Bending and tension strength of finger-jointed boards made of thermally treated beech

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ABSTRACT

This paper describes tests on finger-jointed boards made out of thermally treated hardwood (beech, *Fagus sylvatica*) (TMTB). The finger-jointed boards were tested as a part of an extensive investigation within the EC-FP6 funded project *Holiwood*. The aim of this project is the holistic implementation of European thermally treated hardwood (TMT) in the sector of construction industry and noise protection by sustainable, knowledge-based and value added products. As the dimensions of the structural members to be used in the targeted products exceed the maximum possible dimensions for solid wood TMTB-samples, glued products like glulam will have to be used. For the production of TMTB-glulam finger-jointed boards have to be provided. However, preliminary tests on industrially produced TMTB finger-jointed boards showed bending strengths with minimum values being as low as only 6N/mm^2. Therefore a more detailed analysis was necessary including the study of options for an improvement of the strength level. Thus, two different geometries of fingers glued with a PRF adhesive were selected. The boards were made out of TMTB "Buche forte" from Mitteramskogler GmbH and untreated beech timber as reference. The joints were produced manually. Three different strength tests were executed for each timber-joint combination: flat- and edgewise bending as well as tension loading. While the specimens made out of untreated beech generally failed within the finger-joint area, the TMTB samples showed higher variation in the failure mode with higher amounts of considerable wood failure. Compared to the untreated beech the bending and tension strength of TMTB joints was significantly lower with higher variation of the respective failure loads. However, the observed minimum bending strengths being 25N/mm^2 to 40N/mm^2 depending on joint geometry and loading direction exceeded the respective minimum values of the preliminary tests by far. With these results a first outlook on the potential and limits of finger-jointed TMTB can be made.

INTRODUCTION

In the past 5 years products made out of thermally treated timber are being increasingly used for a wide field of applications. For outdoor use its improved durability and dimensional stability upgrades TMT as a potential substitute for tropical hardwoods or impregnated softwoods. For indoor use as furniture or flooring TMT is becoming a competitor to dark coloured tropical hardwoods due to the wide range of possible colours resulting from the thermal treatment.

Within the EC-funded FP6 project *Holiwood* it is intended to widen the field of uses for TMT made out of European hardwoods to structural applications. Load bearing structures for industrial buildings with a variable indoor climate and structures for noise barrier elements along highways are in the focus of that project.

The heat treatment process limits the possible dimensions and cross sections of solid timber members. Therefore it is required to use glued products within the structures like it is the case in many normal timber constructions. The heat treatment process at Mitteramskogler is limited to thicknesses of about 60mm. However, square-cut timber members made of TMTB with these thicknesses showed considerable deformations like bow and twist which finally lead to reduced usable maximum thicknesses of about 45mm as a result of the required planing. As a consequence glulam instead of solid timber has to be used already for relative small dimension (cross-sections) timber members.

For the development of glued structural products made out of TMTB the production and testing of finger-jointed boards is the first step. However, some preliminary series of finger-jointed TMTB boards produced according to standard conditions showed partly very low minimum bending strengths (6N/mm^2), thus the assessment of suitable finger geometries, adhesive(s) and procedures for the production of improved finger-joints in TMTB was necessary. Therefore a test program was set-up which covered a limited number of the above mentioned parameters.

In the following the results of bending and tension tests on finger-jointed TMTB boards and untreated beech boards are presented as an example of the still ongoing test program designed to determine the structural potential of finger-joints in heat treated timber.

EXPERIMENTAL METHODS

Material

All tests were performed with finger-jointed boards made out of TMTB and untreated beech as reference. As cross-sections boards with 30mm depth *h* and 120mm width *b* were selected. The boards were free of major defects like knots, shakes and bark pockets and did not 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 to the reported dimensions.

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 our test series TMTB which is marketed under the brand name "Buche forte" was used. Detailed data for the respective treatment are not published, however the used combination of temperature and treatment time is selected in such a way that durability class 1 can be guaranteed according to the manufacturer’s experience.

For the production of the fingers two different cutter heads were selected, resulting in finger geometries of 20mm x 6.2mm (Series 1, "FJ1") and 15mm x 3.8mm (Series 2, "FJ2"). The boards were cut in two pieces, the fingers cut and the same pieces rejoined and glued. All joints were produced manually using the PRF adhesive Dynea Prefere 4099 and hardener Prefere 5827. The bonding pressure was applied by c-clamps.

Before testing the finger-jointed boards were stored in standard climate (20°C/65% r.h.) and the tests were executed 6 to 8 weeks after production of the joints. Moisture content and density were determined immediately after testing. An overview of the test material is given in table 1.

Table 1: Test series

		Flatwise		Edgewise		Tension	
	Series	**FJ1**	**FJ2**	**FJ1**	**FJ2**	**FJ1**	**FJ2**
n []	TMTB	18	18	16	16	10	12
	Beech	16	18	15	16	12	14
ρ [kg/m^3]	TMTB	610 - 750	590 - 785	600 - 730	610 - 790	650 - 715	675 - 760
	Beech	640 - 800	635 - 810	645 - 790	650 - 830	685 - 815	675 - 795
u [%]	TMTB	5.4 - 7.4	5.3 - 6.0	5.1 - 7.4	5.3 - 6.2	5.5 - 6.9	5.1 - 6.3
	Beech	10.1 - 12.2	9.7 - 11.7	10.6 - 12.3	9.9 - 12.1	11.1 - 12.5	9.7 - 11.5

Procedures

The finger-jointed boards were tested in bending (flatwise and edgewise) and in tension with the actual tests setups (Fig. 1.) The tests were performed in accordance with EN 408. The span for flatwise bending was 18 times the depth *h* and for edgewise bending 15 times the depth *h*.

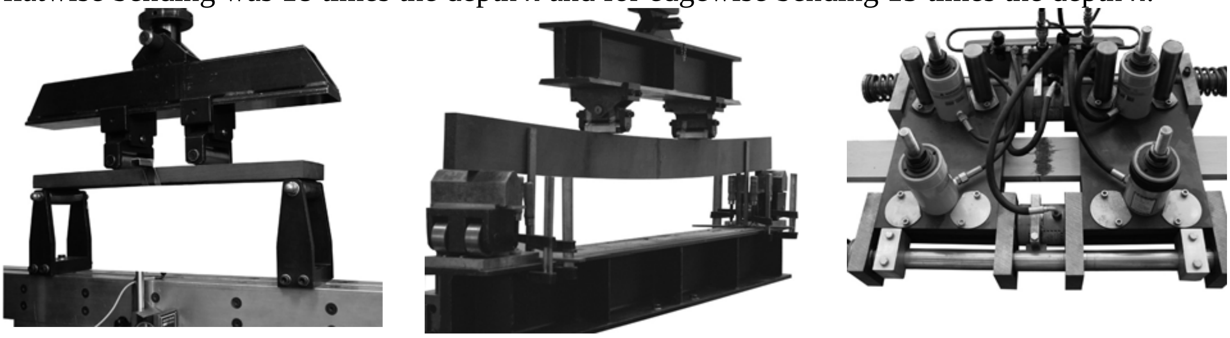

Figure 1: Testing methods with from left to right flatwise bending, edgewise bending and tension

The loading rate was set to achieve a time to failure of 5 minutes, which is a standard loading rate. However, the effective time to failure varied considerably in consequence of the variance of the strength of the TMTB specimens. Deformations were not recorded.
After testing the failure mode(s) were determined visually.

RESULTS AND DISCUSSION

Within all test series the reference beech specimens failed in the adhesive layer or at the wood-adhesive interface of the fingers. As wood fibres could only be observed on less than 40% of the glued finger surface, adhesive failure was determined as the dominant failure mode. In contrary the TMTB samples failed predominantly in the wood (Fig. 2).

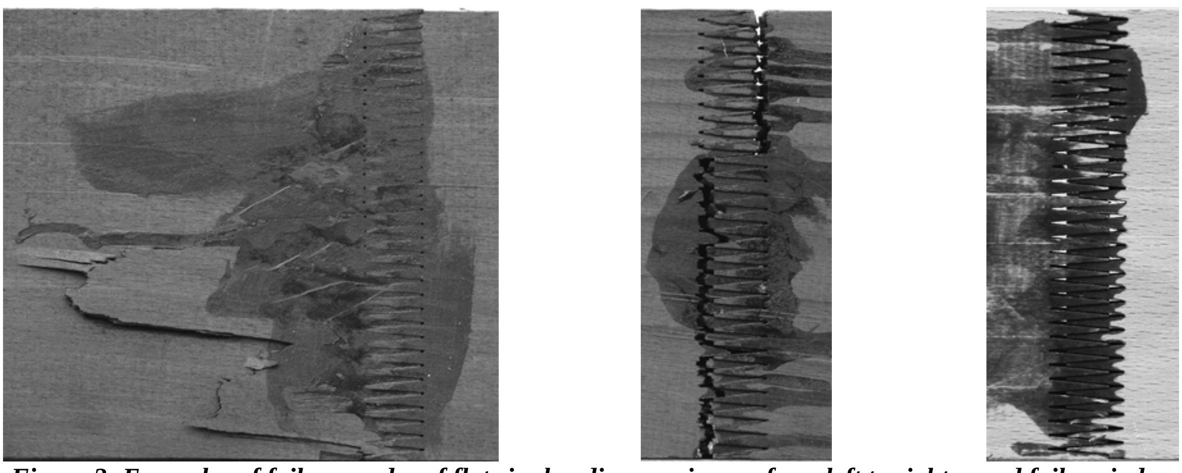

Figure 2: Examples of failure modes of flatwise bending specimens, from left to right: wood failure independent of joint (TMTB), wood failure at base of fingers (TMTB) and adhesive failure (beech)

Failure at the base of the fingers could be observed as well as wood failure that appeared to be independent of the presence of the joint. This was in particular the case for the tension specimens where only 20% of the specimens failed predominantly in the adhesive layer of the joint.

An overview of the test results is shown in Fig. 3. It can be seen that for every combination of wood and finger geometry the strength ranking (from high strength to low strength) flatwise bending – edgewise bending – tension is the same, however with big differences of the respective strength ratios (see further down). The TMTB tension specimens which didn't fail in the wood but in the joint showed (high) tension strengths in the range of the untreated beech specimens. About 50% of the tension specimens TMTB FJ2 failed inside the clamps of the tensile testing machine under low failure loads. Tension tests of TMTB boards without finger-joints showed similar results (not reported in this paper). It is assumed that this behaviour of the TMTB is related to its apparent weakness to support multi-axial stress states and/or local stress concentrations. Therefore it is questionable if the tension tests of TMTB finger-jointed boards deliver reliable and exploitable results for the assessment of the load bearing capacity of the joints. Upcoming tests of glulam beams are expected to show correlations between lamella strength, finger-joint strength and the global strength properties of the beams.

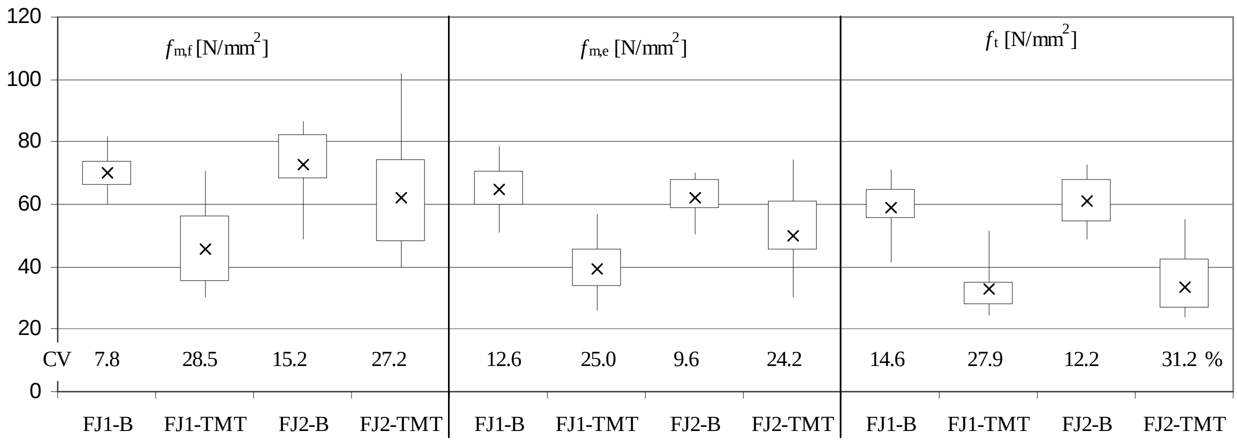

Figure 3: Boxplots of flatwise bending strength $f_{m,f}$, edgewise bending strength $f_{m,e}$ and tension strength f_t together with coefficient of variance CV. "X" within the boxes represent the mean value, medians are not displayed.

Both, bending and tension strength of the TMTB specimens varied considerably compared to the untreated beech specimens. This was also observed for other strength parameters of TMTB which were determined up to now within the *Holiwood* project (not shown here). At the mean level the strength ratio of heat treated /untreated beech specimens was between 0.55 (tension, FJ2) and 0.86 (flatwise bending, FJ2).

For analysing the bending and tension strength the characteristic (5-percentile) values were taken as base. This allows a good estimation of the potential of the finger-jointed boards for structural purposes. Characteristic values were determined in accordance with EN 14358 and compared with respective values determined according to EN 14080. The results vary slightly as both standards use different confidence levels (EN 14080: 84.1%, EN 14358: 75%). For strength values which vary as strongly as the TMTB strengths in our tests the procedure following EN 14358 delivers higher characteristic values than EN 14080, whereas for the untreated beech specimens with significantly lower strength variations it is vice versa. For our data the difference was observed to be up to 10%.

In Table 2 a compilation of the characteristic strength values is shown. It has to be kept in mind that the number of specimens per series is small and with this the determination of the characteristic values is influenced strongly by the application of the relevant factors according to EN 14358. In combination with the high variances of the TMTB strength values this leads to characteristic strengths that are considerably lower than the observed minimum values (compare Fig. 3 with values in Table 2). As a result of the significantly smaller variances the characteristic strength values of the untreated beech series were at the level of the minimum values.

The comparison of flatwise bending strength and tension strength of the untreated beech specimens with values from literature (Beech KA, Blass *et al*. 2005) indicates that the strength performance of our joints was at a similar level und thus the (manual) quality of the production of our finger-joints was judged as being suitable. In particular the strengths of the Beech KA and Beech FJ2 (both having similar finger geometries) as well as the respective flatwise bending/tension strength ratio were at the same level.

Table 2: Characteristic strength values **[N/mm^2]**

	Flatwise bending	Edgewise bending	Tension	Ratio Flatwise/Tension	Ratio Flatwise/Edgewise
TMTB FJ1	25.2	23.1	18.3	1.38	1.09
TMTB FJ2	34.3	30.5	17.3	1.98	1.13
Beech FJ1	59.7	49.4	41.7	1.43	1.21
Beech FJ2	51.1	50.4	45.6	1.12	1.01
Beech KA	55.4		39.7	1.40	
EN 385					1.25

The performance of the TMTB samples was not very good. In particular the bending strength of the joints with the 20mm fingers (FJ1) and the tension strength of both TMTB samples is not sufficient to meet the requirements for the lowest strength class (GL24) according to EN 1194. However, based on the bending tests, finger joints TMTB FJ2 could be classified as being suitable for the production of GL24. The tension and bending strength of the untreated beech samples permit the production of high strength GL36. The TMTB specimens FJ2 performed better under bending than FJ1 but showed lower tension strength. On base of these results it is difficult to determine the influence of the finger geometry on the observed strength.

For a better statistical confidence tests including more samples with larger numbers of specimens per sample have to be performed. This might possibly also help in obtaining higher characteristic strength values. As already mentioned before, a better evaluation of the strength properties of finger-joints in TMTB boards will also require tests for the determination of the global strength of TMTB glulam members made out of finger-jointed boards. If these tests deliver results which allow a classification of TMTB glulam into at least strength class GL24, further steps like the industrialization of the production of the TMTB finger-joints can be initiated. In our tests we used a phenol-resorcinol formaldehyde adhesive which is known to produce reliable and moisture resistant wood bonds. The performance of other adhesive systems like melamine-urea formaldehyde (MUF) and polyurethane (PUR), known for their good behaviour in finger-joints should be studied for application in TMTB in upcoming tests.

CONCLUSIONS

- The minimum flatwise bending strength of TMTB samples could be improved significantly compared to strengths observed in earlier tests.

- Results of the untreated specimens showed that the applied finger-jointing was of a good quality, as the strength values are comparable with values from literature.
- Untreated specimens failed in the joint itself with adhesive failure being dominant, while TMT specimens failed predominantly in the wood independent of the test type. Therefore the strength of TMTB finger-jointed boards depends strongly on the strength of the heat treated wood.
- Finger-joint type 2 performed better than type 1 in edgewise and flatwise bending, however no difference could be observed in tension strength. Thus the validation of the optimal finger geometry is not clear.
- Characteristic flatwise bending strength of the TMTB samples was between 9% and 13% higher than characteristic edgwise bending strength (EN 385: 25%).
- High coefficients of variance in combination with small numbers of specimens within each sample lead to low characteristic strength values of the TMTB samples.
- While the observed strengths of the untreated beech specimens permit to use the respective finger jointed boards for the production of high strength GL36, TMTB finger-jointed boards with finger geometry 15mm x 3.8mm might be used for the production of GL24 on base of the observed bending strength. If this strength class can be finally assigned is however questionable and has to be verified by further test.

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