Density-property Relationships in Thermally Modified Wood

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ABSTRACT

The density-property relationships for five selected physical and mechanical properties were derived from small clear specimens of thermally modified beech, ash and spruce and compared with untreated controls. The relationships were analysed based on changes in relative property level and variability as well as on the density-property correlation. For thermally modified timber (TMT) with small to moderate property changes, density-property relationships similar to solid wood were observed. For TMT with major property changes, relationships are usually less specific and have to be established by tests.

INTRODUCTION

For appropriate and successful applications of TMT a detailed knowledge on its distinct properties is essential. Prior research has shown that a thermal modification will lead to structural and chemical changes in the wood constituents, which may significantly alter the material properties (Hill 2006). For most thermal modification processes improvements in dimensional stability and durability are reported, while strength properties generally decrease. The extent of the property changes will vary depending on the type of process and its specific conditions as well as on the wood species.

However, the induced changes will not only concern the absolute property values, but may also affect the relationships between the different material properties as known from untreated solid wood. These relationships are an important basis in wood science and are frequently used to estimate unknown properties (*e.g.* in grading procedures). Moreover, they are an indispensable part of a comprehensive characterisation of material behaviour and may be a sensitive measure for suspected changes.

Of particular importance in this context is the dependence of numerous technological properties on the wood density. With solid wood, density is frequently the single most important indicator for numerous physical and mechanical properties (Forest Products Laboratory 1999, Kollmann and Côté 1968). For many practical applications it is important to know if these density-property relationships are also valid for TMT. This question is the particular focus of the present paper.

EXPERIMENTAL

The presented analysis is based on pooled data collected in a series of experiments to assess the physical and mechanical properties of thermally modified hardwoods. A commercial thermal modification process (Mitteramskogler 2009) with two treatment levels was used (Table 1). Heat treatment was done on whole boards with test specimens cut subsequently. A similar number of matching control specimens were cut from a section of the same boards left untreated or from a neighbouring board. This procedure assures that modified and control specimens come from the same source of raw material and are thus directly comparable.

Table 1: Thermal modifications ('Treatments')

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

Besides density five selected material properties were assessed according to established standards (Table 2). Bending MOE serves as measure for the material elasticity. Bending MOR, impact bending work and compression strength parallel to grain represent strength properties. Volumetric swelling was chosen as an example of a moisture-related physical property. To assess 'pure' material properties and to exclude the effects of structural defects, small clear specimens were used. For the mechanical tests specimens were conditioned at 20 °C/65% RH. Therefore, mechanical properties include both effects of thermal modification and changed equilibrium moisture content.

Table 2: Experimental details

Property	Label	Unit	Test method	Specimen size (L x T x R)	Details
Density:					
Normal density	ND	[g/cm^3]	DIN 52182	(bulk density of whole specimens from property tests)	mass and volume at 20°C / 65% RH
Oven-dry density	OD				calculated from ND where not measured
Static bending:					
Modulus of elasticity	MOE	[N/mm^2]	DIN 52186	360 x 20 x 20 mm^3	3-point bending test
Modulus of rupture	MOR				
Impact bending work	IBW	[kJ/m^2]	DIN 52189	300 x 20 x 20 mm^3	
Compression strength	CSL	[N/mm^2]	DIN 52185	100 x 20 x 20 mm^3	parallel to grain
Volumetric swelling	VSW	[%]	DIN 52184	10 x 30 x 30 mm^3	sum of radial and tangential swelling

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

Two data sets based on different raw material batches were compiled for beech (*Fagus sylvatica*), ash (*Fraxinus excelsior*) and spruce (*Picea abies*) as examples of a diffuse-porous and a ring-porous hardwood, and a common softwood respectively (Table 3).

Table 3: Data sets with number of test specimens

Data set	Properties [a]	Beech			Ash		Spruce		
		T0 [b]	T1	T2	T0	T1	T0	T1	T2
1	MOE, MOR, IBW, CSL	20	20		20	20			
	VSW	15	15		15	15			
2	MOE, MOR	34	24	26			33	24	26

Abbreviations: [a] Key to properties see Table 2, [b] Key to thermal modifications see Table 1

RESULTS

Examples of density-property relationships regarding bending are shown in Figure 1. A linear relationship is assumed for the limited range of present densities. The data ranges of T0 and T1 are overlapping largely, while T2 is distinctly separated. A progressing shift towards lower densities for the TMT is apparent. While MOE is similar for the three treatment groups, MOR is clearly reduced for the modification level T2, where more frequent brittle fractures lead to a deviating density-property relationship.

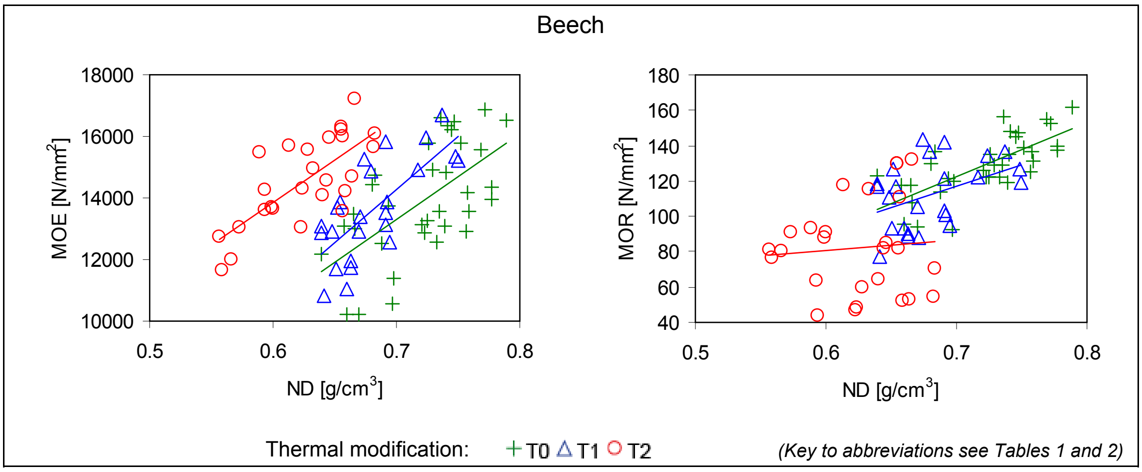

Figure 1: Examples of density-property relationships: Bending MOE and MOR for beech (Data set 2)

The effects of a thermal modification on the material properties are presented regarding relative property level (T0 = 100%) and variability (coefficient of variation) as well as regarding correlation coefficient (Pearson) in Figures 2 and 3.

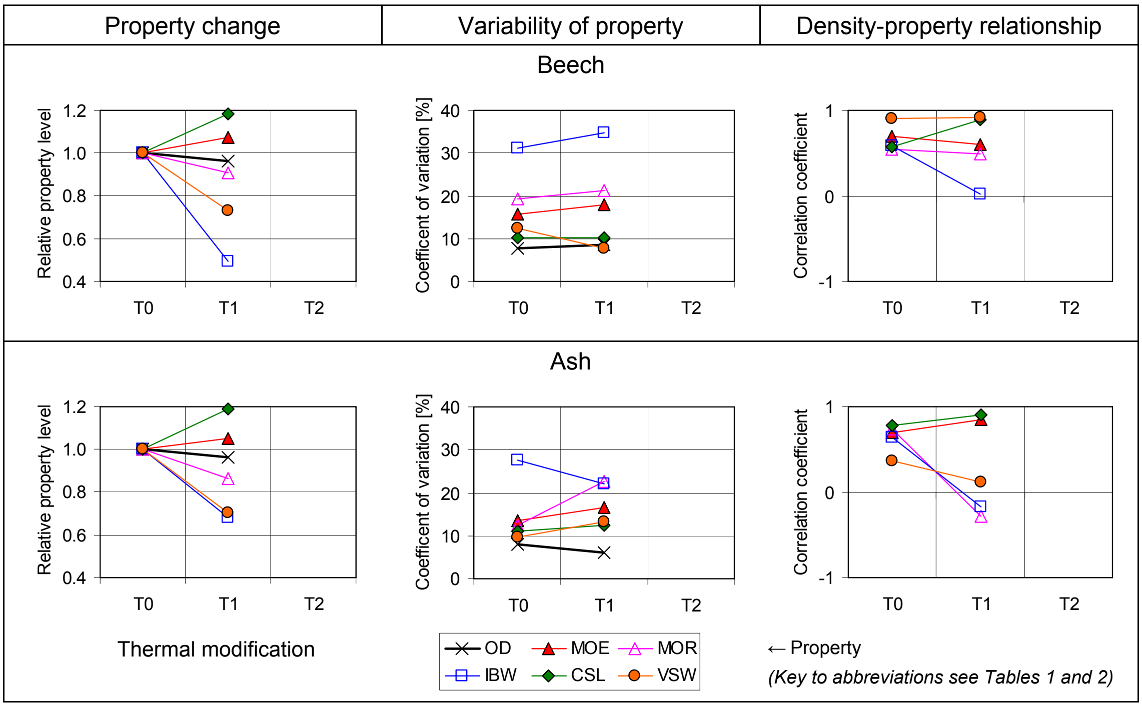

Figure 2: Effect of a thermal modification on property level, variability and density-property relationship regarding selected physical and mechanical properties of beech and ash (Data set 1)

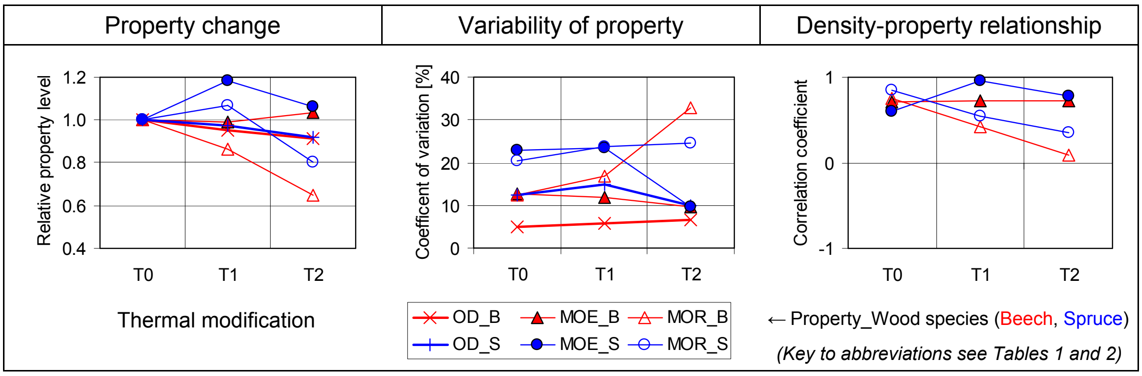

Figure 3: Effect of a thermal modification on property level, variability and density-property relationship regarding bending properties of beech and spruce (Data set 2)

DISCUSSION AND CONCLUSIONS

- Property changes: OD is decreasing slightly with increasing thermal modification (-3% for T1, -8% for T2). MOR and particularly IBW clearly decrease, while MOE and CSL slightly increase. VSW is considerably improved (lower) in TMT.
- Variability shows distinct property-specific values, with comparatively low values for OD and high values for IBW, but generally little change by a thermal modification.
- Density-property relationship: Correlation coefficients usually range between +0.5 and +0.9 for untreated controls. For TMT with small to moderate property changes, density-property correlations similar to the controls were observed. For TMT with major property changes, correlations are usually less specific and may even turn negative. Thus, relationships present in untreated solid wood may not apply any more.
- Practical consequences: Where density is used as an indicator for unknown material properties, the density-property relationships have to be established by tests for the specific wood species - thermal modification combinations in question.

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