VENEER MODIFICATION FOR IMPROVED FORMABILITY WHEN MOULDING LAMINATED VENEER PRODUCTS

Lars Blomqvist,[1] Jimmy Johansson,[2] Dick Sandberg[3]

ABSTRACT
A major problem in the manufacture of 3D-shaped laminated veneer products is the stretching and/or buckling of the veneer, which risks veneer damage if they are subjected to large deformations. This study aimed to compare the advantages and disadvantages of different modifications used to increase veneer formability while moulding laminated veneer products and to avoid damaging the surface veneers. Adhesive penetration was also considered. Three different modifications were performed to study how different parameters damage during moulding: 1) surface veneer pre-bonded with paper and hot melt adhesive at a surface pressure of 1.8 MPa and temperature of 130 °C; 2) densified surface veneer; and 3) unprocessed surface veneer, as the reference. Results showed that one modification used to increase the strength combined with pre-bonding with a chemically hardened adhesive weakened the bond line. Adhesive penetration depended on several factors, including wood type, surface pressure, and veneer stretching.

KEYWORDS: densification, open system, THM processing, wood

[1] Lars Blomqvist, Linnæus University, Department of Forestry and Wood Technology, SE-351 95 Växjö, Sweden. Email: lars.blomqvist@lnu.se
[2] Jimmy Johansson, Linnæus University, Department of Forestry and Wood Technology, Sweden
[3] Dick Sandberg, Luleå University of Technology, Wood Technology, Sweden

1 INTRODUCTION

Moulded laminated veneer products consist of veneers bonded together with adhesive into predetermined shapes. These products have many advantages; laminating veneers makes it possible to create a great variety of strong, flexible shapes for furniture, interiors, and construction materials. It is possible to mix veneers from wood types of different thickness and quality with solid wood in a construction to produce the desired product design. It is also possible to use other types of material such as high pressure laminate. The external veneer should always be of high quality, though it is possible to have lower quality inside the laminate. It is important, however, to understand that internal veneers will affect the entire structure.

A major problem in the manufacture of laminate veneer products is veneer stretching and/or buckling, which risks veneer cracking or damage if they are subjected to large deformations. The degree to which a veneer can be formed during moulding depends on, for example, veneer thickness and preparation, type-related properties, product design, and the mould itself. Bending in one direction is not difficult, as long as the form remains open. Here, an open form refers to an arc with a length less than half of the circle's circumference (periphery). In this case, the radius should not be less than 30 times the veneer thickness in 2-D forms, though 3-D forms demand much greater skill in manufacturing given the risk of breaking the laminate while forming due to the anisotropic structure of the wood. Wood has a low transverse tensile strength and low strain to failure in tension.

It is possible to modify veneers to prevent undesired veneer deformations or cracking while moulding in four principally different ways. For one, veneers can be formatted by removing unnecessary parts of the veneer in areas prone to problems of stretching and/or buckling while moulding. Two, it is possible to bond a fabric, mesh, paper, or other material to the back of the veneer to strengthen it in the transverse direction. This method is often used for the visible, external veneers of thin or brittle wood type. Three, the so-called '3-D veneer' can be formed extremely three-dimensionally. The most well-known 3-D veneer was developed by Reholz GmbH and later introduced to the market [1]. During the production of a Reholz 3-D veneer, narrow grooves spaced 0.1 to 1 mm apart and through the thickness of the veneer are cut to an ordinary veneer along the fibre direction. To keep the wooden strips together, lines of glue are spread on the rear of the veneer. Four, veneers can be modified before moulding by thermo-hydro, thermo-hydro-mechanical, or chemical action [2]. Traditionally, steam has been the most common way to soften wood and make it more susceptible to forming. In thermo-hydro and thermo-hydro-mechanical processes, the glass transition temperatures (T_g) of the different amorphous components of wood are a key factor for good results. For this, the temperature for forming should be selected according to two criteria. First, the minimum temperature at which the wood can be formed is at least 25 °C more than the T_g of the lignin (i.e., approximately 110 °C under moisture-saturated conditions and approximately 140 °C at 80% ambient relative humidity) [e.g., 3]. Second, the maximum temperature, usually considered to be 200 °C when air is saturated, limits the thermal degradation of the wood components. The thermo-hydrous window for the process of forming wood is thus limited to temperature and relative humidity varying, respectively, from 110 to 140 °C and from 80 to 100%. Under these conditions, lignin, hemicelluloses and the semi-crystalline cellulose are relatively mobile.

It is also possible to plasticise wood with chemical additives, a process tested using different chemicals with various results. Most promising has been the use of anhydrous ammonia. A method using hydrazine (N2H4) was patented by Huttunen [3]. Hydrazine is highly toxic and derived from the same chemical processes used to manufacture ammonia [2].

1.1 BACKGROUND

The company that participated in this study addressed problems of rupture of the surface veneer of laminated veneer products subjected to large deformations while moulding. The company also had problems with the adhesive penetration of the surface veneer, especially of ash and walnut.

1.2 AIM

This study aimed to evaluate different modifications used to increase formability and prevent cracks in surface veneers while moulding laminated veneer products. It also sought to investigate adhesive penetration.

2 MATERIALS AND METHODS

Three different tests were performed in this study:

1. *Veneer formability test*: Veneers were modified before moulding to increase formability while moulding a seat shell.
2. *Tensile shear strength test*: Different modifications were analysed for their effects on bond-line strength.
3. *Adhesive penetration test*: Ash surface veneer was modified before moulding to decrease the adhesive penetration of the veneer.

2.1 TEST 1: VENEER FORMABILITY

Test 1 was performed on a double-curved seat shell with two pronounced radii on both sides of a line of symmetry (Figure 1). With the mould closed while pressing the shell, significant stretching occurred along the line of symmetry. All of the veneers except the surface veneer were beech (*Fagus silvatica* L.); the surface (L_{Oak}) veneer was oak (*Quercus robur* L.). The beech veneers were peeled, the oak veneers sliced. The orientation of the veneers according to lengthwise (L) and transverse (T) directions was from front to back: L-T-L-L-L-L-T-L-L_{oak}. The dimensions of the veneers were 1250 × 600 mm, and their thickness 1.5 mm, except for the oak veneer, which was about 0.5 mm thick (Table 1). The veneers were taken from regular production at the participating company.

A urea formaldehyde (UF) adhesive system (Casco Adhesives Inc.) was used, with adhesive 1274 and hardener 2584. The adhesive spread was 164 g/m^2 and surface pressure 1.3 MPa. The pressing time was 5 min, of which the first 2.5 used dielectric heating to cure the adhesive.

Three different modifications were performed to study how different parameters affected damage during moulding:

1. The surface veneer was pre-bonded with paper (Veneer backer VC300+, PWG VeneerBackings GmbH) attached to the veneer with a hot-melt adhesive included with the paper, at a pressure of 1.8 MPa and temperature of 130 °C.
2. A densified surface veneer.
3. Unmodified surface veneer (reference).

The densification of the veneers in Group 2 was performed with a surface pressure of 4.6 MPa at 100 °C for 1 min after the veneers were humidified to 20% moisture content. The veneers were compressed to 77% of their original thickness.

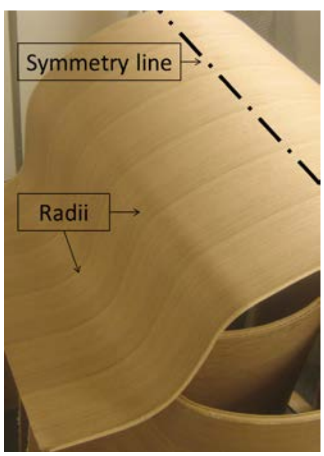

Figure 1: *Surface veneer view of the tested seat shell. Symmetry line indicates area with a high stretching of the surface veneer (oak) while moulding.*

Table 1: *Specifications for the surface veneers of oak*

Group	Samples	Modification	Thickness (mm)
1	4	Veneer + paper	0.53
2	5	Densified	0.41
3	4	Reference	0.53

Directly after pressing and climate cycling, the seat shells were controlled according to damages (Table 2).

Table 2: *Number of measurements and climate during relative humidity cycling*

Number	Climate before measurement (moisture content)	Days in climate
1	-	0
2	20 °C/20% RH (4.5%)	6
3	20 °C/90% RH (21%)	6
4	20 °C/20% RH (4.5%)	6

2.2 TEST 2: TENSILE SHEAR STRENGTH

This tensile shear strength test was performed with a veneer of beech (*Fagus silvatica* L.) in an automated bonding evaluation system (ABES, Adhesive Evaluation Systems, Inc). A UF adhesive system (Casco Adhesives Inc.) was used, with adhesive 1274 and hardener 2584. Four different modifications of the veneers were evaluated:

1. Veneer pre-bonded with paper (Veneer backer VC300+, PWG VeneerBackings GmbH) that included a hot-melt adhesive and was added to the veneer at a pressure of 1.8 MPa at 130 °C.
2. Veneer pre-bonded with polypropylene fabric (Spunbond 50 g, Scandinavian Nonwoven Ltd.) glued to the veneer with the abovementioned UF adhesive system at a surface pressure of 1.0 MPa at 80 °C.
3. Densified veneers.
4. Unmodified veneers (reference).

The densification of the veneer in Group 3 was performed at a surface pressure of 8.9 MPa at 100 °C for 1 min after the veneers had been conditioned to 20% moisture content. The veneers were compressed to 50% of their original thickness. Each group consisted of 10 replicates. At the beginning of the test, the bond line was stronger than the wood material, since wood failure occurred in the unmodified part of the sample. This failure was resolved with a paper-strengthened veneer (Table 3).

Table 3: *Specifications of the groups*

Group	Modification	Design of the specimens: Layers from above with bond line (BL) between paper (P) and veneer (V)
1	Paper (P)	P–V – BL – P–V
2	Nonwoven (NW)	P–V – BL – NW–V
3	Densified (D)	P–V – BL – D
4	Reference (R)	P–V – BL – V–P

Test 2 was performed in an ABES testing machine (Adhesive Evaluation Systems, Inc.; Figure 2). The test was a single lap joint test according to EN 205 [4] with some modifications. The following parameters were used for Test 2:

Sample size (mm)		
Length	117	
Width	20	
Thickness	0.4/0.2	Unmodified/densified
Bond area (mm^2)	60	Overlap 3 mm
Adhesive (g/m^2)	150	
Pressing		
Temperature (℃)	90	
Pressure (MPa)	1.5	
Duration (s)	60	
Cooling time (s)	30	With air

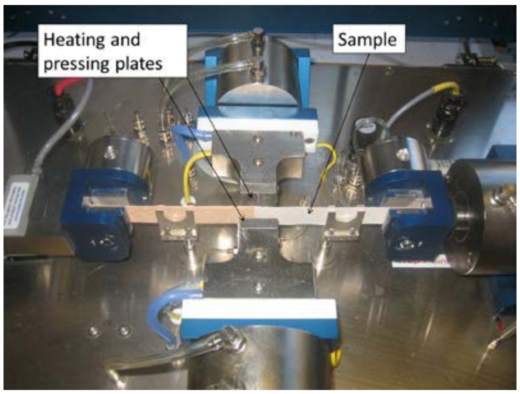

Figure 2: *Automated bonding evaluation system testing machine*

2.3 TEST 3: ADHESIVE PENETRATION

Test 3 was performed on a curved shelf shell (Figure 3). The highest stretching occurred at the top of the shelf waves (Figure 3). The of the waves were about 45 mm. All veneers were birch (*Betula pubescens* Ehrh.), except for the surface (L_{Ash}) veneer, which was ash (*Fraxinus exelcior*). The orientation of the veneers according to lengthwise (L) and transverse (T) directions was from front to back: L_{Ash}-T-L-T-L-L-L-T-L-T-L. The dimensions of the veneers were 1050 × 350 mm. The thickness was 1.0 mm for all veneers, except for the ash veneer, which was about 0.5 mm (unmodified) or 0.25 mm (densified) thick. Birch veneers were peeled and ash veneers sliced with vertical annual rings.
Adhesive penetration of the surface veneer during moulding was studied with three groups of modifications:

1) Pre-pressed surface veneer: The surface veneers were plane-pressed and bonded with a second veneer before moulding (with UF same as in moulding) at a pressure of 1.2 MPa at 90 °C for 6 min.
2) Densified surface veneer.
3) Unmodified veneer (reference).

Each group contained two replicates. The veneers in Group 2 were densified at a pressure of 7.85 MPa at 100 °C for 1 min. These veneers were conditioned to 20% moisture content before densification compressed them to 50% of their original thickness. A UF adhesive system (Casco Adhesives Inc.) was used to mould the shelf, with adhesive 1274 and hardener 2584. The adhesive spread was 123 g/m^2 and surface pressure during moulding 1.2 MPa. Pressing time was 2.5 min, of which the first minute included dielectric heating to cure the adhesive. The veneers were taken from regular production at the participating company. The degree of adhesive penetration was assessed visually.

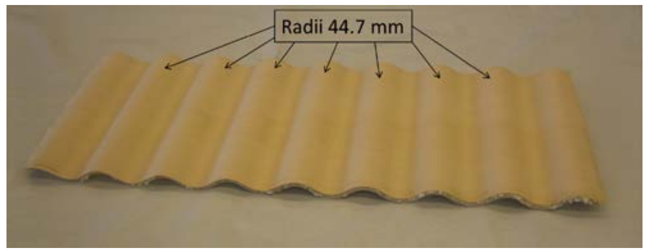

Figure 3: *The tested shelf, with arrows indicating where the stretching of the veneer was critical*

3 RESULTS AND DISCUSSION

3.1 TEST 1: VENEER FORMABILITY

No cracking occurred while moulding the visible surfaces of the shells regardless of test group. There was no difference in the shape stability between the groups during RH cycling. Reasons for the positive results were discussed with the company, and it was concluded that the Hawthorne effect [5] may be an explanation.

3.2 TEST 2: TENSILE SHEAR STRENGTH

Table 4 shows the results of the tensile shear strength test. Strength was equal for specimens in Groups 1, 3 and 4, though the nonwoven specimens (Group 2) had significantly lower strength. Table 5 shows the different types of failure that occurred. *Wood failure* means that the bond line was stronger than the wood sample; *fibre failure* means that the fibres remained on both sides of the bond line, which is positive; and *bond-line failure* means that the adhesive did not sustain adhesion between different parts of the sample. All samples in Group 2 experienced bond-line failure, which only one other sample in the other groups did as well (Table 5). The reason why adhesion failure recurred in Group 2 likely depends on the fact that nonwoven specimens in Group 2 were pre-bonded with UF, a chemically curing adhesive that provides a smooth surface that new adhesion finds difficult to penetrate.

Table 4: *Results from the tensile shear strength test.*

Group	Type of modification	Strength (MPa)	*SD*
1	Paper (P)	8.9	1.1
2	Nonwoven (NW)	5.3	1.0
3	Densified (D)	9.7	1.8
4	Reference (R)	9.7	1.7

Table 5: *Type and number of failures in the different groups from tensile shear strength test*

Group:	1	2	3	4
Type of failure				
Wood	2	0	4	1
Wood/Fibre	0	0	3	4
Fibre	3	0	3	4
Fibre/Adhesion	4	0	0	1
Adhesion	1	10	0	0

3.3 TEST 3: ADHESIVE PENETRATION

Of the surfaces with ash veneer, only surface veneers with a pre-plane pressed second veneer had no adhesive penetration (Table 6 and Figure 4). The densified surface veneer (Figure 4b) and unmodified surface veneer (Figure 4c) showed adhesive penetration in areas of the vessels. Adhesive penetration occurred primarily on top of the shelves waves, while the unmodified veneers showed a penetration in the form of adhesive pearls (Figure 4c). Penetration in the densified veneer more closely resembled larger, flattened pearls (Figure 4b). There was no adhesive penetration of the peeled birch veneer on the opposite side of the shelves.

An explanation for the low adhesive penetration of the pre-plane pressed surface veneers is reduced stretching in plane pressing. All adhesive penetration occurred in areas where surface veneer was subjected to very high strain from vessels.

Table 6: *Number of surfaces (ash veneers) from the adhesive penetration test showing adhesive penetration*

Group	Modification of surface veneer (ash)	Surfaces with adhesive penetration
1	Pre-plane pressed	0 of 2
2	Densified	2 of 2
3	Unmodified	2 of 2

a) *b)* *c)*

Figure 4: *Examples of a) pre-pressed surface veneer, b) densified surface veneer, and c) unmodified surface veneer—all of ash.*

CONCLUSIONS

The results of this study show that:

1) The densification of surface veneers or pre-bonding of the surface veneers with paper did not demonstrate differences in cracking.
2) The tensile shear strength of the bond line is not influenced by veneer densification or any pre-bonding of the surface veneers with paper.
3) The tensile shear strength of the bond line weakens when the veneer is strengthened with polypropylene fabric.
4) The veneers of wood types like e.g. ash may show adhesive penetration of the veneer during moulding, especially in areas where the surface veneer is under high tensile strain. Pre-plane pressing of such veneers will reduce the problem.

ACKNOWLEDGMENTS

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