Distortion in Laminated Veneer Products Exposed to Relative-Humidity Variations – Experimental Studies and Finite-Element Modelling

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A shortcoming of the laminated bending process is that the product may become distorted after moulding. This study focused on the influence of fibre orientation deviation for individual veneers on the distortion of a moulded shell. The distortion of 90 cross-laminated shells of the same geometrical shape, consisting of seven peeled birch veneers, were studied under relative humidity variation. All the veneers were straight-grained in the longitudinal-tangential plane, but to simulate a deviation in fibre orientation, some of the individual veneers were oriented at an angle of 7° relative to the main orientation of the other veneers in the laminate. A finite element model (FEM) was applied to study the possibility of predicting the results of a practical experiment. The study confirms the well-known fact that deviation in fibre orientation influences shape stability. The results also show how the placement of the abnormal veneer influences the degree of distortion. From this basic knowledge, some improvements in the industrial production were suggested. However, the FE model significantly underestimated the results, according to the empirical experiment, and it did not show full coherence. The survey shows the complexity of modelling the behaviour of laminated veneer products under changing climate conditions and that there is a great need to improve the material and process data to achieve accurate simulations. Examples of such parameters that may lead to distortion are density, annual ring orientation in the cross section of the veneer, the orientation of the loose and tight sides of the veneer, and parameters related to the design of the moulding tool.

Keywords: Birch; Cup; FEM; Veneer; Wood; Twist

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INTRODUCTION

There are various methods of producing laminated wood, but this study considers the shape stability of veneers simultaneously formed and laminated against a mould (Fig. 1). This process is generally called laminated bending, and the products are called laminated veneer products (LVPs). Peeled veneers are most frequently used in LVPs, and these veneers have their longitudinal and tangential directions in the plane. In general, an odd number of veneers are used to give as symmetrical a construction as possible. Symmetry means that the veneer properties are balanced in the laminate, *i.e.*, the veneers at equal distances on either side of the centre veneer in the thickness direction have similar characteristics (Blomqvist 2016).

Poor shape stability of LVPs can be a significant problem in the manufacturing and use of the final product, such as furniture and interior fittings, and it is not uncommon for the assembled products to fail to meet the customer's requirements.

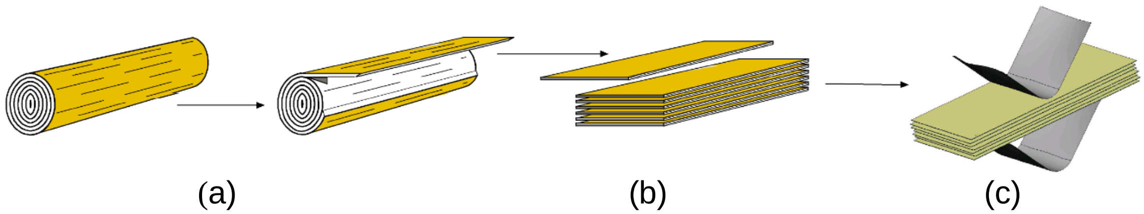

Fig. 1. Production of laminated veneer products: a) peeling of log to thin veneers, b) cutting of veneers sheets to the right dimensions for the moulding, and c) assembling of veneer sheets into the moulding press-tool (Ormarsson and Sandberg 2007)

There are several reasons why the LVPs lack shape stability. Stresses developed during moulding will, in most cases, "reopen" the moulded shape, *i.e.*, increase the radius of LVPs' curvature when the product is removed from the mould. This phenomenon is referred to as spring-back, and the resulting change in shape is merely a minor problem, as the deformation is fairly predictable if the production conditions in general is not varying (Navi and Sandberg 2012). Stresses introduced during the moulding process can, in extreme cases, lead to cracking during the moulding as well as later when the product is exposed to natural climate variations (Hvattum *et al.* 1978; Lind 1981; Cassens *et al.* 2003).

After moulding, the LVPs may also alter their shape because of natural changes in the surrounding climate, which lead to variations in the moisture content (MC) and shrinkage/swelling of the LVP. To avoid distortion, moulded components should be kept in a constant climate before assembly (Blomqvist *et al.* 2013a) or be modified chemically (Emmerich *et al.* 2019).

One of the most problematic causes of distortion, at least from an industrial point of view, occurs when the fibre orientation of the veneers deviates, resulting in uncontrolled veneer orientations and twisting of the LVPs. When the MC of the LVP changes, a laminate with deviating fibre orientation will inexorably distort (Boulton 1920; Forest Products Laboratory 1922; Ormarsson and Sandberg 2007; Blomqvist *et al.* 2013a). Such a distortion, usually related to twisting, can be eliminated by selecting only straight-grained veneers and, above all, by ensuring that all the veneers are conditioned to the same MC before moulding. However, trees are not symmetrical cylinders, and this makes it virtually impossible to peel a veneer that is parallel to the grain both on its face and throughout its thickness (Blomqvist *et al.* 2014).

The purpose of the present study was to investigate the effect of deviating fibre orientation on the distortion of moulded LVPs exposed to moisture variations, as well as to implement a FE model that describes this behaviour. The FEM tool should, in the long term, be able to improve the design of LVPs and decrease the need for empirical tests in product development.

OVERVIEW OF THE STUDY

The example product used in the study was a 3.3-mm-thick moulded shell used as a shelf in a brochure rack (Fig. 2). The inner radius of the bend was 9 mm. This particular LVP has been shown to be extremely prone to distortion in production as well as in use, and fibre deviation in the veneer has been identified as a probable cause.

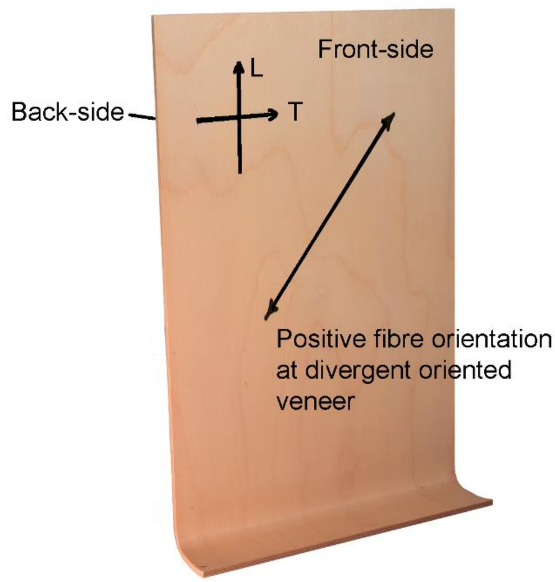

Fig. 2. The moulded shell was made of seven birch veneers. The different definitions used in this paper: front- and backside of the shell, positive fibre direction, lengthwise (L), and transverse (T) orientations of surface veneers are also used as orientation descriptions.

The survey was conducted in three stages: (1) empirical testing of the effects of deviating fibre orientation on the distortion of an LVP; (2) implement of a finite-element (FE) model to predict the distortion of LVPs; and (3) comparison of the result achieved from the FE model with the empirical results. A pre-stage of the study has been presented by Blomqvist *et al.* (2013b, 2015).

EXPERIMENTAL

Birch (*Betula pubescence* Ehrh.) veneers were used for the moulding. Each shell consisted of seven peeled veneers, and the surface veneers were sanded on the "tight" face before moulding. The in-plane dimensions of the veneers were 400 x 660 mm^2. The thickness of the sanded veneers was 0.4 mm, while the other five veneers were 0.5 mm thick. All the veneers were sorted and cut so that they could be considered to be straight-grained or with a fibre deviation of 7°. Before assembly, the veneers were conditioned at 20 °C and 20% relative humidity (RH), which corresponds to an equilibrium moisture content (EMC) of 4.5%.

A total of 90 shells divided into six groups were moulded and used in the study, as shown in Table 1.

A urea-formaldehyde (UF) adhesive system (Casco Adhesives Inc., Sweden, Resin No. 1274 and Hardener No. 2584) was used. A total of 200 g/m^2 of adhesive was spread on both sides of the transverse veneers (Fig. 1). Moulding was conducted at a mean surface pressure of 0.5 MPa for 4 min and 10 s, and high-frequency (HF) heating was used for 1 min during moulding, reaching a maximum temperature of *ca*. 110 °C (Fig. 3). After pressing, the shells were placed in a holder to be uniformly cooled to room temperature.

Table 1. Assembly of Veneers (v.) in the Shells

Group No.	No. of shells	Definitions of veneer	Variation in orientation of veneer (fibre deviation)	Orientation of veneer front to back*
1	15	Lengthwise v. (L)	0°	L–T–L–T–L– T–L
		Transverse v. (T)	0°	
2	15	Lengthwise v. (L)	Surface v.: L_7=+7°	L–T–L–T–L– T– **L_7**
		Transverse v. (T)	0°	
3	15	Lengthwise v. (L)	Surface v.: L_1=-7°, L_7=+7°	**L_1**–T–L–T–L– T–**L_7**
		Transverse v. (T)	0°	
4	15	Lengthwise v. (L)	Surface v.: L_1=+7°, L_7=+7°	**L_1**–T–L–T–L– T– **L_7**
		Transverse v. (T)	0°	
5	15	Lengthwise v. (L)	Veneer: L_5=+7°	L–T–L –T– **L_5**– T–L
		Transverse v. (T)	0°	
6	15	Lengthwise v. (L)	0°	L–T –L–T–L– **T_6**–L
		Transverse v. (T)	Veneer: T_6=+7°	

* Veneers with a fibre deviation (±7°) are in bold type. Veneers had lengthwise (L) or transverse (T) orientations in the assembly from front to back (Fig. 1).

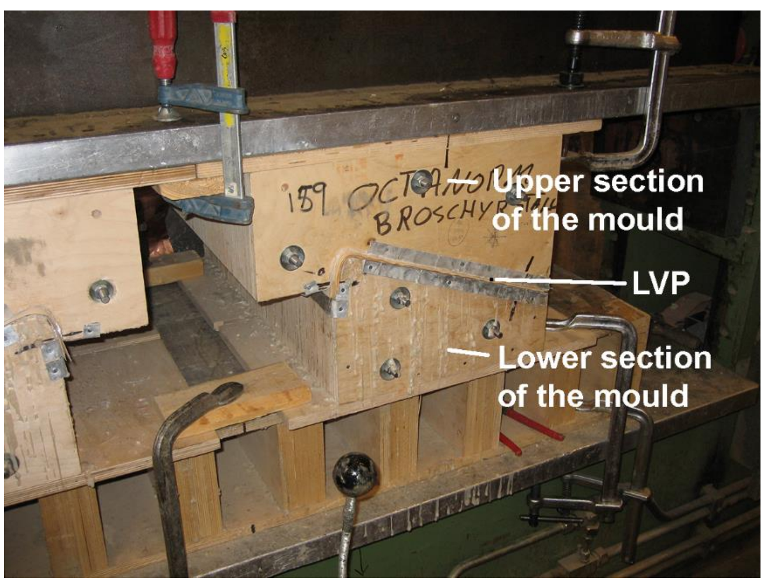

Fig. 3. The laminated veneer product (LVP) in the mould during pressing. The press force is applied vertically

Distortion of the Shells

A gauge was constructed to measure the distortion of the moulded shell. The modes of distortion, *i.e.*, the deviations of the shape of the shell from that of the mould, were measured as cup, position, and twist (Fig. 4). Cup is the maximum distance between a straight line drawn between two locations on the shell's surface at a distance of 567 mm. Position is the average distance between the same two locations and the gauge (0.5 · (X1+X2)). Twist is the difference between the same two locations and the gauge (X1-X2).

Positive (+) values of cup are values beyond the line, and negative (-) values are inside the line, as seen from the side of measurement. Positive (+) values of twist are counter clockwise, and negative (-) values are clockwise, as seen from the front to back direction. The accuracy in the deformation measurement was approximately ±0.1 mm. The first measurement made directly after the shell was released from the mould resulted in the spring-back value.

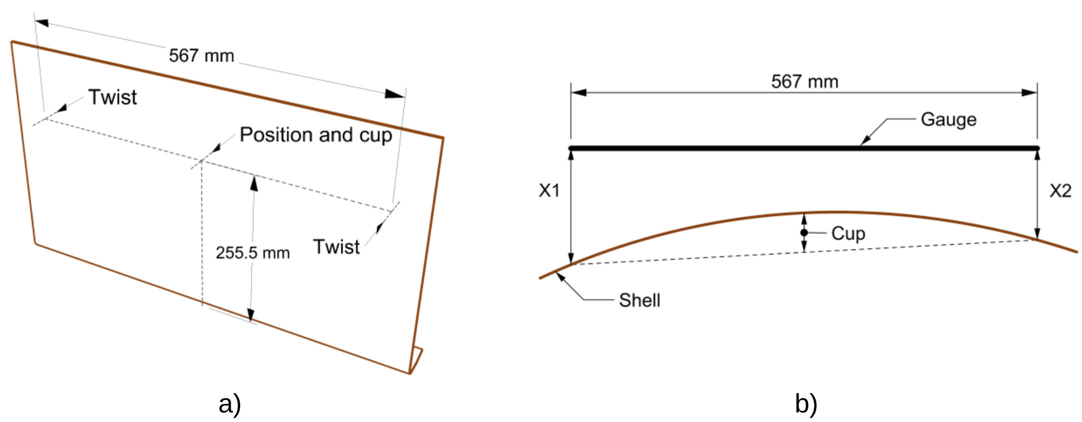

Fig. 4. Measurement of the distortion of the shell with help of a gauge: a) side view of the shell, b) top view of the shell and gauge (the back side of the LVP was in the direction of the gauge)

After moulding and conducting the first distortion measurement, the shells were stored in a climate chamber, where they were exposed to various RH values at a temperature of 20 °C, depicted in Table 2. The distortion was measured at the end of each climate period.

Table 2. Shell Climate Storage after Moulding

Climate period No.	Total time (days)	Time in climate (days)	Climate (EMC)
1	0	0	Immediately after moulding
2	41	41	Dry: 20 °C/20% RH (4.5%)
3	89	48	Humid: 20 °C/90% RH (21%)
4	103	14	Dry: 20 °C/20% RH (4.5%)

FE Model

A three-dimensional FE model of the moulded shell was developed using the standard FE code Abaqus 12.2 (Dassault Systèmes Simulia Corp. RI) with a user-defined material subroutine of the constitutive model (Ekevad 2006). The constitutive model is linear elastic for orthotropic material. The material parameters were dependent on temperature and moisture content. It includes the mechano-sorption effect. This is a phenomenon that occurs in wood (and other sorptive materials) due to stress in combination with a change in the surrounding RH, giving a moisture-distribution change in the loaded wood. The result of mechano-sorption is an added strain increment. In the user-material the mechano-sorption is based on Ranta-Maunus (1990) theory. From Ekevad (2006), the differential vector for a linear elastic for the three-dimensional case,

$$d\bar{\varepsilon} = \bar{\bar{F}} d\bar{\sigma} + \alpha_o dT + \beta_o du - \bar{\bar{F}}\left(\bar{\bar{M}}_T \bar{\sigma} dT + \bar{\bar{M}}_u \bar{\sigma} du\right) + \bar{\bar{M}} \bar{\sigma} du \tag{1}$$

where, $\bar{\varepsilon}$ is the strain vector and is a state function of the $\bar{\sigma}$ the stress vector, the T temperature and the moisture content u. $\bar{\bar{F}}$ is the elastic flexibility matrix, $\beta_o$is the moisture expansion coefficient vector at zero stress, and α_o is the thermal expanion coefficient vector at zero stress. The expression inside the parentheses is the change of the elastic modulus during the increment. The last term, in the parenthesis, is proportional to stress and moisture content change. M_t and M_u are diagonal matrices and function of temperature and moisture, respectively. The mechano-sorptive contribution in the constitutive model comes from the last term, where M contains the mechano-sorptive constants.

The FE model had a total of 4,092 elements per veneer layer. The elements used was reduced integration C3D8R. A Cartesian coordinate system was used to specify material directions. Free body movement was prevented by fixing three nodes. The first point (blue dot in Fig. 5) was locked from movement in *x*-, *y-and* *z*-directions. The second node (red dot) was locked from movement in only the *z*-direction and the third node (orange dot) was fixed in the *y*-direction. The bond-line between the veneers was modelled as a tied constraint condition.

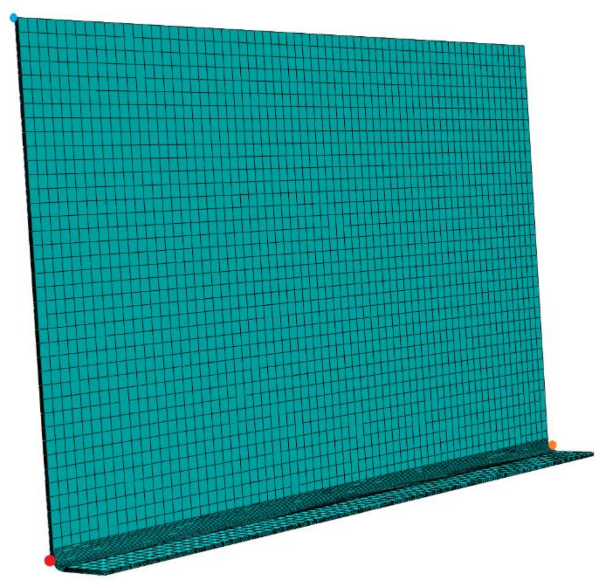

Fig. 5. FE-model boundary conditions. The point of the shell marked with a “blue dot” in upper left corner was constrained from movement in *x-, y-and z*-directions. The “red dot” was constrained in *z*-direction, and the “orange dot” was constrained in *y*-direction.

The step time was 8,900,000 seconds, and the moisture loading varied according to Table 2. The outputs from the model were the displacements at the measuring points defined in Fig. 2. In this FE model, only temperature- and relative humidity-related deformations were considered, *i.e.*, the elastic spring-back deformation directly after moulding was not included in the simulations.

The stiffness parameters used in the simulations were based on data presented by Dinwoodie (2000) for birch wood (Table 3). The parameters E_R, E_T, and E_L are the Young's moduli in the radial (R), tangential (T), and longitudinal (L) directions, respectively. G_{RT}, G_{TL}, and G_{LR} are the shear moduli in the RT, TL, and LR directions, respectively. The shrinkage/swelling parameters (α) for birch in the longitudinal, radial, and tangential directions were taken from Träfakta (1995). Mechano-sorptive parameters are not available for birch, so published data for Norway spruce were used (Ormarsson 1999).

The veneer orientation followed the figures shown in Table 1, which complies with the empirical study. The moisture variations were assumed to be homogeneous during the conditioning time for all the veneer sheets. The effects of temperature and moisture content on the stiffness properties were based on relations presented by Ekevad (2006).

Table 3. Material Parameters used in the FE-model

Parameters	Units			
Elastic	MPa	E_R= 1,100	E_T = 620	E_L =16,300
	MPa	G_{RT} =190	G_{RL} = 1,180	G_{TL} = 910
	-	ν_{RT} = 0.78	ν_{LT} = 0.034	ν_{RT} = 0.018
Shrinkage/swelling coefficients	-	α_R=0.177	α_T=0.26	α_L=0.02
Mechano-sorptive	MPa^{-1}	m_R=0.15	m_T=0.20	m_L=0.1·10-3
	MPa^{-1}	m_{LR}=0.8	m_{LT}=0.008	m_{RT}=0.008

RESULTS AND DISCUSSION

Figure 3 shows the cupping distortion results from the empirical tests and FEM analysis. In the empirical study, the reference group (No. 1) with straight-grained veneers exhibited minimal cupping throughout the moisture variation cycle, and a similar low level of cupping was observed when the two outermost veneers had a deviant fibre orientation in the same direction (No. 4), or when one of the inner longitudinally oriented veneers had a deviant fibre orientation (No. 5). The other combinations of veneers had considerable cupping, to an extent that is not acceptable in the final product, and the cup was especially large when a transverse veneer had a deviant fibre orientation (No. 6). This LVP behaviour agrees with results and explanations presented in other studies, such as those by Blomqvist *et al.* (2013a) and Navi and Sandberg (2012).

The FE model focuses on LVP distortion after moulding and does not take into account the spring-back deformation. Therefore, the initial distortion is lacking in the FE model results. It can, however, be concluded from the empirical results that the spring-back deformation is considerably influenced by the fibre orientation in the single veneers (Figs. 6a and 8a) and that it should be included in the FE model for a more correct

The FE model described the distortion well in all cases except for groups No. 2 and No. 6, where an outer longitudinal or a transverse veneer had a deviant fibre orientation. In the first case, the total distortion was small and the difference between the experimental and simulation results can probably be attributed to variations in the experimental results.

The lathe checks on the loose side of the veneers were not taken into consideration in the FE model, but they have an effect on the shape stability of the LVPs (Blomqvist 2014). The lathe checks and the adhesive influence may explain the difference in cupping between the empirical and FE results.

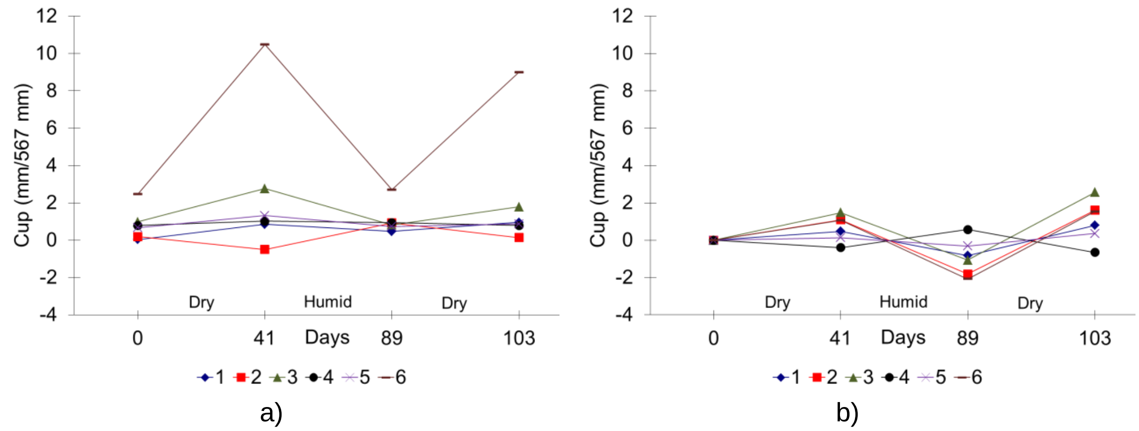

Fig. 6. Cupping of moulded shells with different configurations of the veneers (1-6) according to Table 1: (a) mean cupping of shells in the empirical, and (b) cupping in the FEM study

Figure 7 shows the position distortion results from the empirical and FEM tests. Both studies show an overall large shell distortion during moisture cycling. It is rather surprising that both the experimental and the FEM studies show that the shell design with the same degree and orientation of fibre deviation in the outer veneers (No. 4) exhibited less position distortion than the reference group with straight-grained veneers. On the other hand, the design with the outer veneers in opposite directions (No. 3) gave an extremely large position distortion.

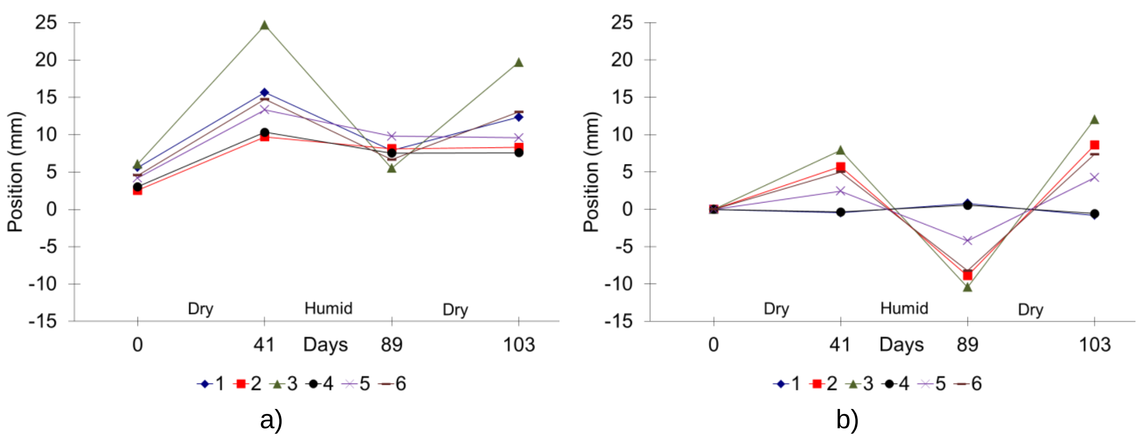

Fig. 7. Position of moulded shells with different configurations of the veneers (1-6) according to Table 1: (a) mean position of shells in the empirical, and (b) position in the FEM study

Figure 8 shows the twist distortion results from the empirical and FEM tests. The twist distortion of the shells with no fibre deviation or with a fibre deviation in the same direction of the outer veneers (Nos. 1 and 4) was small. The FEM results for these two groups were extreme, showing no twist at all and showing the dominant effect of fibre orientation on twist.

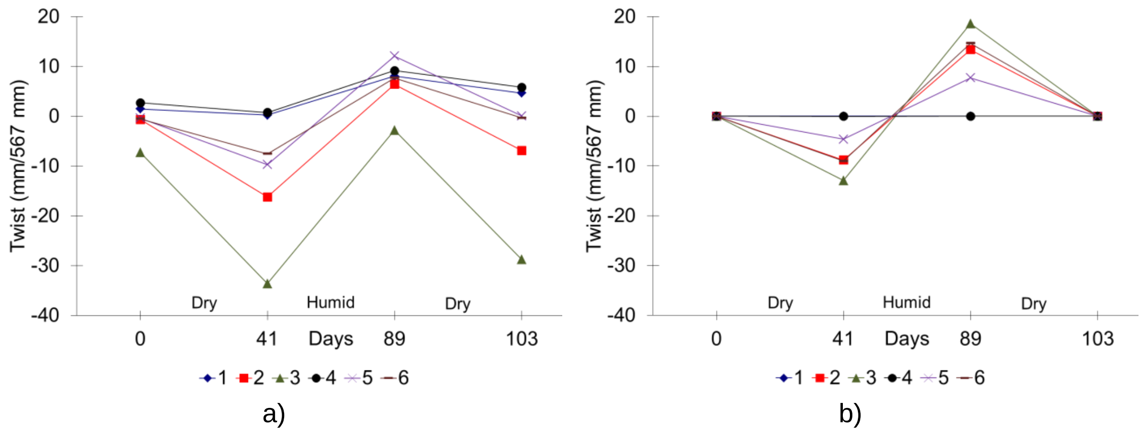

Fig. 8. Twist of moulded shells with different veneer configurations (1-6) according to Table 1: (a) mean twist of shells in the empirical, and (b) twist in the FEM study

The standard deviation (STD) of the empirical distortion results was generally large and it increased during the moisture cycling, as shown in Table 4. The large STD showed the complexity in trying to predict the distortion in LVPs, especially for LVPs exposed to moisture variations in use. Distortions are influenced not only by material parameters, but also by all manufacturing factors, starting with the moulding process.

Table 4. STD (mm) Values in the Empirical Study

Group No.	Position (days)				Twist (days)				Cup (days)			
	0	41	89	103	0	41	89	103	0	41	89	103
1	3.0	7.6	4.9	6.8	8.7	25.5	11.5	21.6	1.4	5.5	1.5	4.1
2	1.7	5.0	3.0	2.7	3.4	8.8	8.3	14.1	1.3	4.7	1.4	3.8
3	2.9	4.9	3.0	4.6	4.3	6.0	7.6	4.4	0.9	2.3	1.0	1.6
4	2.1	3.1	3.6	4.9	4.1	17.6	6.4	15.3	0.5	1.4	1.0	1.3
5	3.1	4.6	3.3	4.0	7.6	19.9	8.8	17.5	1.2	2.0	1.4	1.7
6	1.6	5.3	2.8	3.1	5.3	17.2	5.8	15.3	0.9	2.4	1.0	1.8

The FE model describes in some cases the behaviour of the LVPs studied quite well, especially when the large scatter in the empirical results is taken into consideration. There are, however, some weaknesses in the FE model, which lead to a low degree of agreement between the model and empirical results, as can be seen in the cupping results. A similar experience is described in the literature, where the FEM results underestimate the distortion of LVPs. Constant *et al.* (2003) developed a FE model that predicted distortion in plywood and compared the results with empirical data observed under different climate conditions. Two types of simulation models were used; one describing the properties of each veneer according to the longitudinal and tangential swelling, as well as the wood density before the moulding, and the other using the mean density and average swelling coefficients for the LVP. The results using the first model rendered a good but underestimated description of the empirical results. The second model was much less accurate, especially in describing distortion in the longitudinal direction of the plywood.

The results of the present study demonstrate the importance of veneer fibre orientation in determining the level of distortion in LVPs. However, there is a complex united action between several material and production parameters that lead to distortion, and there are several opportunities for improving the FE model by including some of these parameters. Other studies have pointed out several important parameters for the distortion, such as density, annual ring orientation in the cross section of the veneer, and the orientation of the loose and tight sides of the veneer; see Navi and Sandberg (2012) and Blomqvist (2016) for an overview.

CONCLUSIONS

The effect of the veneers' fibre orientation on the distortion of moulded LVPs exposed to moisture variations has been examined in empirical studies and modelled with the help of a finite-element approach.

1. The fibre orientation in single veneers is important for the shape stability of laminated veneer products (LVPs), and a deviation of a few degrees from the optimal orientation of the veneers (in general, every second veneer oriented exactly 90° to each other) can considerably increase LVP distortion.
2. If, for some reason, it is not possible to guarantee the use of straight-grained veneers to reduce LVP distortion, veneers should be organized during assembly in such a way that the same fibre deviation is achieved for all the lengthwise and crosswise veneers. This, of course, requires that the veneers are assembled in a precise orientation in relation to each other.
3. The "cross-wise orientation" of lengthwise oriented veneers (group No. 3), which is often used, increases the effect of fibre-orientation deviation on distortion, rather than reducing the distortion as expected.
4. The FE model describes in some distortion modes the behaviour of the LVPs studied quite well, but some weaknesses in the model were observed. To improve the model, better material and process data, such as wood material properties and the influence of the thermo-hydro-mechanical forming process, must be included.

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REFERENCES CITED

Blomqvist, L. (2016). *Laminated Veneer Products: Shape Stability and Effect of Enhanced Formability on Bond-Line Strength*, Ph.D. Dissertation, Linnaeus University, Växjö, Sweden.

Blomqvist, L., Johansson, J., and Sandberg, D. (2013a). "Shape stability of laminated veneer products – An experimental study of the influence on distortion of some material and process parameters," *Wood Material Science and Engineering* 8(3), 198-211. DOI: 10.1080/17480272.2013.803501

Blomqvist, L., Johansson, J., and Sandberg, D. (2013b). "Shape stability of laminated veneer products – How to decrease the negative effects of fibre deviation?" Forest Products Society (FPS) 67th International Convention, June 9-11, Austin, TX.

Blomqvist, L., Sandberg, D., and Johansson, J. (2014). "Influence of veneer orientation on shape stability of plane laminated veneer products," *Wood Material Science and Engineering* 9(4), 224-232. DOI: 10.1080/17480272.2014.919022

Blomqvist, L., Berg, S., and Sandberg, D. (2015). "Chipless machining: Challenges in manufacture of laminated veneer products," in: *Proceedings of the 22nd International Wood Machining Seminar*, IWMS 22, June 14-17, Quebec City, Canada, 1, pp. 155-164.

Boulton, B. C. (1920). *The Manufacture and Use of Plywood & Glue*, Sir Isaac Pitman and Sons Ltd, London, UK.

Boutelje, J. B., and Rydell, R. (1995). "Träfakta: 44 träslag i ord och bild," ("Facts on wood: 44 species in words and pictures"), Trätek, Stockholm (in Swedish).

Cassens, D., Leng, Y., and McCabe, G. (2003). "Face check development in veneered furniture panels," *Forest Products Journal* 53(10), 79-86.

Constant, T., Badia, M. A., and Mothe, F. (2003). "Dimensional stability of Douglas fir and mixed beech–poplar plywood: Experimental measurements and simulations," *Wood Science and Technology* 37(1), 11-28. DOI: 10.1007/s00226-003-0165-9

Dinwoodie, J. M. (2000). *Timber, Its Nature and Behaviour*, Taylor & Francis, London, UK. DOI: 10.4324/9780203477878

Ekevad, M. (2006). *Modelling of Dynamic and Quasistatic Events with Special Focus on Wood-Drying Distortions*, Ph.D. Dissertation, Luleå University of Technology, Skellefteå, Sweden.

Emmerich, L., Bollmus, S., and Militz, H. (2019). "Wood modification with DMDHEU (1.3dimethylol-4.5-dihydroxyethyleneurea) – State of the art, recent research activities and future perspectives," *Wood Material Science and Engineering* 14(1), 3-18. DOI: 10.1080/17480272.2017.1417907

Forest Products Laboratory. (1922). "Notes on the manufacture of plywood," Madison, WI.

Forest Products Laboratory. (2010). "Wood handbook wood as an engineering material," General technical report FPL GTR-190, U.S, Dept. of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.

Hvattum, O., Lind, P., and Osvik, H. (1978). *Springback of Laminated Bends* (Technical Report No. 16), Norsk Treteknisk Institut (NTI), Oslo, Norway.

Lind, P. (1981). *Corner Joints and Laminated Bends – Movements Caused by Moisture Changes* (Technical Report No. 26), Norsk Treteknisk Institut (NTI), Oslo, Norway.

Navi, P., and D. Sandberg (2012). *Thermo-Hydro-Mechanical Processing of Wood*, EPFL Press, Lausanne, Switzerland.

Ormarsson, S. (1999). *Numerical Analysis of Moisture-related Distortions in Sawn Timber*, Ph.D. Dissertation, Chalmers University of Technology, Göteborg, Sweden.

Ormarsson, S., and Sandberg, D. (2007). "Numerical simulation of hot-pressed veneer products: Moulding – spring-back – distortion," *Wood Material Science and Engineering* 2(3-4), 130-137. DOI: 10.1080/17480270801945355

Ranta-Maunus, A. (1990). "Impact of mechano-sorptive creep to the long-term strength of timber," *Holz als Roh- und Werkstoff* 48, 67-71.

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