ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 9 N° 4 2013
pp. 549-556

BASIC KNOWLEDGE OF WOOD PROPERTIES FOR IMPROVED PERFORMANCE OF LAMINATED VENEER PRODUCTS

Lars BLOMQVIST
Doctoral student – Linnæus University – Department of Forestry and Wood Technology
Address: SE-351 95 VÄXJÖ, Sweden
E-mail: lars.blomqvist@lnu.se

Jimmy JOHANSSON
Ass.Prof.Dr.Eng. – Linnæus University – Department of Forestry and Wood Technology
Address: SE-351 95 VÄXJÖ, Sweden
E-mail: jimmy.johansson@lnu.se

Dick SANDBERG
Prof.Dr.Eng.habil.Dr.h.c. – Linnæus University – Department of Forestry and Wood Technology
Address: SE-351 95 VÄXJÖ, Sweden and Luleå University of Technology, Division of Wood Technology, SE-931 87 SKELLEFTEÅ, Sweden,
E-mail: dick.sandberg@lnu.se, dick.sandberg@ltu.se

Abstract:

To ensure success in the production of laminated veneer products, it is necessary to acquire a sound basic understanding of the behaviour of the wood, and to understand the inherent reactions of wood to adhesive, heat, moisture, strain and stress. This can ensure an efficient wood utilization and promote the development of new processes and products that take advantage of the visco-elastic nature of wood.

A shortcoming of the laminated bending process is that the products may become distorted after moulding and during use. In this study, we have examined how the performance of laminated veneer products can be improved through the implementation of basic knowledge of wood in the design and production process.

The results show that the material and process parameters and storage in a changing relative humidity have a clear impact on distortion. Fibre orientation of the veneers in the moulded assembly was the most critical parameter to control. Fibre deviations mainly resulted in twist of the product. A moisture content in one veneer deviating from that of the rest of the veneers in the assembly before moulding resulted in distortion of the laminated veneer products both after moulding and during use. To decrease the negative effect of fibre orientation and moisture content on shape stability, the veneer should be straight-grained and well-conditioned to a moisture level adapted to the use of the final product. Special care should also be taken to orientate the veneers during assembly before moulding.

Key words: *shape stability; distortion; thermo-hydro-mechanical processing; furniture production.*

INTRODUCTION

A laminated veneer product consists of veneers and adhesive bonded together under pressure into a predetermined shape and, in general, under increased temperature to shorten the curing time of the adhesive. This process is generally called *laminated bending* and the products are called *laminated veneer products*. The process is commonly used in furniture production and can be used for the production of complex forms. The performance of laminated veneer products is dependent on the properties of the wood and on how this material is handled in the different processing steps from log to final product, Fig. 1.

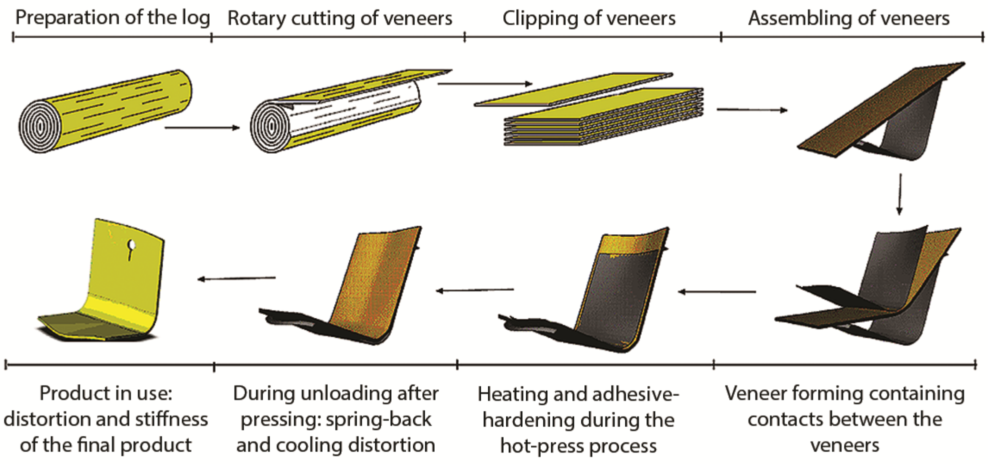

Fig. 1
Manufacture of a laminated veneer product from log to final seat shell and distortion of the product after pressing.

The wood industry in the industrialized countries has in recent decades undergone significant changes. Among other things, there have been increasing demands for short manufacturing lead times, more product varieties and a focus on price and quality, which have forced companies to reorganize. Another effect of this change is that the technical systems used in previous production-oriented companies, where mass production was in focus, now have to change towards one-piece-flow and small-batch production. The products are also more complex in design to satisfy customers with the ability to pay for the product. This places new demands on knowledge of the manufacturing process and of how it affects the final product.

Poor shape stability and cracking in the surface veneer are major problems for laminated veneer products that become increasingly apparent the more advanced the product becomes. Shape stability refers to the correct size and shape of the product in the various manufacturing steps, which are a prerequisite for efficient production, and that the product retains the intended shape in the final use. In addition, advanced forms and especially thin constructions can also result in problems with low stiffness and low strength of the product.

The reason for poor shape stability can be found both in the wood and in the manufacturing process and can result in significant problems in the final use of the product. The following materials and process parameters are reported in the literature to affect the shape stability of laminated veneer products:

- wood characteristics and their variation (fibre direction, density, annual ring width etc.)
- ambient relative humidity and temperature,
- moisture content and the wetting properties of the veneer,
- type, distribution and amount of the adhesive,
- pressure distribution and strains in different veneers during pressing,
- the entire thickness of the construction and the individual veneer thicknesses,
- design of the mould and type of heating during pressing, and
- treatment before, during and especially directly after the pressing.

When processing rotary cut and sliced veneers, one side of the veneer develop cracks from the knife and that side is called the loose side (Perry 1942, Lutz 1974). To avoid checks on the surfaces of the product, the loose side of the surface veneers should be added in compression, i.e. usually with the loose side turned inwards in the construction (Clark 1965, Frihart and Hunt 2010). However, the knowledge of how the orientation of the loose side of the veneer influences the shape stability is low.

This study deals, however, only with how basic wood material properties and moisture can affect the shape stability of laminated veneer products.

OBJECTIVE

This paper is about how the performance of laminated veneer products can be improved through the implementation of basic knowledge of wood in the design and production process. The aim of the work has been to present useful advice for the manufacturing furniture industry.

MATERIAL AND METHOD

To exemplify the influence of wood properties on the shape stability of laminated veneer products a moulded seat shell of beech (*Fagus silvatica* L.) or birch (*Betula pubescens* Ehrh.) was studied, Fig. 2.

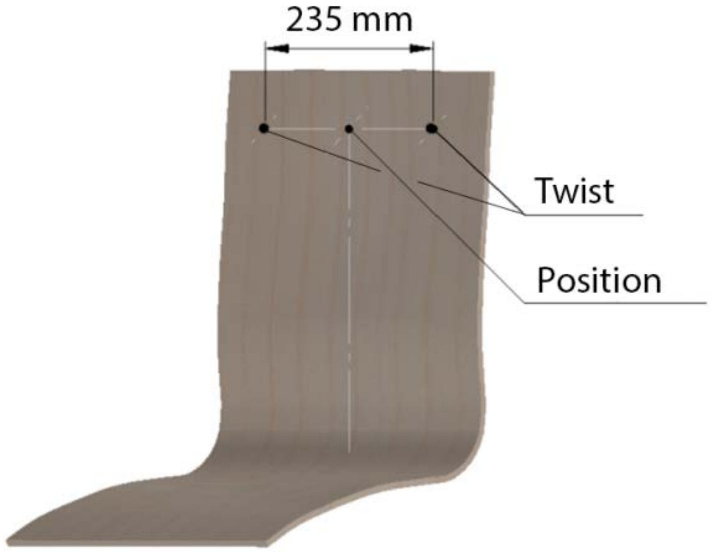

Fig. 2
The studied seat shell in its shape after moulding and before further processing and the locations for the determination of distortions.

The in-plane dimensions of the veneers were 1055x500mm. All the veneers were rotary cut and conditioned to equilibrium moisture content in a climate chamber before the tests. The exact assembly and moisture contents of the veneers are presented in Table 1. In all the tests, an urea formaldehyde (UF) adhesive system was used and the adhesive was spread by a roller system. The amount of adhesive was 165g/m^2, regularly checked by weighing the veneer before and after the adhesive was added. In test 3, adhesive was spread according to the conditions indicated in Table 1.

The effect on shape stability of four different parameters (Table 1) has been studied: (1) species, (2) moisture content of the veneers, (3) adhesive distribution, and (4) fibre orientation of the veneers.

Distortion was measured as *position* and *twist* of the seat shell backrest in relation to a well-defined gauge, Fig. 2. Position is equal to zero if the seat shell fits snugly against the mould. If the seat shell is opened up (the angle between seat and back increases), the position is positive (+) and if it is closed together it is negative (-). This means that the position at time zero is equal to what is normally defined as spring-back.

Twist is measured at a distance between the measuring points of 235mm and twist is then given as mm/235mm. The direction of twist is defined as positive (+) when clockwise rotation of the backrest occurs (seen from the front of the seat shell). In tests 1-3, twist is presented as absolute values and in test 4 twist is given with the sign (+/-). The seat shells were measured according to distortion on the following occasions:

1. directly after moulding (time equal to zero), and
2. after subsequent storage in a defined climate in a climate chamber.

ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 9 N° 4 2013
pp. 549-556

Table 1

Design of the different tests

Test No.*	Group No.*	No. of samples	Species	Veneer MC (%)	Orientation of veneers "front to back" AND Thickness of veneer (mm) (bold character is veneers with adhesive)	Specific condition for this test
1: Species	1	15	Beech	5	L-**L**-T-**L**-T-**L**-T-**L**-L	
	2	15	Birch	5	1.0-1.5-1.5-1.5-1.5-1.5-1.5-1.5-1.0	
2: Moisture content of veneers						Moisture content (MC) of single veneers
	1	30	Birch	5	L_1-$\mathbf{T_2}$-L_3-$\mathbf{T_4}$-L_5-$\mathbf{T_6}$-L_7	Reference (same MC In all veneers)
	2	30	Birch	→	1.3-1.5-1.5-1.5-1.5-1.5-1.3	5 veneers with 4% MC veneers (L_1 and L_7) with MC 7 %
	3	15	Birch	→		1 veneer (L_1)with 19 % MC and 6 with 5% MC
	4	15	Birch	→		3 veneers with 19 % MC (L_1, T_2 and L_3) and 4 with 5% MC
3: Adhesive distribution						Description of adhesive distribution (extra adhesive means more than 165 g/m^2 in a ca. 100 mm wide area)
	1	15	Birch	5	L-**L**-T-**L**-T-**L**-T-**L**-L	Reference (even adhesive distribution on veneers)
	2	15	Birch	5	1.0-1.5-1.5-1.5-1.5-1.5-1.5-1.5-1.0	25 % extra adhesive applied diagonally
	3	15	Birch	5		25 % extra adhesive applied on the left side
4: Fibre orientation of veneers						Fibre orientation
	1	5	Beech	5	L_1-$\mathbf{T_2}$-L_3-$\mathbf{T_4}$-$\mathbf{T_5}$-L_6-$\mathbf{T_7}$-L_8	Reference (no deviation in fibre orientation in veneers)
	2	5	Beech	5	1.0-1.5-1.2-1.5-1.2-1.2-1.5-1.0	Irregular fibre structure in transverse (T) veneers
	3	5	Beech	5		Divergent fibre orientation in veneer L_1= +5° and L_8= −5°

** In the diagrams, Test No. and Group No. are referred to as "Test No:Group No", e.g. 1:2 for Test No. 1 and Group No. 2.*

RESULTS AND DISCUSSION

Influence of species and the anisotropy of the wood

Anisotropy of wood is the main reason for a reduced shape stability of laminated veneer products, but anisotropic behaviour is also the underlying reason why such a product cannot be freely formed in 3D to any great extent. An understanding of anisotropy and especially its relation to wood moisture content is one of the key factors in reducing the rejection of products.

Table 2 shows some basic values for beech and birch, which are the species studied in this paper. Beech has a greater shrinkage than birch in the tangential direction, which is one of the reasons for the well-known fact that beech is a "moving wood". In addition, the difference in E-modulus perpendicular to the fibre results in differences in product design between beech and birch, e.g. a thicker construction is needed when birch is used to achieve the same appearance of the product as when beech is used. To a great extent, it is the fibrillar orientation in the S2-layer which determines the mechanical properties of the wood fibre. This applies both to strength and stiffness and to swelling properties (Sahlberg *et al*. 1997).

Reaction wood and juvenile wood have another fibril angle than mature wood, which also results in different shrinkage and swelling (Shmulsky and Jones 2011). Using a veneer containing reaction or juvenile wood can lead to a non-symmetric construction.

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 9 N° 4 2013
pp. 549-556

Table 2

Some properties of beech and birch (Perem and Thunell 1952)
MC – moisture content, parallel (//) and perpendicular (⊥) to the fibre

Species	Density at 0 % MC	Shrinkage (%)			E-modulus at 12 % MC (MPa)		Strength at 12 % MC (MPa)				
	(kg/m^3)	Radial	Tang.	Long.	//	⊥	Bending	Compression	Tensile		
								//	//	⊥ radial	⊥ tang.
Beech	680	5.8	11.8	0.3	16,000	1,500	105	53	135	7	7
Birch	580	5.3	7.8	0.6	15,000	800	107	53	137	7	7.5

Fig. 3 show the twist for seat-shells made of beech and birch, but with all other material and production parameters the same. Immediately after pressing, the twist for the both types of shell was about the same, but when the shells were subjected to changing relative humidity, the shells of beech showed a dramatic movement while the birch shells were fairly stable. This clearly illustrates how the choice of species can influence the appearance of a laminated veneer product.

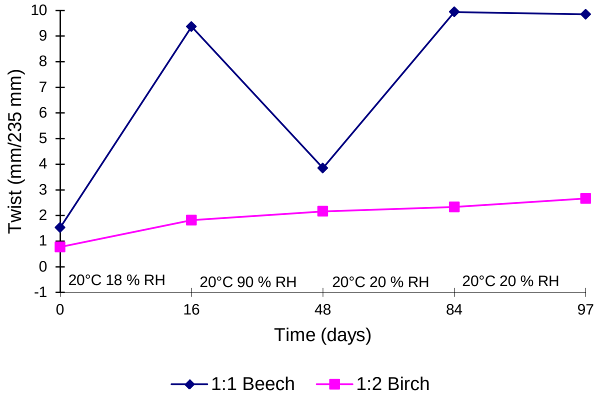

Fig. 3
Mean twist in seat shells of beech and birch (rotary cut veneers) exposed to cyclic relative humidity. Test groups 1.1-1.2 according to Table 1.

The way the veneer is cut with respect to the principal directions of the wood influences the properties of the veneer. Veneer can be rotary cut (peeling), sliced or sawn from a log or a flitch (a block of wood). Rotary cut veneer is the most frequently used in laminated bending, and such veneers have their LT-direction mainly in the plane of the lamina. There are various methods of slicing veneer which give different textures and properties to the veneer, and the orientation in the plane of the lamina can vary from the LT-direction to the LR-direction. Veneers can also be sawn but that technique is more wasteful than peeling and slicing depending on the saw kerf and it is only used on wood that for some reason is difficult to peel or slice. Sawing does have the advantage that it is not necessary to heat the log or flitch prior to cutting, the two sides of the veneer are essentially the same in quality, and thicker veneers can be produced without developing cracks in the veneer.

If the fibre orientation of the veneers deviates from the main direction of the veneers there will be a tendency for the laminated assembly to distort as a result of moisture content changes. Such distortion can be eliminated by selecting only straight-grained veneers. However, trees are not symmetrical cylinders, and it is therefore virtually impossible to produce a veneer that is parallel to the fibres throughout its thickness. In any of the processes for producing veneer, distortion of the grain occurs.

How can shape-stable laminated veneer products be achieved?

As mentioned, a shortcoming of laminated bending is that the products may become distorted after moulding and during use. The stresses in a newly produced product will normally tend to reopen the bend, i.e. to increase the radius of curvature, when the product is removed from the mould. This is often referred to as spring-back and this change in shape is normally not as great a problem as other modes of distortion, e.g. twist, that can occur.

The principle of symmetry

The importance of a symmetrical construction with respect to fibre orientation and moisture content of the veneer cannot be underestimated. In order to maintain control of a laminated veneer construction, according to shape stability, symmetry should be sought (Boulton 1920, Brouse 1961, Navi and Sandberg 2012). The *principle of symmetry* prevents distortion and has the following conditions: (1) on either side of the *centre veneer* there must be an equal number of veneers, i.e. the number of laminae in the construction must always be odd (the "centre veneer" can consist of two veneers if these veneers have properties that they can be considered as one when glued together); (2) for each veneer on one side of the centre veneer there must be a corresponding veneer in the same relative position on the opposite of the centre veneer, both being of the same thickness and the same species, having the same moisture content and, preferably, being cut in the same manner; and (3) the fibre orientations of the two veneers at the same distance from the centre veneer must run in the same direction. The reasons for choosing this construction are primarily the phenomena of shrinkage and swelling of wood. Due to the great difference between the shrinkage and swelling parallel to the fibres and perpendicular to the fibres, stresses will always arise or be released in laminated veneer products when the moisture content changes.

Moisture content of veneer

In general, the well-known rule of thumb for the user of wood should be followed: veneers should be conditioned to a moisture content that together with the added moisture from the adhesive used in the process matches the climate where the final product will be used. This is of course a very rough target moisture content since the climate in most surroundings varies a lot during the year. However, this is the main reason why the target moisture content of veneer is different with different producers.

A variation in the climate where the laminated products are stored can result in great distortion, as shown in Fig. 3, although the veneers before moulding were well-conditioned to the same moisture content. Variations in the moisture content in the products release internal tensions and distortion occurs. In general, the shape of a laminated veneer product is sensitive to changes in moisture content. However, if the veneers are not well conditioned before moulding, distortion may occur even if the products are stored in a very stable climate, as shown in the examples below.

Fig. 4 show the position and twist for seat shells of birch with different moisture contents in some of the veneers in the assembly, according to test No. 2 in Table 1. Immediately after moulding, there were only small differences in position and twist for the different groups. After 13 days of conditioning at a constant relative humidity, the seat shells in group 2.4 which had the most asymmetric moisture-content profile exhibited a substantial reduction in position and increase in twisting, i.e. poor shape stability. The shells with all the veneers at the same moisture content or with only one or both of the outermost veneers at a higher moisture content showed only a moderate change in shape during storage.

The results indicate that, if the veneers are well-conditioned before moulding, the distortion of the moulded assembly in use is reduced, and that a high moisture content in several of the veneers in the assembly can lead to considerable distortion after moulding, especially when the moisture is asymmetrically distributed in the assembly.

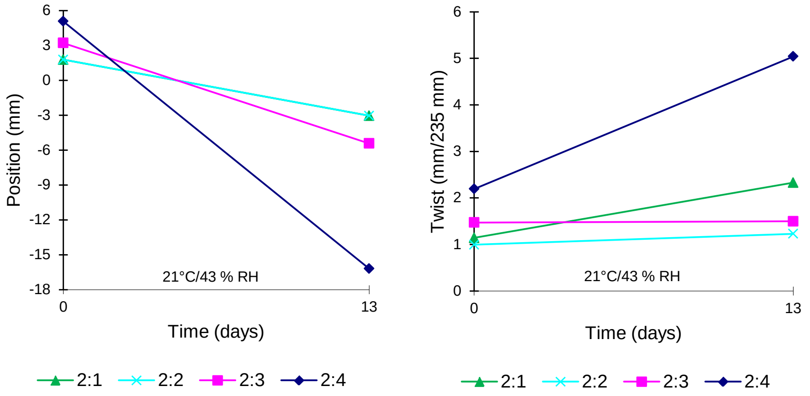

Fig. 4
Mean position and twist in seat shells of birch manufactured with veneers with different moisture contents and exposed to a constant climate. Test groups 2.1-2.4 according to Table 1.

Added water from the adhesive

Most types of adhesives contain water that increase the moisture content of the veneers when adhesive is added. It is thus easy to imagine that an uneven distribution of adhesive on the veneers will result in an uneven moisture distribution in the veneers, with subsequent problems with the stability of the product. In an attempt to show the effect of uneven adhesive distribution, extra adhesive was added to the veneers in a controlled way, as shown in test 3 in Table 1.

Fig. 5 show the position and twist for seat shells of birch glued with different adhesive distribution. Spring-back (position at time equal to zero) was lower with an even adhesive distribution. This difference disappeared when the shells were moistened, but came back after the shells were dried. There was no difference in position between the samples with extra adhesive applied diagonally and the samples with extra adhesive applied on the side. The differences in spring-back are of great importance for designing the mould so that laminated veneer products have the desired shape after moulding. The twist results showed that the shells were very stable both after pressing and during moisture cycling.

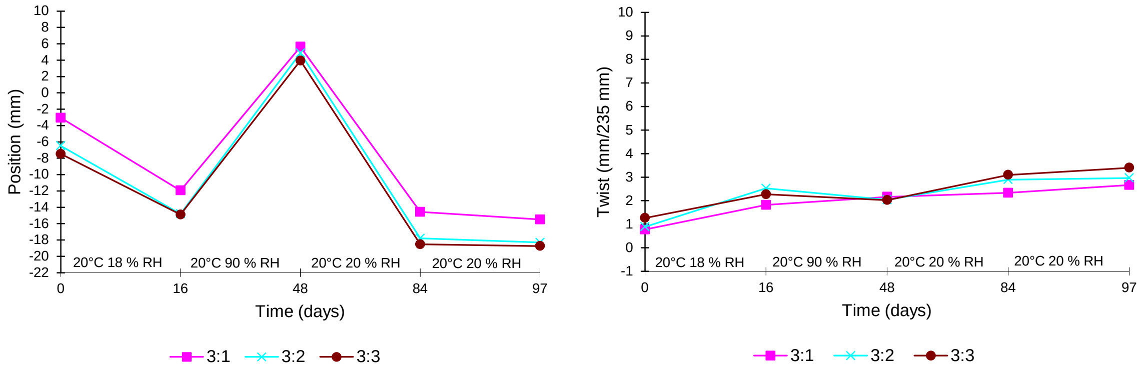

Fig. 5
Mean values of position and twist in seat shells of birch glued with different adhesive distributions. Test groups 3:1-3:3 according to Table 1.

Fibre orientation of veneer

Straightness of grain does not preclude the possibility that the laminated assembly may twist as a result of a moisture change, unless the grain is absolutely parallel with the sides or parallel grain exists throughout the assembly. If the fibres in the veneers are in a spiral form or deviate from the main directions of the veneers, there will be a tendency for the assembly to twist on drying.

Fig. 6 show the position and twist of seat shells of beech with different fibre orientations in some of the veneers in the assembly, as in test 4 in Table 1. The results show clearly that deviation in fibre orientation of individual veneers results in an increased spring-back and twist directly after moulding. After exposure to a cyclic relative humidity, there is no clear relation between position and fibre orientation.

The influence on the twist of a deviation in fibre orientation was clear. The seat shells with no fibre deviation or an irregular fibre structure showed a low twist after moulding and during humidity cycling. The twist that nevertheless occurs in these two groups may be a consequence of a variation in wood properties and the assembly of the veneers, or of an inaccuracy in the deformation measurement.

The seat shells with the outer veneers orientated 5 degrees in opposite directions exhibited a small twist directly after moulding. During the first 48 days of storage, the seat shells dried and exhibited a dramatic increase in twist. When the relative humidity was increased to 90% RH, the moisture content of the shells increased and the twist decreased and changed direction.

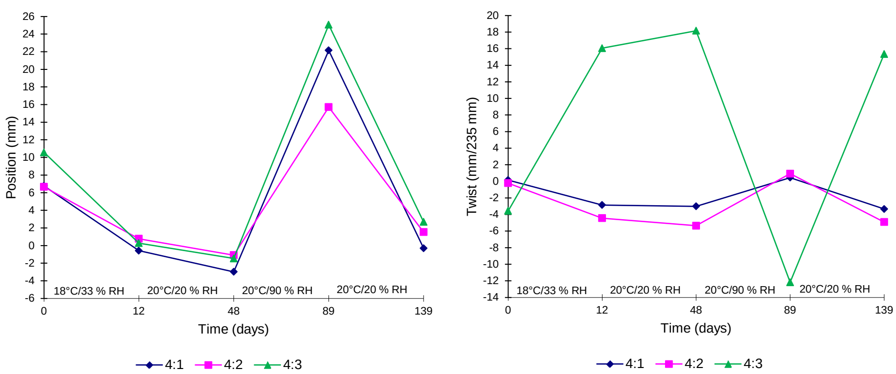

Fig. 6
Mean position and twist in seat shells of beech manufactured with veneers with different fibre orientations. **Test groups 4:1-4:3 according to Table 1.**

CONCLUSION

The results in this paper show that it is possible to increase the shape stability of laminated veneer products through implementation of a basic knowledge of wood in the design and production process.

The choice of species is important for the shape stability and this fact should be considered, at least in the choice of veneer for the product's internal regions.

The key factors for poor shape stability when only one species is considered were different fibre orientations in veneers and between veneers in combination with moisture content variations. The distortions were in general small directly after moulding, but when the products were subjected to variations in relative humidity the distortion increased. This was especially evident when the principle of symmetry was not followed.

To have a good control in production of moisture content and fibre orientation of veneers, and circumstances that will affect these parameters, will create opportunities to significantly reduce wastage of laminated veneer products as a result of poor shape stability, both in production and during the use of the product.

REFERENCES

Boulton BC (1920) The manufacture and use of plywood & glue. Sir Isaac Pitman & Sons, Ltd. Bath, Melbourne, Toronto, New York

Brouse D (1961) Some causes of warping in plywood and veneered products. Report No. 1252, Forest Products Laboratory, Madison, Wis., US

Clark WM (1965) Veneering and wood bending in the furniture industry. Pergamon Series of Monographs on furniture and timber, Volume 3, Pergamon Press, Oxford, London

Frihart CR, Hunt CG (2010) Adhesives with Wood Materials: Bond Formation and Performance. In: Wood handbook wood as an engineering material. Dept. of Agriculture, Forest Service, Forest Products Laboratory, General technical report FPL GTR-190, pp. 228-251, Madison, Wis., US

Lutz JF (1974) Techniques for peeling, slicing and drying veneer. Dept. of Agriculture, Forest Service, Forest Products Laboratory, Research paper 228, Madison, Wis., US

Navi P, Sandberg D (2012) Thermo-hydro-mechanical processing of wood. EPFL Press, Lausanne, Switzerland

Perem E, Thunell B (1952) Svenskt trä. (Wood from Sweden) Strömbergs, Stockholm

Perry TD (1942) Modern plywood. Pitman Publishing Corporation, New York, Chicago

Sahlberg U, Salmén L, Oscarsson A (1997) The fibrillar orientation in the S2-layer of wood fibres as determined by X-ray diffraction analysis. Wood Science and Technology 31:77-86

Shmulsky R, Jones PD (2011) Forest products and wood science: an introduction (sixth edition). Wiley-Blackwell, West Sussex, UK