ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 11 N° 4 2015
pp. 43-49

THE EFFECT OF VENEER MODIFICATION ON THE BOND-LINE STRENGTH IN LAMINATED VENEER PRODUCTS

Lars BLOMQVIST
Linnaeus University, Department of Forestry and Wood Technology
SE-351 95 Växjö, Sweden
E-mail: lars.blomqvist@lnu.se

Magdalena STERLEY
SP Technical Research Institute of Sweden, SP Wood technology
Box 5609, SE-114 86 Stockholm, Sweden
E-mail: magdalena.sterley@sp.se

Dick SANDBERG
Luleå University of Technology, Wood Science and Engineering,
Forskargatan 1, SE-931 87 Skellefteå, Sweden
E-mail: dick.sandberg@ltu.se

Jimmy JOHANSSON
Linaeus University, Department of Forestry and Wood Technology
SE-351 95 Växjö, Sweden
E-mail: jimmy.johansson@lnu.se

Abstract

A major problem in the manufacture of three-dimensional laminated veneer products (LVP) is damage due to stretching and/or buckling of the veneer. To reduce or eliminate this problem, veneer densification or adding a strengthening layer to the veneer can be an alternative. To study how veneer modification influences the veneer-to-adhesive bond strength, three methods of modification were studied in relation to an unmodified reference veneer: (1) densified veneer, (2) veneer pre-bonded with paper and hot melt adhesive (HMA), (3) veneer pre-bonded with non-woven polypropylene (NW) fabric glued to the veneer (a) with a urea formaldehyde (UF) adhesive, (b) with a mixture of UF and polyvinyl acetate (PVAc) adhesive, and (c) with a PVAc adhesive. Densification, pre-bonding with paper, and NW with UF/PVAc adhesive mixture resulted in no or only a slight decrease in strength of the bond-line compared to the reference. NW glued with UF or PVAc adhesive showed a considerable reduction in the strength of the bond-line. The climatic cycling had no significant influence on the bond strength.

Key words: *densification; HMA; pre-bonding, PVAc; strengthening; THM processing; UF; wood.*

INTRODUCTION

Moulded and laminated veneer products (LVP) consist of veneers bonded together with an adhesive into a predetermined shape. Laminating veneer makes it possible to create a great variety of high strength components for use in furniture, interior fittings, and constructions. A major problem in the manufacture of LVP is that the veneers may stretch and/or buckle under moulding, which can result in damage to the product. The degree to which a veneer can be shaped during moulding depends, for example, on the veneer thickness and preparation, specie-related properties, product design, and the mould itself. Bending in one direction is in general not difficult, while a strongly three-dimensional shell can be very difficult to mould without damage the veneer.

It is possible to modify veneers in different ways to prevent undesired veneer deformation or cracking during moulding: (1) Veneers can be formatted by removing “unnecessary parts” of the veneer in areas prone to problems of stretching and/or buckling while moulding. (2) A fabric, mesh, paper, or other material can be pre-bonded to the back of the veneer to strengthen it in the transverse direction; a method often used for the visible, outermost veneers of thin or brittle veneers. (3) A ‘3-D veneer’ can be formed extremely three-dimensionally. The most well-known 3-D veneer was developed by Reholz GmbH and was later introduced onto the market (Müller 2006). (4) The veneer is modified before moulding by thermo-hydro, thermo-hydro-mechanical, or chemical action (Navi and Sandberg 2012). Traditionally, heat and moisture have been the most common way to soften wood and make it more susceptible to shaping. In the thermo-hydro processes, the glass transition temperatures (Tg) of the amorphous components of the wood are a key factor for a good result (e.g. Huttunen 1973).

Adhesive properties such as curing time, adhesion, wettability, friction, stiffness and strength are important parameters that can influence both the spring-back deformation and the total stiffness of the final product (Ormarsson and Sandberg 2007). The mechanical and chemical properties of wood surfaces influence the quality of the adhesive bonding (Marra 1992). Surface fractures or wood extractives can lead to poor bond strength. Wetting, flow and penetration of adhesive can be impeded by both physical deterioration and chemical contamination of the wood surfaces (Frihart and Hunt 2010). Variations in moisture content can cause stresses in the bond line (Forest Products Laboratory 1957). The surface energy of wood in general is influenced by time elapsed from cutting because of low molecular substances such as extractives contaminate the surface. This change in surface energy will influence the adhesion during gluing which is represented by strength of the bond (Marra 1992).

OBJECTIVE

The purpose was to study how some modifications to the veneer during moulding influences the veneer-to-adhesive bond strength and how seasonal variations may affect the strength.

MATERIALS AND METHODS

The material used for the study was a sliced veneer of beech (*Fagus silvatica* L.) with varying annual ring orientation in the cross section, but straight grained in the veneer surface. Three different modifications of the veneers were evaluated:

1. Unmodified veneers as reference.
2. Densified veneers, i.e. veneers densified at a surface pressure of 8.9 MPa at 100°C for 1 minute, after the veneers had been conditioned to a moisture content of 20%. The compression remaining after spring-back was 50% of the original veneer thickness.
3. Veneer pre-bonded with paper (Veneer backer VC300+, PWG VeneerBackings GmbH) that included a hot-melt adhesive (HMA) and was applied to the veneer at a pressure of 1.8 MPa at 130°C.
4. Veneer pre-bonded with *non-woven* polypropylene fabric (NW) (Spunbond 50 gram, Scandinavian Nonwoven Ltd.):
    - 4.1. glued to the veneer with a UF adhesive system (Casco Adhesives Inc.) composed of resin 1274 and hardener 2584 with a spread of 120 g/m^2 at a surface pressure of 1.0 MPa at 80°C,
    - 4.2. glued to the veneer with a 50/50 mixture of the UF adhesive system in 4.1 and PVAc in 4.3 with a glue spread of 120 g/m^2 at a surface pressure of 1.0 MPa at 80°C, and
    - 4.3. glued to the veneer with a PVAc (Casco Adhesives Inc.) adhesive 3339 with a spread of 120 g/m^2 at a surface pressure of 1.0 MPa at 80°C.

Densification of the veneers (group 2) was tested because such veneers are more flexible than unmodified veneers, (see Navi and Sandberg 2012, p. 291). The methods used in groups 3 and 4.1 were based on the fact that these modifications are regularly used in the industry producing LVP. In Blomqvist et al. (2014) such modifications resulted in low shear-strength values for group 4.1. In the present paper, alternative adhesive systems were tested (groups 4.2 and 4.3) together with NW.

To avoid failure in the wood material during the tensile-shear test, the unmodified parts of the samples were strengthened with a paper of the same type as that used in group 3, glued on the flat side of the wood (outer parts of the samples). Each group was divided into two subgroups designated A and B. Subgroup A was tested in a sequence controlled by the testing machine directly after bonding and cooling of the samples, and samples in subgroup B was exposed to a cycle of low and high relative humidity (RH) after bonding before the final tensile shear strength test (Table 2). Each subgroup consisted of 10 replicates, and all 120 replicates were tested.

Table 1

Design of specimens for tensile shear test
P'V and VP' – unmodified veneer (V) strengthened with paper (P´)

Group No.	Type of modification	Order of materials in the specimens in relation to the tested bond-line (BL)
1	Unmodified (reference)	P'V – BL – VP'
2	Densified veneer (DV)	P'V – BL – DV
3	Paper-reinforced veneer (PV)	P'V – BL – PV
4.1 – 4.3	Fabric-reinforced veneer (NWV)	P'V – BL – NWV

The tensile shear strength test was performed in an automated bonding evaluation system (ABES) machine (Adhesive Evaluation Systems, Inc.) as shown in Fig. 1. The test was a single lap-joint test according to EN 205 (2003), but with modified dimensions. Table 2 shows the parameters used in the test. After testing, the mode of failure was determined, defined as adhesion failure, fabric failure, fibre failure, paper failure, wood failure or mixed failure.

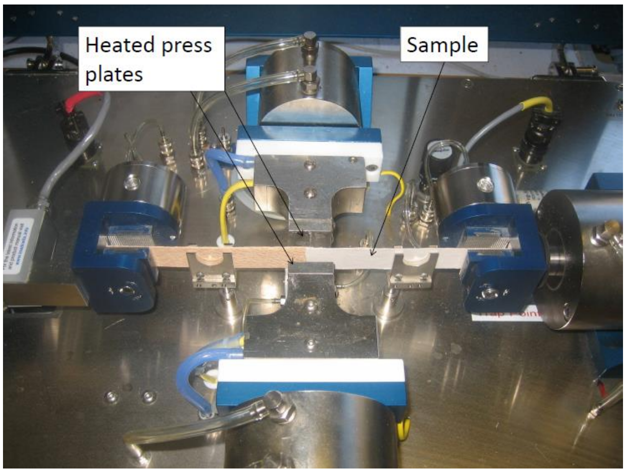

Fig. 1.
Automated bonding evaluation system (ABES) machine

Table 2
Parameters for the tensile shear strength test

Parameter	**Quantity**	**Comment**
Samples (mm)		
• Length of test piece	231	
• Length of test slip	117	
• Length of overlap	3	
• Width	20	
• Thickness	0.4/0.2	Unmodified/densified
Bond area (mm^2)	60	
Adhesive in bond line (BL)		UF adhesive system (Casco Adhesives Inc. resin 1274 and hardener 2584)
Adhesive quantity (g/m^2)	150	
Pressing		
• Temperature (°C)	90	
• Pressure (MPa)	1.5	
• Duration (s)	60	
Subgroup A		
1.Cooling time before tensile test (s)	30	With air
Subgroup B		
1.Climate cycling at 20°C (days)	4/5/32	4 days at 20% RH after bonding, then 5 days at 85% RH and finally 32 days at 20% RH before the tensile test.

The results of the shear strength test were analysed by statistical methods to identify significant differences in mean values, using ANOVA with 95% confidence intervals.

In addition 12 samples were bonded together, two in each group, for a study of the bond-line zone without subjecting them to the tensile shear strength test. Of these, one from each group was RH cycled as for subgroup B. Scanning electron microscopy (SEM) was used to study the micro-structure of the bond-line zone. The samples were prepared by an ultraviolet (UV) laser ablation technique developed by Seltman (1995) (Fig. 2). Samples for SEM studies were prepared in time for the testing of subgroup A and after climatic cycling of subgroup B.

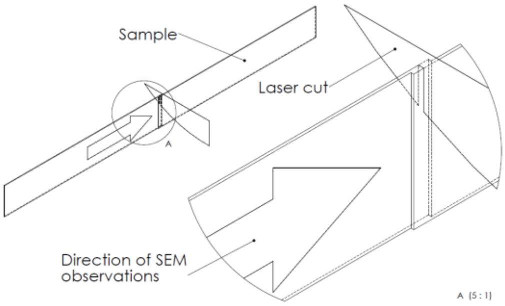

Fig. 2.
Sample preparation for SEM studies using UV-laser ablation. To the left, a full view, and to the right, a detailed view of a sample. The laser cut shows where the sample was divided before the SEM study. The arrow shows the direction of the SEM observations

RESULTS AND DISCUSSION

Fig. 3 shows the results of the tensile shear test. There was no significant difference in adhesive-bond strength between the modifications with densified veneer, paper-reinforced veneer pre-bonded with HMA, fabric-reinforced veneer pre-bonded with a mixture of UF and PVAc (groups 2, 3, 4.2) and the reference specimens (group 1), but the specimens with fabric-reinforced veneers pre-bonded with UF and PVAC (group 4.1 and 4.3) had a significantly lower strength, for both subgroups of specimens. The climatic cycling influenced the strength of the adhesive bonds of both group 3 and group 4.1 and slightly reduced the bond strength. However, the failure path was influenced by the climatic cycling, as shown in Table 3. There were no significant differences in strength between groups 1 2, 3 and 4.2. The results of statistical evaluation are shown in Fig. 3. Confidence intervals which overlap each other indicate no significant difference between means at the 95% confidence level.

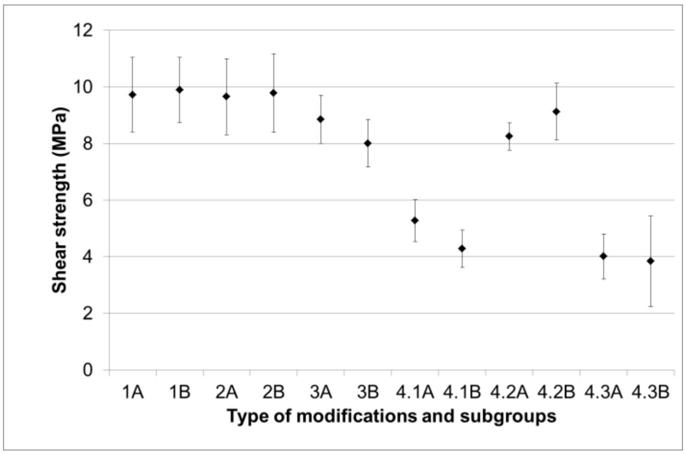

Fig. 3.
Mean shear strength (symbol) and 95% confidence intervals (bar) of adhesive bonds for test groups according to Table 1, directly after gluing (A), and after RH cycling (B)

Table 3 shows the different types of failure that occurred in the bond-line during the tensile shear test. Different modes of failure have been defined: (1) “Wood failure” means that the bond-line was stronger than the wood sample and that failure occurred only in the wood, (2) “fibre failure” means bond failure with the wood fibres remaining in the failure surface, and (3) "adhesion failure" means that the adhesive did not maintain adhesion between the different parts of the sample. "Adhesive bond failure" can be divided in (4) "cohesive failure" within the adhesive when adhesive remains on both sides of the bond-line surface, (5) "adhesion failure" is when adhesive remains on one side and wood on the other side of the bond-line surface, and (6) "wood/fibre failure" where failure occurred in the interphase between wood and adhesive. There was also (7) "mixed failure" where several types of failure interact. Failures in (8) the paper and in (9) the fabric also occurred.

Failure in subgroup A was well organised for most of the groups. In the reference (group 1) and the group with densified veneer (group 2), all the failure was wood and fibre failure. The group with paper-reinforced veneer (group 3) showed a more diversified character of failure including wood, fibre, adhesion and paper failure. In the groups with fabric-reinforced veneers pre bonded with UF and/or PVAC (group 4.1 – 4.3), all the failure was either adhesion or fabric failure.

For subgroup B (after climate cycling) the mode of failure changed for the group with densified veneer (group 2) to include adhesion failure, but this did not influence the shear strength. The mode of failure also changed in the group pre-bonded with paper (group 3), where adhesion failure occurred in most of the samples that were humidity cycled. This may be due to the swelling that occurred in the paper when the RH was increased.

Table 3

Type and number of failures in tensile shear test for specimens tested directly after pressing (subgroup A) and specimens RH cycled

Type of failure	**Group No. – subgroup A**						**Group No. – subgroup B**					
	1	**2**	**3**	**4.1**	**4.2**	**4.3**	**1**	**2**	**3**	**4.1**	**4.2**	**4.3**
Wood	8	10	3				4	2				
Wood/Fibre							2					
Fibre	2		1				4	1				
Wood/Adhesion									1			
Fibre/Adhesion			1					7				
Adhesion (A)			2	7	4	1			8	6	1	
Wood/Paper			2									
Wood/Paper/A			1									
Paper/A									1			
Fabric/A				3	5	1				4	6	
Fabric					1	8					3	10

Fig. 4 show examples of SEM photomicrographs from the bond-line zones of specimens not exposed to shear strength test.

The references, the densified veneers, and the veneers pre-bonded with paper or NW glued with the UF/PVAc adhesive mixture showed good penetration of the adhesive into the wood in the bond-line zone (Fig. 4a, b, c, d and g).

The densified veneer showed set-recovery after the RH cycling (Fig. 4c), and the paper to strengthen the veneer swelled during the RH cycling (Fig.4c).

The hot-melted adhesive (HMA) used to pre-bond the paper penetrated into the lumens during the pre-bonding (Fig. 4d, e) and this resulted in good bond strength.

The non-woven polypropylene fabric (NW) can be seen as dark areas in the bond-line zone in Fig. 4f-h. It is clear that the sample pre-bonded with NW and UF (group 4.1) had areas without any bonding in the bond-line zone (Fig. 4f). UF is a chemically curing adhesive that penetrated the NW and provided a smooth surface that the adhesive had difficulty in wetting and penetrating. This resulted in a poor bond-line strength.

The sample pre-bonded with NW and PVAc (group 4.3) also had problems in bonding, as shown in the SEM study as extensive delamination (Fig. 4h). The PVAc adhesive is more ductile than UF and can better resist the swelling and shrinkage due to climatic changes, and thus give higher bond strength. However, NW was still the weakest link in the bond, especially after climatic changes. All the failures in this case were in the fabric, indicating that the fabric was not penetrated by PVAc adhesive. Only poor adhesion between PVAc and non-woven polypropylene could be observed.

A mixture of UF and PVAc in the pre-bonding of the veneer with NW (group 4.2) gave a much better shear strength than either UF or PVAc, and the microscopy study showed that the bond-line had no cracks or delamination after gluing, indicating good adhesion (Fig. 4g). An explanation of the improved performance can be that the PVAc adhesive did not penetrate NW and that the UF adhesive penetrated NW less than the UF adhesive only in pre-bonding, which gave a more open NW for the secondary bonding.

The selected SEM images in Fig. 4 are representative of the study. Samples after RH cycling showed nothing other the re-swelling of the densified veneer and the swelling of the paper used to strength the veneers (Fig. 4c).

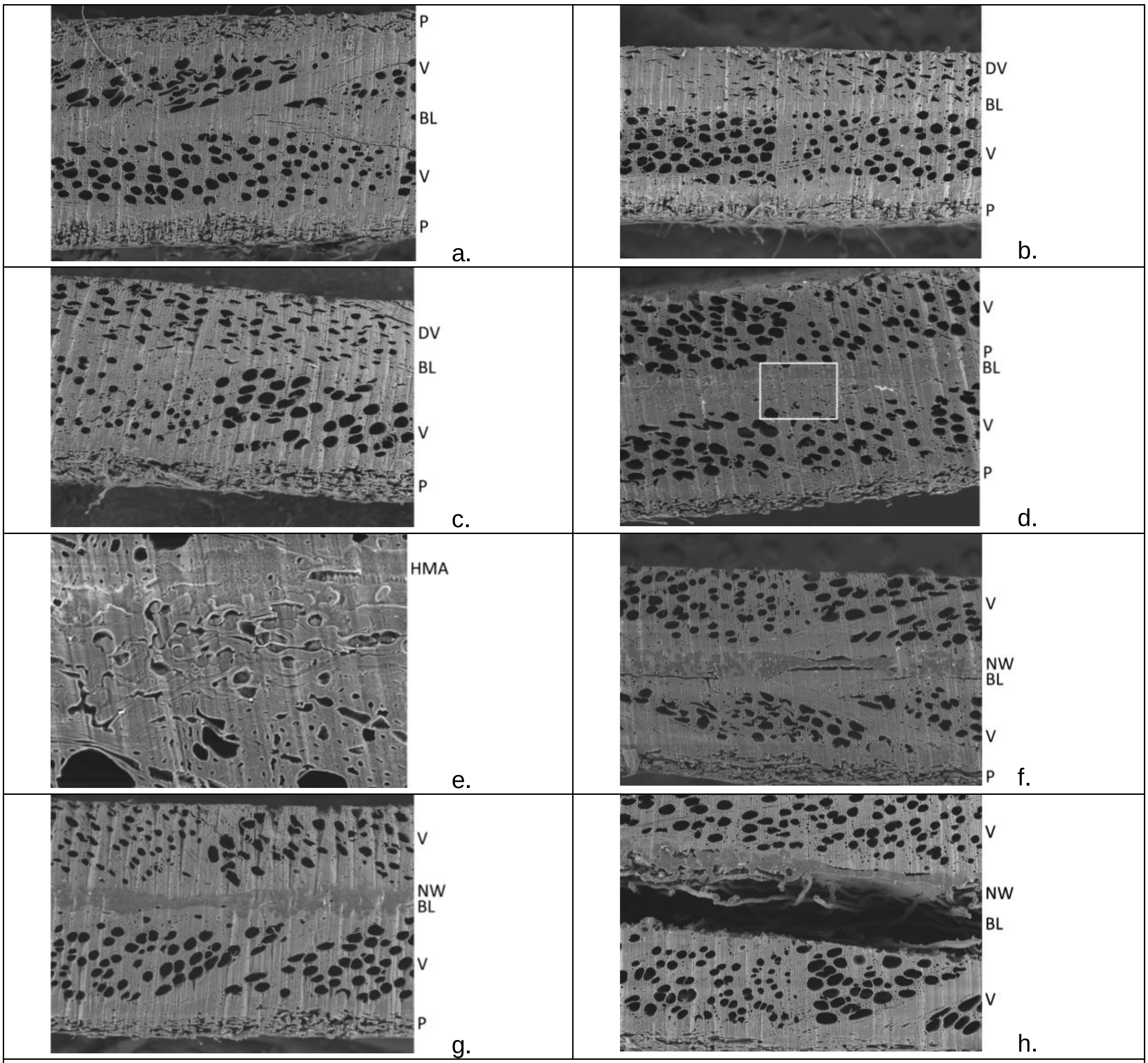

Fig. 4.
SEM micrographs showing cross sections of the bond-line zone for samples not exposed to RH cycling (subgroup A) and exposed to RH cycling (subgroup B). P – paper, V – veneer, BL – bond-line, HMA – hot-melt adhesive, and NW – non-woven polypropylene.

1 to 4.3 are test groups according to Table 1.

a. 1A: The bond-line zone in the reference sample.
b. 2A: The bond-line was not in the middle since one of the two veneers was densified.
c. 2B: The densified veneer had partly re-swelled and the paper had swelled.
d. 3A: Bond-line between paper and veneer in paper-reinforced veneer. The rectangle describing the area is enlarged in Fig. 4e.
e. 3A: HMA-filled lumen adjacent to the paper in the pre-bonding veneer.
f. 4.1A: The NW filled with UF has a darker shade of grey in the SEM than the veneers. The cracks in the bond-line indicate low adhesion between adhesive and veneer.
g. 4.2A: The NW pre-bonded with a mixture of UF and PVAc. The penetration in the bond-line and adhesion seem to be very good.
h. 4.3A: The NW pre-bonded with PVAc. The penetration and adhesion of the adhesive in the bond-line was low, as is shown by the openings in the bond-line.

CONCLUSIONS

The bond-line strength of different reinforcement methods to strengthen veneer for the moulding of laminated veneer products has been studied. The results of the tensile shear strength test on different combinations of modified veneer showed that the bond-line strength was not influenced by:

1. densification of the veneer,
2. pre-bonding of the veneers with paper without climate cycling, or
3. pre-bonding of the veneers with non-woven polypropylene fabric when pre-bonded with a mixture of UF and PVAc adhesive.

However, pre-bonding of the veneers with paper led to a lower strength after climatic cycling. The bond-line strength was considerable lower than to the reference for a veneer strengthened with non-woven polypropylene fabric pre-bonded with UF or PVAc adhesive. The RH cycling changed the type of failure especially for the group with densified veneer and the group with veneer pre-bonded with paper.

ACKNOWLEDGEMENT

Financial support from the Swedish Research Council Formas (project EnWoBio 2014-172) is greatly acknowledged. EnWoBioEngineered Wood and BiobasedBuilding Materials Laboratory.

REFERENCES

Blomqvist L, Sterley M, Sandberg D, Johansson J (2014) The influence of veneer modification on adhesive bond strength. In: Peter Wilson(ed.), Proceedings of the 10th meeting of the Northern European network for wood science and engineering (WSE), Edinburg, Scotland pp. 150-155.

EN 205. (2003) Adhesives — Wood adhesives for non-structural applications — Determination of tensile shear strength of lap joints. Brussels: European Committee for Standardization.

Forest Products Laboratory (1957) Shrinking and Swelling of Wood in Use, Rev. August 1957, No. 736. Madison, Wis.

Frihart C, Hunt C (2010) Adhesives with Wood Materials: Bond Formation and Per-formance, Wood handbook wood as an engineering material. General technical report FPL GTR-190. Madison, Wis.: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory: 228-251. 1 online resource, pp. 509.

Huttunen J (1973) Method for plasticizing wood. U.S. Patent No. 3894569.

Marra AA (1992) Technology of wood bonding: principles and practise. New York: Van Nostrand Reinhold.

Müller A (2006) Method for the production of a three-dimensional, flexibly deformable surface element. U.S. Patent No. 7131472B2.

Navi P, Sandberg D (2012) Thermo-hydro-mechanical processing of wood. Presses Polytechniques et Universitaires Romandes, EPFL Press, Lausanne.

Ormarsson S, Sandberg D (2007) Numerical simulation of hot-pressed veneer products: moulding, spring-back and distortion. Wood Material Science and Engineering, 2(3/4):130-137.

Seltman J (1995) Opening the wood structure by UV-irradiation. Holz als Roh- und Werkstoff, 53:225-228. (In German).