	No
	Untreated	-	40	Steady	4.2	No

CONCLUSIONS

1. An innovative method was developed and demonstrated for assessing the 3D-molding of veneers based on maximal caving values.
2. Stamping tool diameter was found to be a significant ($P<0.05$) factor affecting deflections during 3D molding. With increasing stamping tool diameter, the deflections of veneers also increased. However, the result of increased deflections with increasing stamping tool diameter is not to be attributed to the influence of stamping tool dimensions, but rather to the influence of increased test pieces dimensions, the thickness of which did not change.
3. Based on the measured results, type of wood species was found to be a significant ($P<0.05$) factor affecting the deflections of veneers during 3D molding. It is evident from the results that higher deflections occurred for birch wood.
4. Plastification of veneers by steaming was found to significantly ($P<0.05$) increase wood bendability. With the effects of plastification, an average maximal deflection of 4.6 mm was achieved, whereas the average value for the untreated pieces was 3.6 mm. From the comparison of the results measured for the aforementioned sets of test

pieces, a significant ($P<0.05$) difference in favor of the plastification of test pieces arises, though this difference can be considered insufficient from a practical aspect.

5. The most significant contribution of the work was seen in the establishment and testing of the new innovative method of veneer modification before 3D molding, specifically veneer lamination. With the effect of veneer lamination, maximal deflections were increased from an average value of 3.6 mm for untreated pieces to a value of 11.6 mm with the use of laminating foil of 80-μm thickness. The effect of foil, which acted as a flange during 2D molding of wood, was significant.
6. The occurrence of curls can be observed on the margins of test pieces for all sets of test pieces with caving values greater than 5 mm.

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REFERENCES CITED

Antti, L. (1999). *Heating and Drying Wood using Microwave Power*, Ph.D. dissertation, Division of Wood Physics, Luleå University of Technology, Skellefteå, Sweden.

Gaff, M., and Zemiar, J. (2008). “Vplyv vlhkosti dreva a ohrevu lisovacieho nástroja na tvarovú stabilitu a kvalitu nerovnomerne zlisovanej plochy osikového dreva,” in: *Trieskové a Beztrieskové Obrábanie Dreva,* Ladislav Dzurenda, Zvolen, Technická univerzita vo Zvolene, pp. 315-320.

Hansson, L. (2007). *Microwave Treatment of Wood*, Ph.D. dissertation, Department of Wood Physics, Luleå University of Technology, Skellefteå, Sweden.

Huber, R., and Reinhard, H. (2007). “Dreidimensional verformten Furnier im Trend, Informationsbedauf über Grundlagen derVerarheitung und Anwendung,” HK 1, pp. 50-53.

Lábsky, O. (1974). “Vplyv amoniaku na drevo a jeho zložky,” ŠDVÚ, Bratislava, p. 64.

Matlák, J. (2014). *Vznik a Priebeh Porusenia dyh pri ich 3D-Tvárneni,* Master's thesis, Technická univerzita vo Zvolene, Zvolen, Slovakia.

Sandberg, D., and Navi, P., (2007) “Introduction to thermo-hydro-mechanical (THM) wood processing”. Växjö: School of Technology and Design, 177 s.

Schellberg, D. (2012). *Innovativer Möbelbau - Aktuelle Materialien und Techniken.* Gebundenes Buch mit Schutzumschlag, Germany.

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

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

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

Wagenfuhrer, A., Buchelt, B., and Pfriem, A. (2006). “Material behaviour of veneer during multidimensional moulding,“ *Holz als Roh-und Werkstoff* 64, 83-89. DOI: 10.1007/s00107-005-0008-5

Yamashita, O., Yokochi, M., Miki, T., and Kanayama, K. (2009). “The pliability of wood and its application to molding,” *Journal of Materials Processing Technology* 209, 5239-5244. DOI: 10.1016/j.jmatprotec.2008.12.011

Zemiar, J., and Fekiač, J. (2014). “Testing and evaluation of 3D-formability of veneers,” *Acta Facultatis Xylologiae Zvolen* 56(1), 31-38.

Zemiar, J., Gáborík, J., Solár, M., and Kotrády, M. (1999). Tvárnenie dreva ohýbaním. Zvolen : Technická univerzita vo Zvolene. Zvolen, Slovakia.

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