Mechanical properties of thermal treated hardwood (beech): Bending and tension strength and stiffness of boards

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ABSTRACT

This paper describes structural tests on boards fabricated from thermally treated timber of beech *fagus sylvatica* (TMTB). In particular bending and tension strength and stiffness were determined. The results were correlated to parameters like density and dynamic modulus of elasticity (MOE) as indicators for the possibility of predicting strength classes by machine grading.

INTRODUCTION

In the past 5 years products made out of thermally treated timber (TMT) are being increasingly used for a wide field of applications. For outdoor its superior durability and dimensional stability makes TMT being a good substitute for tropical hardwoods or impregnated softwoods. For indoor uses the wide range of possible colours of TMT made it becoming a competitor to dark coloured tropical hardwoods.
Within the EC-funded FP6 project *Holiwood* the partners intend to widen the field of uses for TMT made out of European hardwoods to structural applications in particular for an outdoor environment. An extensive test program has been set up to determine the strength and stiffness parameters of TMTB. For the determination of respective characteristic values only bending strength and stiffness as well as density have to be tested according to EN 384, all other values can be calculated on base of this. As tests with small dimensions indicated that the relation between several strength/stiffness parameters could differ from respective specifications given in EN 384 the tests will have to cover all parameters that are needed to assign *eg.* TMTB to (a) strength class(es) according to EN 338.
In the following the results of bending and tension tests on TMTB boards are presented as an example of the still ongoing test program designed to determine the structural behaviour of this material.

EXPERIMENTAL

Material

All tests were executed with TMTB and untreated beech as reference. As cross-sections boards with thicknesses from 28 to 30mm and widths between 120mm and 150mm were selected. The boards were free of major defects like knots and bark and also didn't show significant deformations like twist, cup or bow. However, as slope of grain is difficult to

determine on beech, this feature could not be verified before testing. All boards were planed.
The boards were provided by Mitteramskogler GmbH which is based in Gaflenz, Austria. This company uses the THA thermal treatment process where the respective heating process is executed under a gas atmosphere. According to the desired end-use of the material, the heating temperature can vary between 160°C and 250°C with treatment times from 2h to 16h (Mitteramskogler 2007). For the tests material that has undergone different heat treatments was used. One series, with untreated beech as reference was treated under 180° and treatment times of 4h, 8h and 16h. For all other series TMTB which Mitteramskogler sells under the brand "Buche forte" was used. Detailed data for the respective treatment are not published, however the used fix combination of temperature and treatment time is selected in such a way that durability class 1 can be guaranteed according to the manufacturer.
Before testing the boards were stored in standard climate (20°C/65%r.h.). Moisture content and oven-dry density were determined immediately after testing.
An overview of the test material is given in table 1. Each board of series 2 (S2) was divided into a tension and a bending specimen in order to achieve a respective comparison at the best.

Table 1: Test series

Series [-]	**Treatment**	**Temperature** T [°C]	**Time** t [h]	**Number** n [-]	**Density** ρ_0 [kg/m³]	**moisture content** u [%]
T0	Beech untreated	-	-	26	580-820	9.7-11.7
T4	TMTB	180	4	26	580-790	6.5-7.3
T5	TMTB	180	8	26	570-800	6.0-6.7
T6	TMTB	180	16	26	580-780	5.3-6.0
S1	TMTB "Buche forte"	nn	nn	57	590 - 750	5.1 – 6.9
S2	TMTB "Buche forte"	nn	nn	38 + 38	570 - 750	5.4 – 7.4

Procedures

Before the tests were executed, the MOE was determined by using two different methods in order to check the possibility for future machine grading of TMT. First an ultrasonic device "Sylva Test" was used to determine the speed of sound v within each specimen. Together with the density ρ measured at the same moment it was possible to calculate a dynamic MOE $E_{\text{dyn},1}$ using the following equation:

$$E_{dyn,1} = \rho \cdot v^2 \qquad (1)$$

With the "Grindosonic" equipment another possibility to determine a dynamic MOE $E_{\text{dyn},2}$ was available and used. This determination is based on the measurement of the first eigenfrequency of the board when it is supported as a single beam and can be calculated as follows (Görlacher, 1984):

$$E_{dyn,2} = \frac{4\pi^2 \cdot \ell^4 \cdot f_0^2 \cdot \rho}{m_n^4 \cdot i^2} \cdot \left(1 + \frac{i^2}{\ell^2} \cdot K_1\right) \qquad (2)$$

The bending- and tension tests were executed according to EN 408. For the 4-point bending tests the bending strength f_m as well as the deformations required to determine the global ($E_{m,g}$) and local ($E_{m,\ell}$) modulus of elasticity (MOE) were recorded. For the determination of the MOE in tension parallel to grain the deformations were measured on a length of 700mm on both sides of the specimens. This reference length equals around 6 times the width which is a deviation from EN 408 that requires a reference length of 9 times the width.

RESULTS AND DISCUSSION

Strength and Stiffness

All specimens were tested up to failure. Figure 1 shows the results for the series with different heat treatments. The mean bending strength of the heat treated specimens was around 30% to 40% lower (50% lower at minimum level) compared to the untreated reference specimens but the mean local bending MOE of the TMTB specimens exceeded the respective MOE of the reference by 8% to 10%. However, the variation between the different treatments – here: treatment time – was not significant. In particular remarkable in regards to its desired use as a structural material are the significant higher coefficients of variance CV for the bending strengths of the TMTB samples whereas the CV for the MOE's are more or less on an equal level for untreated and heat treated beech.

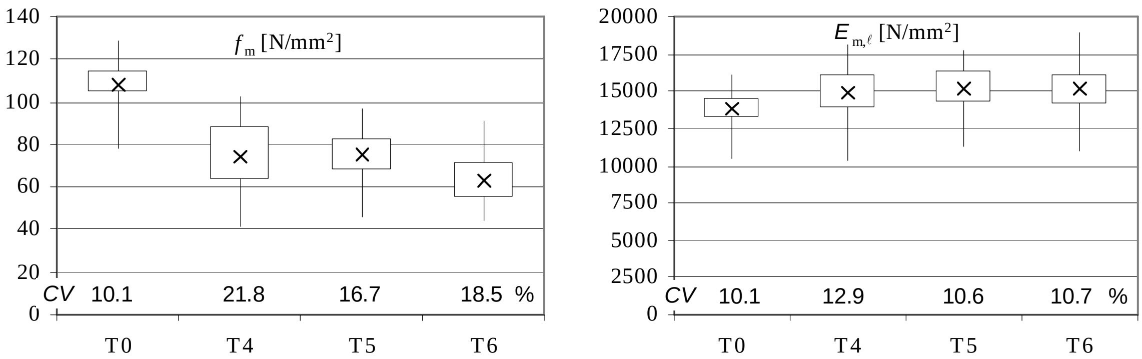

Figure 1: Boxplots including coefficients of variance CV for bending strength and local bending MOE of boards with different heat treatments.

Figure 2 gives an overview of the results for the series designed to investigate the relation between the behaviour of bending and tension loading of TMTB-boards. In particular series 2 (S2) allows a good comparison as bending and tension specimens were taken from one and the same board. After that, the mean tension strength parallel to grain $f_{t,o}$ is about 45% of the mean bending strength f_m and at the minimum level $f_{t,o}$ reaches only 35% of f_m .

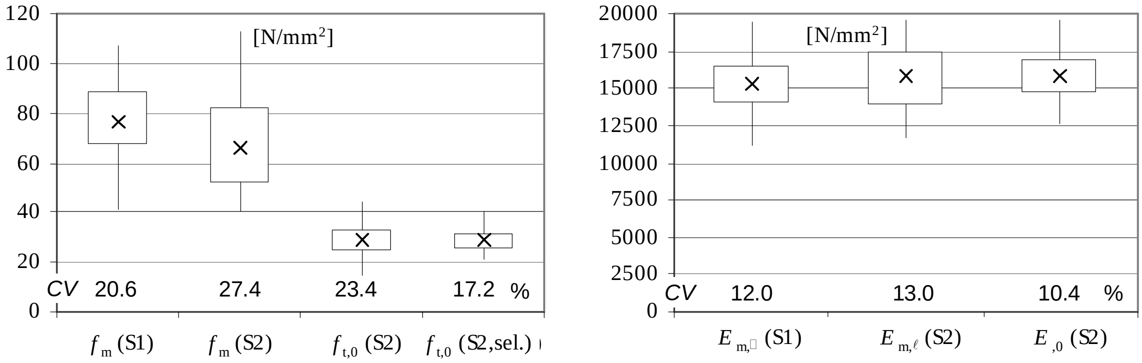

Figure 2: Boxplots including coefficients of variance CV for bending- and tension strength parallel to grain as well as local bending- and tension parallel to grain MOE of boards with treatment "Buche forte".

As expected, there is no significant difference between bending and tension MOE. The respective data for series 2 correlated well (R^2 = 0.64).

If the tension strength of the specimen that failed completely or partly in the gripping device of the testing machine (40% of the specimens) are sorted out, the tension strength of the remaining specimens (S2,sel) is 50% of the respective bending strength. With this $f_{t,o}$ in any case does not reach 60% of f_m which is given in EN 338 for the respective relation on a characteristic level.

Correlations in regards to machine grading

The obtained strength and stiffness values were correlated to measurements taken in advance to the tests. With this it should be assessed if these data could be taken into account for machine grading of TMTB. The strength values were correlated to respective MOE's and densities as well as to combinations of both (dynamic MOE's). It can be shown that the local bending MOE $E_{m,g}$ correlates well with both dynamic MOE's E_{dyn1} and E_{dyn2} and thus can be predicted with these measurements. The coefficient of determination R^2 within the single series varies between 0.56 and 0.81 with the Grindosonic (E_{dyn2}) measurements prediction being slightly better than the Sylvatest measurements (E_{dyn1}). Prediction of the bending strength on base of MOE however doesn't work well in all cases, with R^2 varying between 0.03 and 0.49. Tension strength and tension MOE within "S2,sel" correlated with an $R^2 = 0.41$.

CONCLUSIONS

The mean bending strength of defect free boards of TMTB is 30% to 40% lower, mean bending MOE of TMTB is 8% to 10% higher compared to untreated beech.
The mean and minimum tension strengths of TMTB boards are 45% to 50% lower than the respective bending strength but tension and bending MOE's are at a same level.
Strength values of TMTB-boards vary significantly stronger compared to untreated reference boards.
Dynamic MOE based prediction of MOE works well for TMTB but a prediction of strength values is limited.

ACKNOWLEDGEMENTS

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