

Transverse Anisotropy in Thermally Modified Beech and Spruce

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ABSTRACT

The anisotropic characteristic of selected physical and mechanical properties in the transverse plane of beech and spruce after thermal modification was investigated. Anisotropy factors (ratio of tangential to radial property value) were determined for swelling, tensile strength perpendicular to grain, shear strength parallel to grain and hardness and compared to untreated controls. While thermal modification changes properties considerably, thermally modified timber nonetheless retains the distinct anisotropic characteristic of wood. For practical applications of thermally modified timber it has particularly to be taken into account that despite the reduced swelling, the largely unchanged transverse anisotropy may still lead to shape distortions.

INTRODUCTION

Thermally modified timber (TMT) is being increasingly used as an alternative wood based material in applications where an improved dimensional stability and durability are required. However, the thermal modification leads to structural and chemical changes in the wood constituents, which may significantly alter the material properties as compared to untreated solid wood. TMT is therefore regarded in many aspects a 'new' material, whose particular properties have to be known and carefully considered for appropriate and successful applications. Current research has facilitated a considerable knowledge of the physical and mechanical properties of TMT (Hill 2006), but little is known about possible changes regarding special property relationships familiar from solid wood. This is for example the case for the directional dependence of most material properties regarding the three principal axes in the tree trunk (longitudinal, tangential, radial) known as anisotropy or (more precise) orthotropy (Dinwoodie 2000). Usually, anisotropy is most pronounced between properties measured parallel and perpendicular to grain. However, also in the transverse plane (tangential and radial directions) considerable differences may exist (Schniewind 1959). Except when concerning shrinkage and swelling, this topic has received little attention so far regarding TMT. Anisotropy may be changed in TMT, since the thermal modification leads to a partial degradation of the hemicelluloses and therefore to changes in the wood matrix properties (Hill 2006, Bergander and Salmén 2002).

The aim of this paper is to assess the transverse anisotropy of selected physical and mechanical properties of TMT made from hard- and softwoods and discuss possible consequences for practical applications.

EXPERIMENTAL

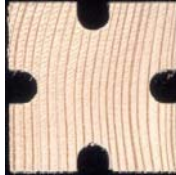
The data used in this analysis has been collected within a larger project to assess the physical and mechanical properties of thermally modified beech (*Fagus sylvatica*) and spruce (*Picea abies*). A commercial thermal modification process (Mitteramskogler 2007) with two treatment levels was used (Table 1).

Table 1: Thermal modifications

Code	Description
T0	untreated controls
T1	'mild' heat treatment, max. temperature 180 °C
T2	'intense' heat treatment, max. temperature 220 °C

For each wood species and thermal modification level (T1 and T2), 4 entire boards were heat treated. Small clear specimens were subsequently cut from the treated boards, with matching control specimens cut from a section of each board left untreated. Care was taken to achieve a parallel/perpendicular orientation of the growth rings within the specimens cross-section. From each board 2 replicate specimens were cut, adding up to 8 and 16 replicates per modification level and untreated controls respectively. Some replicate specimens were discarded because of imperfections.

Table 2: Experimental details

Property	Swelling coefficient	Tensile strength perp. to grain	Shear strength parallel to grain	Hardness (Brinell)
Unit	[%/%RH]	[N/mm ²]	[N/mm ²]	[N/mm ²]
Test method	DIN 52184	special	DIN 52187	EN 1534
Specimen shape, size (L x T x R)	disc 10 x 30 x 30 mm ³	notched disc 10 x 30 x 30 mm ³ 	block (cube) 40 x 40 x 40 mm ³ (block shear test)	block (cube) 40 x 40 x 40 mm ³
Details	hygroscopic range 35-85% RH	2 axially matched replicates	2 axially matched replicates	beech only, means of 2 indentations
specimens conditioned at 20 °C / 65% RH				
Parameters	h_T : T direction h_R : R direction	TP_T : load R, fracture T plane TP_R : load T, fracture R plane	SL_T : load L, fracture T plane SL_R : load L, fracture R plane	HB_T : T face HB_R : R face
Anisotropy factor	A_h = h _T / h _R	A_{TP} = TP _T / TP _R	A_{SL} = SL _T / SL _R	A_{HB} = HB _T / HB _R

Abbreviations: L: longitudinal, T: tangential, R: radial, RH: relative humidity

Four different material properties to be assessed regarding both radial and tangential growth ring orientation on the same or on axially matched specimens were chosen. Experimental details are given in Table 2. Swelling served as an example of a moisture related physical wood property. Tensile strength perpendicular to grain, shear strength parallel to grain and hardness are examples of different mechanical properties. Tensile strength perpendicular to grain was assessed by a non-standard procedure on notched discs. The other properties were measured according to common tests methods.

RESULTS AND DISCUSSION

The mass loss induced by the thermal modification is reflected in a 3% and 7% decrease in oven-dry density for T1 and T2 respectively. As expected, swelling was improved (reduced) considerably by the thermal modification, while tensile strength perpendicular to grain decreased in the same order of magnitude. Shear strength parallel to grain and hardness were reduced noticeably only at the higher modification level T2. As an example, data for tensile strength perpendicular to grain are shown in Figure 1. While for beech distinct treatment differences and transverse anisotropy are apparent, treatment effects are less pronounced for spruce and hardly any transverse anisotropy is present.

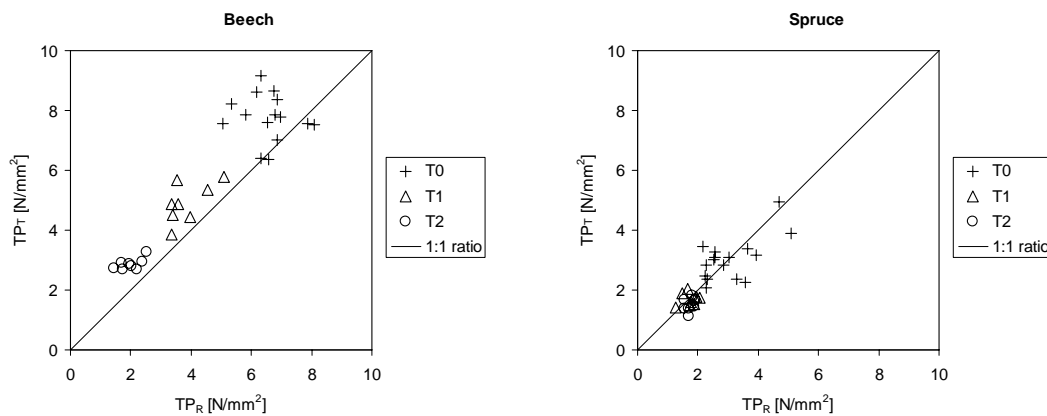


Figure 1: Example of transverse properties: Tensile strength perpendicular to grain for beech and spruce

The calculated anisotropy factors and their changes after thermal modification appear to be highly species and property specific (Figure 2). As expected, transverse anisotropy is much more pronounced for swelling than for the mechanical properties. Anisotropy with swelling is higher for spruce than for beech, while the opposite is the case for the mechanical properties. Overall, the thermal modification has little effect on anisotropy.

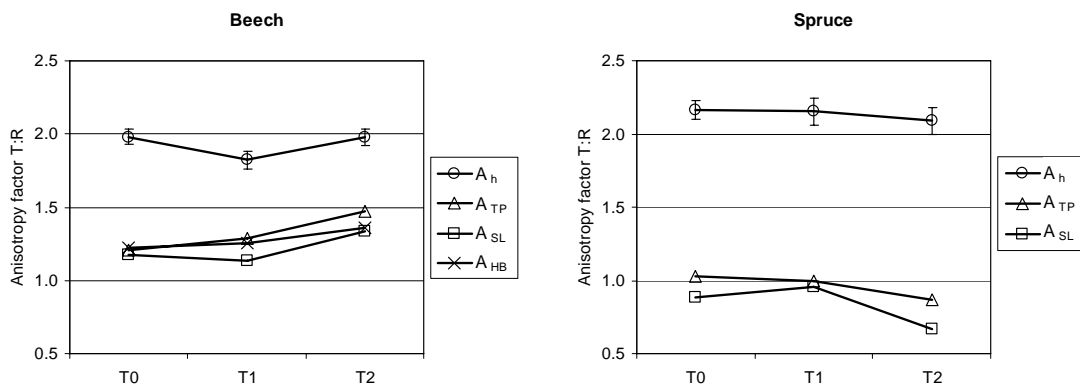


Figure 2: Anisotropy factors (Exemplary error bars for A_h indicate standard error of means)

A statistical evaluation using analysis of variance techniques confirms the observation on the graphed data. All properties show significant transverse anisotropy except

tensile strength perpendicular to grain with T0 and T1 and shear strength parallel to grain with T1 for spruce. Multiple comparison tests of anisotropy factors indicate no difference between the treatments regarding swelling, but a slight increase of the anisotropy with the mechanical properties for beech and a slight decrease for spruce with treatment T2 (Table 3). However, changes in anisotropy are too small to be of practical relevance.

Table 3: Results of multiple comparison tests for anisotropy factors in different treatment levels^a

Modification	Beech				Spruce		
	A _h	A _{TP}	A _{SL}	A _{HB}	A _h	A _{TP}	A _{SL}
T0	A	A	A	A	A	A	A
T1	A	AB	A	AB	A	A	A
T2	A	B	B	B	A	A	B

^aDifferent letters (A, B) indicate significantly different anisotropy factors (5% error level)

CONCLUSIONS

- Despite the considerable changes of the physical and mechanical properties induced by a thermal modification, wood retains its distinct anisotropic characteristic. Obviously, the structural features which are responsible for the transverse anisotropy, remain largely unaffected by the thermal modification.
- Although a thermal modification reduces swelling considerably, shape distortions (e.g. cupping) still have to be expected in TMT pieces because of the unchanged transverse anisotropy.
- Regarding the anisotropy of mechanical properties in the transverse plane, a similar behaviour can be expected for untreated solid wood and TMT. However, the general decrease of mechanical properties, the changed equilibrium moisture content and the increased brittleness of TMT have to be considered.

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