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THERMALLY MODIFIED BEECHWOOD AS A STRUCTURAL MATERIAL: ALLOCATION TO EUROPEAN STRENGTH-CLASSES AND RELEVANT GRADING PROCEDURES

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ABSTRACT: In this paper the evaluation of strength and stiffness properties of thermally modified beech (*fagus sylvatica*) structural timber (TMTB) is described. Bending, tension parallel to grain and compression parallel and perpendicular to grain properties were determined. The parameters were linked to the European strength class system for structural timber. It turned out, that the used strong thermal treatment of the beech wood reduced most of its strength parameters significantly but didn't have a big effect on its stiffness. The brittle behaviour and big variations in strength turned out to be the main downside of TMTB. On base of test results the possibilities and limits for relevant grading and factory production control of TMTB are shown and discussed.

KEYWORDS: Structural timber, Thermally modified beech, Stiffness, Strength, Grading

1 INTRODUCTION

In recent years products made of thermally modified timber (TMT) are being used increasingly in a wide field of application. For outdoor use 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 being competitive to naturally dark coloured tropical hardwoods.

The EC-funded FP6 project Holiwood aimed at widening the field of application for TMT made of European hardwoods – here in particular beech (*fagus sylvatica*) - to structural applications in an outdoor environment, e.g. for noise barrier elements.

It is known that a downside of TMT is its reduced strength compared to untreated timber [1]. For a given thermal treatment hardwoods show even higher strength losses than softwoods. Therefore an extensive test program had been set up to determine the strength and stiffness parameters of thermally modified beech timber (TMTB) and to assess its suitability for structural applications.

In order to be used for structural purposes TMTB has to be strength graded and assigned to a strength class, e.g. according to EN 338 [2]. Following the procedures of EN 384 [3] it is possible to determine only bending strength and stiffness as well as density by testing in order to assign a batch of timber to an EN 338 strength class. All other strength and stiffness values can be calculated on base of the data that were obtained by tests and the application of conversion equations given in EN 384. Because preliminary tests indicated that the relation between several strength/stiffness parameters could differ significantly from respective specifications given in EN 384, the tests had to cover all parameters that are needed to assign TMTB to strength classes according to EN 338.

In the following bending-, tension- and compression tests on TMTB specimens are presented. Additionally selected data are chosen and analyzed in such a way that the feasibility of a machine grading for this material can be judged.

2 MATERIAL AND METHODS

2.1 RAW MATERIAL

The beech wood was taken from three different stands in Austria. It was bought appearance graded and not strength graded. The visual strength grading took place with the already heat treated specimens before testing.

All specimens met the requirements for (visual) strength class LS13 according to the German standard DIN 4074-5 [4] which would permit an assignment of the untreated timber to strength class D35 according to EN 1912 [5]. The specimens were free of major defects like big knots and also did not show significant twist or bow deformations. However, cup deformations existed in almost all beams and boards but did not exceed the limit of 2% for strength class LS13. Slope of grain is difficult to determine on beech and thus was disregarded as

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grading criteria which is in line with the requirements according to DIN 4074-5. The effective quality of the untreated timber in particular regarding knots implies a much greater potential for these wood samples than strength class D35.

2.2 THERMAL MODIFICATION

The specimens were thermally treated by Mitteramskogler GmbH in Gaflenz, Austria. This company uses the THA thermal treatment process [6] where the respective modification 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. For all tests TMTB with the brand "Buche forte" was used [6]. This thermal treatment has to be considered as being an intensive modification. Detailed data for the respective treatment are confidential and thus not published. The used combination of modification temperature and time is selected in such a way that durability class 3 can be reached according to preliminary tests. Mitteramskogler also offers beech wood that underwent a stronger thermal modification under the brand "Buche forte exterior" and guaranties durability class 1 [6]. However this strongly modified wood was assumed to behave too brittle in order to be used as a structural material.

2.3 SPECIMENS

There were $n = 100$ square-cut TMTB specimens and $n = 40$ boards per sample available for testing. The nominal specimen dimensions were $\ell \cdot b \cdot h = 3000 \cdot 50 \cdot 180\ \mathrm{mm}^3$ for the beams and $\ell \cdot b \cdot h = 2800 \cdot 150 \cdot 35\ \mathrm{mm}^3$ for the boards. Width and depth varied slightly from specimen to specimen which resulted from drying and thermal treatment processes. The specimens for bending and compression tests were cut from the same square-cut timber. As cross-sections for the bending tests square-cut timbers with a length of 2565 mm, a depth of 135 mm and a nominal width of 50 mm were selected. All specimens were planed in thickness.

For the compression tests perpendicular to grain the dimensions of the specimens were taken as given in EN 408 [7] with $\ell \cdot b \cdot h = 70 \cdot 45 \cdot 90\ \mathrm{mm}^3$ and the size of the specimens for the compression tests parallel to grain was: $\ell \cdot b \cdot h = 180 \cdot 30 \cdot 30\ \mathrm{mm}^3$ which in fact results in tests with small clear specimens.

For the tension tests boards with a $\ell \cdot b \cdot h = 2200 \cdot 150 \cdot 35\ \mathrm{mm}^3$ were used, the reminder of the boards of one series was used for bending tests in order to compare bending- and tension behaviour directly.

A small sample of $n = 14$ specimens of untreated beech was used as a reference for the bending and compression parameters of the modified wood.

2.4 MOISTURE CONTENT

Apart from the bending specimens all other specimens were conditioned in standard climate and the effective moisture content was determined by the oven-dry method (EN 13183-1) [8], see Table 1. Under identical climatic conditions TMTB shows significantly lower moisture content than untreated beech. At standard climate (20°C, 65%r.h.) the moisture content varied between around 5% and 6.5% compared to around 12% expected for untreated beech. Therefore the effect of moisture content on strength and stiffness parameters within service-classes 1 to 3 according to EC 5 [9] can be assumed to be less pronounced than for untreated wood. This was be verified on base of tests with small clear specimens. In consequence the tested strength and stiffness values were not adapted to a reference moisture content.

Table 1: *Overview of the three TMTB samples and the untreated beach samples. Moisture content and density were determined on the bending specimens.*

Series	Treatment	Density ρ [kg/m^3]	Moisture content u [%]
TMT1	forte	500 - 670	4.6-6.5
TMT2	forte	530 - 800	5.2-6.2
TMT3	forte	570 - 760	4.6-6.3
Beech2	untreated	670 - 820	11.9 – 13.7

2.5 EXPERIMENTAL PROCEDURES

The characteristic density was determined from the mass of the entire bending specimens divided by their volume prior to testing.

Figure 1: *Determination of the longitudinal ultrasonic wave speed with the help of a "Sylvatest" device.*

Before the bending tests were executed, the dynamic MOE E_{dyn} was determined in order to verify the possibilities for future machine grading of TMTB. The ultrasonic device "Sylvatest" was used to measure the longitudinal wave speed v within each specimen. Together with the density ρ measured at the same time it was possible to determine E_{dyn} using the equation: $E_{\mathrm{dyn}} = \rho \cdot v^2$ [10].

The bending, tension and compression tests were executed according to EN 408. The characteristic strength and stiffness parameters were calculated according to EN 384.

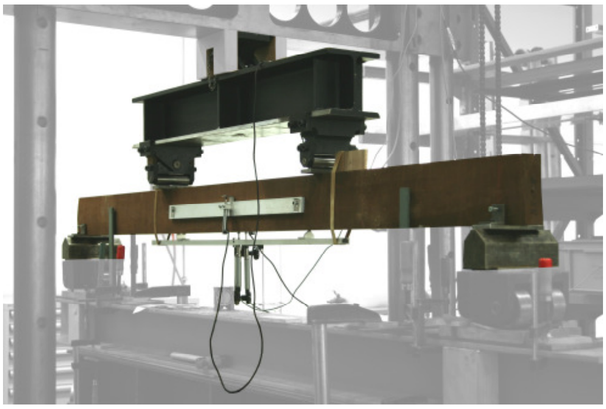

Figure 2: *4-point bending tests of TMTB beams according to EN 408 in order to determine the local MOE, global MOE and bending strength.*

The bending tests were executed as 4-point bending tests. The bending strength was determined on base of the maximum force using standard procedures. The MOE in bending was determined on the base of the measured total beam deflection as a global bending MOE $E_{m,g}$ and additionally on base of the measured beam deflection in between the two loading points as this is shown in Figure 3.

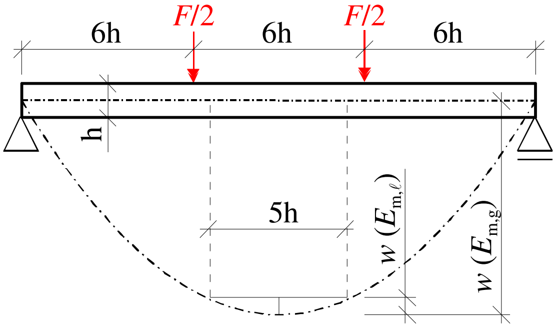

Figure 3: *Principle of the measurement of the local bending MOE* $E_{m,l}$ *and global bending MOE* $E_{m,g}$ *according to EN 408.*

The tension tests were executed in a tension testing device as shown in Figure 4. The boards were clamped on a length of 320 mm on either side and the free length of the boards between the clamping yaws was 1580 mm.

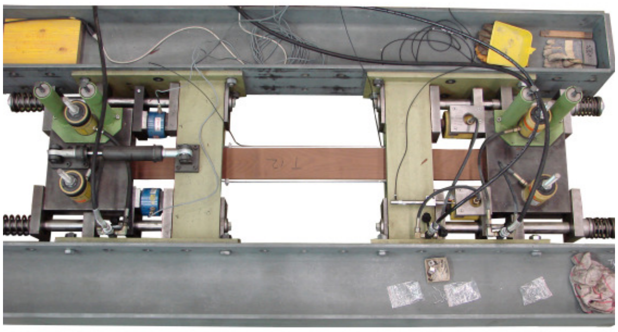

Figure 4: *Set-up of tension tests.*

Within the preliminary series also the tension MOE was determined on base of a measuring length of 750 mm. For this purpose LVDT's were fixed on both sides of the boards. For the same series bending MOE and bending strength were assessed by standard 4-point bending tests on additional sections of the same boards. This allowed a good direct comparison of bending and tension behaviour of TMTB.

3 RESULTS AND DISCUSSION

For an easy comparison, most of the results are displayed as boxplots and include the data as shown in Figure 5.

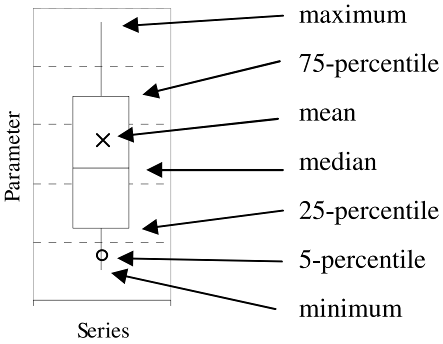

Figure 5: *Display of results*

The percentiles given in the graphs were calculated using the method provided by the NIST [11] and as used in MS-Excel. In contrary to that the 5-percentile values for the calculation of characteristic values were determined by ranking and interpolation if required according to EN 384.

3.1 DENSITY

The boxplots shown in Figure 6 represent the density of the beams that were used for the bending tests. The decrease in density due to the "forte" heat treatment can be estimated on base of the samples TMTB2 and Beech 2 and added up to about 12% at the mean level.

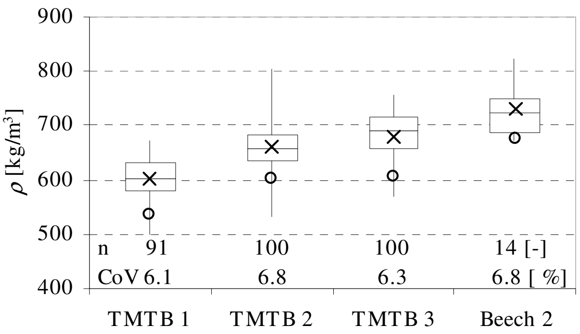

Figure 6: *Density of three TMTB samples and one untreated beech sample. The mean moisture content of the TMTB samples varied between 5.5% and 6.5%, in the untreated beach sample the mean moisture added up to 13.2%.*

For the determination of the characteristic density no adjustments for moisture content and size were made. The characteristic density was calculated to be $\rho_k = 580$ kg/m^3. This allows a classification of TMTB into strength class D35 whereas the obtained mean density of 650 kg/m^3 only refers to strength class D30.

3.2 BENDING STRENGTH

The TMTB square-cut beams showed a brittle failure mode. A lot of the specimens failed almost explosively accompanied by the development of a small wood dust cloud and several small sized timber particles emitting from the beam. Different failure patterns could be observed, some typical are shown in Figure 7. The ten specimens per sample that showed the lowest bending strength were analysed visually in order to obtain information about possible reasons for the low strength values. General or local significantly increased angles of grain at the failure area could be observed on several of these specimens, however no visual indicators for the low strength of other beams could be found.

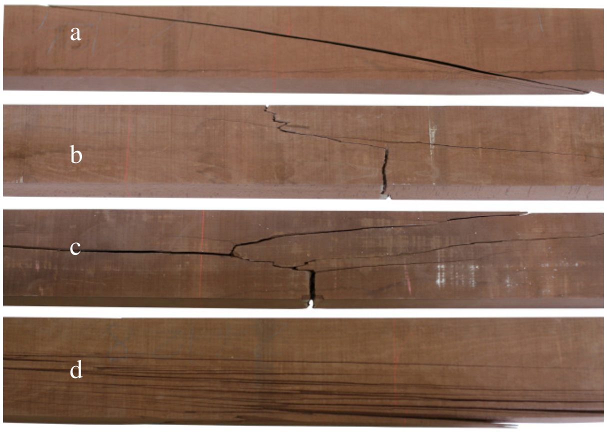

Figure 7: *Typical fracture patterns of the bending specimens, with a: failure due to increased slope of grain, b: failure in tension zone without secondary shear failure, c: failure in tension zone with secondary shear failure and d: failure in tension zone with a big number of cracks. If compared to the upper three fracture patterns specimens with a fracture pattern d reached the highest bending strength.*

The mean bending strength of TMTB with the mentioned heat treatment reaches only about 65% of the mean bending strength of untreated beech (Figure 8). It has to be kept in mind that the shown reference sample consisted of only 14 tested specimens. However preliminary tests with small sized defect free specimens showed a similar drop in mean bending strength. Decisive for structural applications are 5-percentile values and at this level the drop exceeding 50% is even much more pronounced. This goes in line with much higher strength variations within the treated samples compared to the untreated sample which is indicated by the comparably high CoV's.

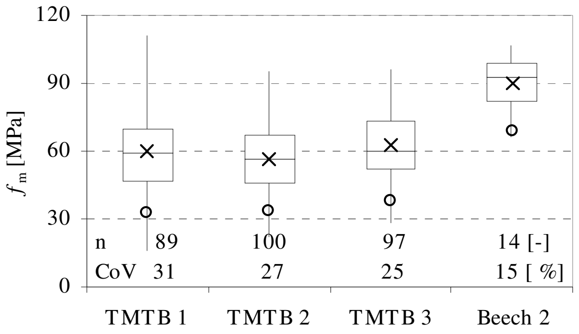

Figure 8: *Bending strength f_m of three TMTB samples and one untreated beech sample.*

Following the identification of the 5-percentile bending strength of each sample with the application of the relevant factors k_h and k_l (EN 384) the overall characteristic bending strength was determined under the consideration of k_s and k_v factors (EN 384) to be: $f_{m,k} = 30.9$MPa. This bending strength refers to strength class D30 according to EN 338. It has to be remarked, that within the sample 1 the minimum observed bending strength added up to only 16.2 MPa.

3.3 BENDING STIFFNESS

The bending MOE was determined as global MOE $E_{m,g}$ and as local MOE $E_{m,l}$ according to EN 408 and as shown in Figure 3.

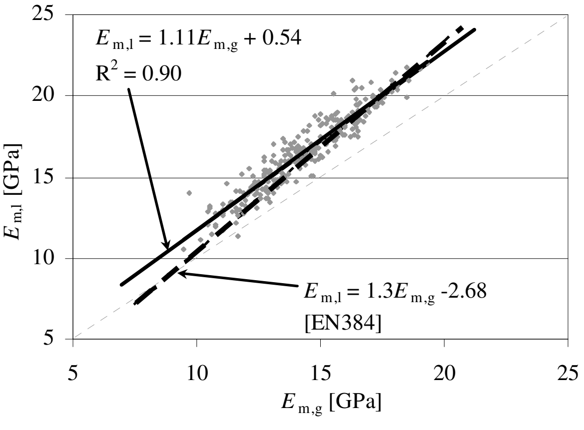

Figure 9: *Local bending MOE $E_{m,l}$ versus global bending MOE $E_{m,g}$ for all three TMTB samples*

Figure 10 displays the local MOE results. The stiffness of treated and untreated beech (sample 2) doesn't show a significant difference. In EN 384 the determination of the MOE parallel to grain E_0 is given as a function on base of a linear regression between $E_{m,g}$ and $E_{m,l}$ as follows: $E_0 = 1.3\ E_{m,g} - 2.68$ [GPa]. Our data fitted well ($R^2 = 0.90$) to a linear regression without offset: $E_{m,l} = 1.15\ E_{m,g}$ which indicates that the local MOE exceeds the global MOE by about 15%. This is in line with observations made for timber of several untreated species [12].

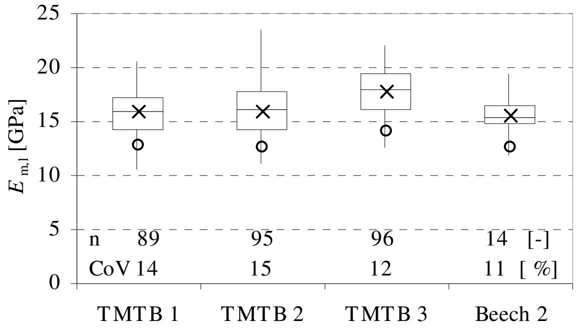

Figure 10: *Local bending MOE $E_{m,l}$ of three TMTB samples and one untreated beech sample*

The data analyse was made according to EN 384 but adapted in so far as additionally for comparison the measured $E_{m,l}$ was taken to determine $E_{0,mean}$.as follows:
On base of mean local MOE:
$E_{0,mean} = E_{m,l} = 16.6$ GPa
On base of mean global MOE (EN 384):
$E_{0,mean} = 1.3E_{m,g} - 2.86 = 16.0$ GPa
These MOE refer to strength class D50 according to EN 338. The 5-percentile value of the local MOE added up to $E_{0,05} = E_{m,l,05} = 13.2$ GPa which also fits TMTB into strength class D50.

3.4 COMPRESSION STRENGTH PARALLEL AND PERPENDICULAR TO GRAIN

In Figure 11 the results of the compression tests parallel to grain are shown. It can be observed, that the compression strength parallel to grain of the treated and untreated samples do not differ that importantly as they do for other strength properties, like e.g. the bending strength f_m that has been discussed further up.

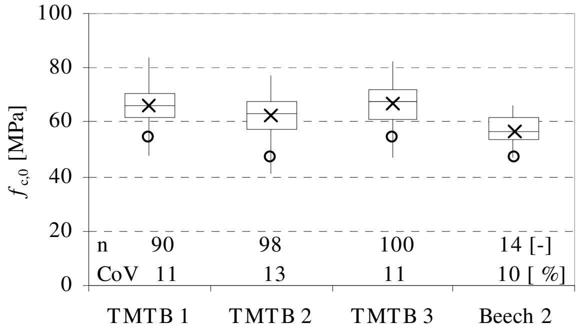

Figure 11: *Compression strength parallel to grain $f_{c,0}$ of three TMTB and one untreated beech sample.*

According to EN 384 the compression strength parallel to grain $f_{c,0}$ of softwood species can be determined on base of the characteristic bending strength. However, in EN 338 the same relation is used for hardwood species too. In consequence of the observed $f_{m,k} = 30.9$ MPa the characteristic compression strength parallel to grain should be:
$f_{c,0,k} = 5 \cdot (f_{m,k})^{0.45} = 5 \cdot 30.9^{0.45} = 23.4$ MPa

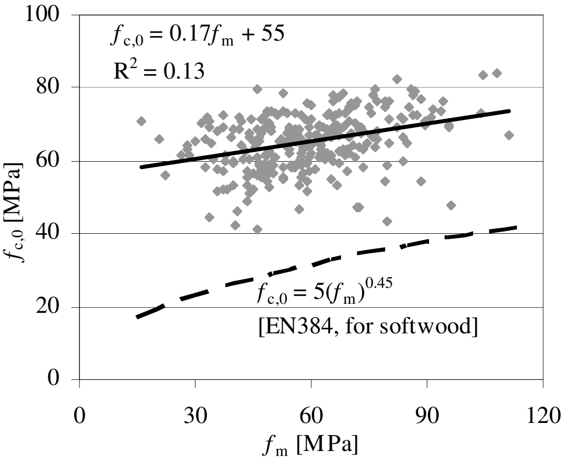

Figure 12: *Compression strength parallel to grain $f_{c,0}$ against bending strength f_m for all three TMTB samples.*

The observed compression strength parallel to grain of TMTB exceeded this by far (see Figure 11 and Figure 12). On base of the observed $f_{c,0,k} = 44.3$ MPa TMTB would fit into the highest strength class D70 ($f_{c,0,k} = 34$ MPa) according to EN 338. This high compression strength parallel to grain has to be attributed to the fact, that small clear specimens were used. The use of small clear specimens is permitted for hardwoods according to EN 384, however it is proposed not to use the high values achieved from the tests but to stick to the tabulated values in EN 338 for respective structural calculations.
The performance of TMTB regarding compression perpendicular to grain differed strongly from its good performance in compression parallel to grain. In Figure 13 it can be seen that at the mean level the compression strength perpendicular to grain of the modified samples drops to about 80% of the strength of the (small) untreated sample. The drop in strength at the 5% level however is much more pronounced

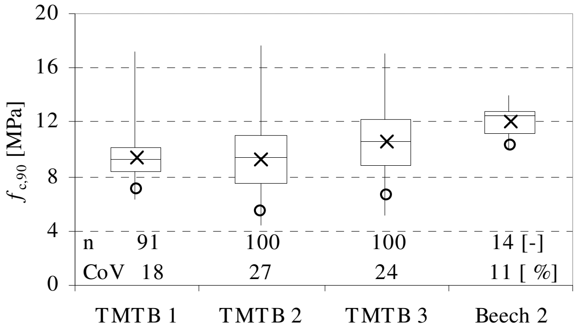

Figure 13: *Compression strength perpendicular to grain $f_{c,90}$ of three TMTB and one untreated beech sample.*

The calculated compression strength $f_{c,90,k} = 6.03$ MPa implies that TMTB cannot even be allocated to the lowest hardwood strength class D30 (EN 338: $f_{c,90,k} = 8.0$ MPa), but on the other hand exceeds the compression strength of the highest softwood strength class C50 (EN 338: $f_{c,90,k} = 3.2$ MPa) by more than 100%.

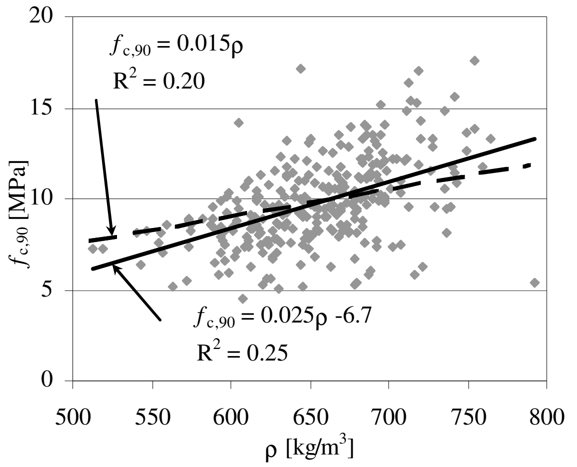

Figure 14: *Compression strength perpendicular to grain $f_{c,90}$ against bending strength f_m for all three TMTB samples.*

In general the linear regression (with intercept = 0) of the correlated compression strength perpendicular to grain and density corresponds well with the standard (EN 338: $f_{c,90,k} = 0.015\rho_k$) as can be seen in Figure 14. However, this represents the mean-level and if this calculation is done discretely at the 5-percentile level the characteristic compression strength perpendicular to the grain $f_{c,90,k}$ of TMTB would be overestimated:

$f_{c,90,k}/\rho_k = 6.03/580 = 0.010 < 0.015$.

Therefore at least this conversion given in EN 384 cannot be used for TMTB and therefore compression strength perpendicular to grain for TMTB has to be stated discretely.

3.5 TENSION STRENGTH PARALLEL TO GRAIN

The tension tests parallel to grain were executed with n = 42 boards each out of four series (TMT 1 to TMT 3 and a preliminary series). Each board of the preliminary series was split up into one tension and one bending specimen. This should enable a good comparison of the bending and tension behaviour of these boards.

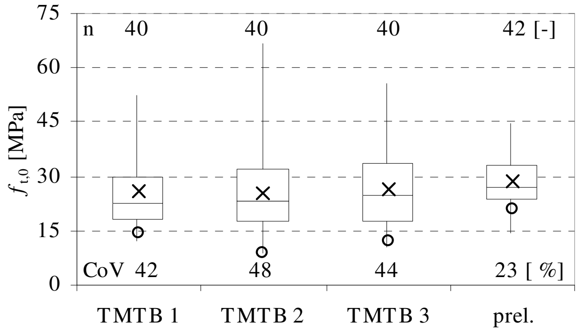

Figure 15: *Tension strength parallel to grain $f_{t,0}$ of three TMTB samples and a preliminary TMTB sample.*

More than 60% of all failures appeared partly or completely within the clamping jaws. This indicates that TMTB is sensible to multi-axial stresses. Additionally in series TMTB 2 and TMTB 3 about 50% of the specimens showed cracks in longitudinal directions as a consequence of applying the clamping pressure. As these cracks in most cases didn't run parallel to the board's axis, this resulted in a reduction of the effective cross section on one side of the board and with this in an unequal stress distribution. This led eventually to failure loads that were lower in comparison to what could have been expected for the same board under the assumption of a uniform stress distribution over the cross section.

The main reason for the development of cracks that appeared already in the clamping phase of the tests was the existing deformation (in particular cup deformations) of the boards due to the thermal treatment. These deformations were within the limits for strength class LS13 according to DIN 4074-5 (D35 according EN 1912/EN 338). On the other side these deformations proved to be too big to be compensated by clamping without initiating cracks.

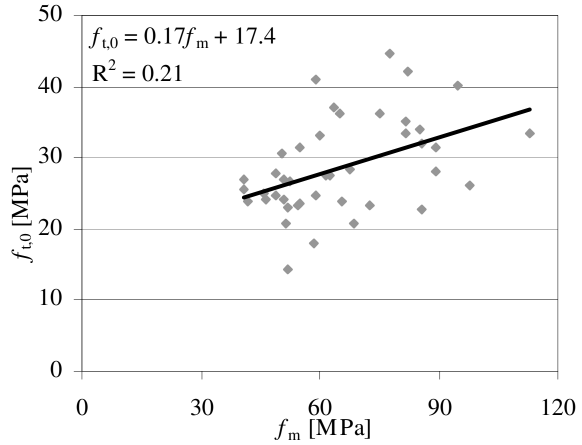

Figure 16: *Tension strength parallel to grain $f_{t,0}$ versus bending strength f_m of the preliminary series with n = 40.*

The characteristic tension strength parallel to grain $f_{t,0,k}$ was calculated on base of the data of all 4 series and with the application of the relevant factors k_s and k_v according to EN 384 and was found to be 10.4 N/mm².

This characteristic tension strength parallel to grain has to be regarded as being very low. According to EN 384 the relation between tension and bending strength for softwoods is defined as $f_{t,0,k} = 0.6 \cdot f_{m,k}$ (EN 338 uses the same relation also for hardwoods) and thus could be expected to reach around 20 MPa on base of the above mentioned 30.9 MPa for the square cut timber.

On base of our data it can bee seen clearly, that the tension strength in relation to bending strength of TMTB is lower than for softwood according to EN 338/EN 384. Therefore it is not suggested to use the conversation rate of 0.6 for the determination of tension strength on base of a known bending strength of TMTB but to determine the tension strength discretely. It has to be remarked, that this low tension strength mainly has to be attributed to the presence of the longitudinal cracks that were mentioned further up. It can be expected, that planed boards experience higher tension strengths, as could also be shown with the preliminary boards series, where boards were used for testing that had significantly lower cup deformations. Further tests to confirm this assumption are on the way.

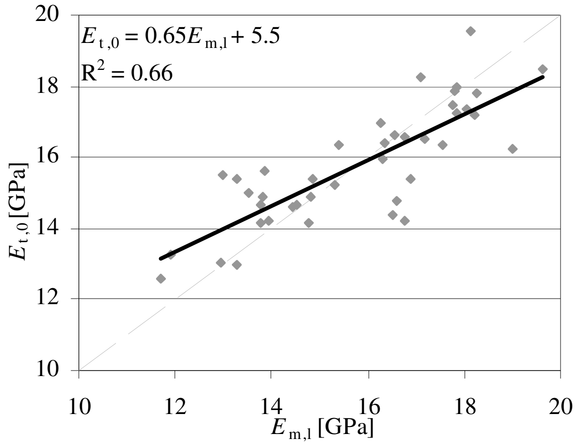

Figure 17: *MOE in tension parallel to grain $E_{t,0}$ versus local bending MOE $E_{m,l}$. of the preliminary series with n = 40.*

A comparison of the bending and tension properties within the preliminary series showed that tension and bending strength correlate only marginal (R^2 = 0.21, see Figure 16) for all boards and moderate (R^2 = 0.40) for the boards which did not fail within the clamps. The bending and tension MOE were at the same level and showed a good linear correlation (R^2 = 0.66, see Figure 17). The European standard EN 384 states that for a given strength class the characteristic tension strength can be taken as 60 percent of the characteristic bending strength. Based on a comparison of the 5-percentiles found in our tests it can be seen that with:
$f_{t,0,05} / f_{m,05,corr}$ = 18.1 / 29.7 = 0.61 the determination of the tension strength on base of the bending strength at the 5-percentile level can be confirmed for the boards within this series. For the comparison the bending strength $f_{m,05}$ of the preliminary series' boards was corrected to $f_{m,05,corr}$ with the application of the factor k_h according EN 384 in order to account for the reduced specimen depth in flatwise bending.

3.6 GRADING

As mentioned in the material section, the timber was graded visually. The timber was of a superior visual quality in particular regarding knots. However, the bending strength showed high variations and there was no clear evidence for the low strength values of certain specimens. Therefore the possibility of machine grading was evaluated. The bending strength was correlated to data that are often used for machine grading, like stiffness, density and ultrasonic speed of sound and combinations thereof (Table 2).

The measured static MOE's $E_{m,g}$ and $E_{m,l}$ can be well predicted by E_{dyn}. Compared to each other the two single parameters speed of sound v and density ρ that influence the dynamic MOE have a more or less similar importance for the prediction of the static MOE.

Table 2: *Matrix of coefficients of correlation R^2 of several possible parameters to grade TMTB*

R^2	ρ	v	E_{dyn}	$E_{m,g}$	$E_{m,l}$
v	0.07				
E_{dyn}	0.60	0.66			
$E_{m,g}$	0.60	0.52	0.88		
$E_{m,l}$	0.45	0.65	0.87	0.90	
f_m	0.06	0.23	0.22	0.25	0.27

None of the measured parameters allows a satisfying estimation of the bending strength f_m as it is indicated by the low coefficients of determination in the bottom line of the matrix in Table 2. Ultrasonic speed of sound, static and dynamic MOE correlate with bending strength on a similar low level compared to each other whereas density is found to have no influence on the bending strength of TMTB. As an example the graph in Figure 18 shows the dependence of bending strength f_m on the local bending MOE $E_{m,l}$. An important factor for the low linear correlations might be the good wood quality and in particular the absence of knots. As knots would have a strong influence on bending strength as well as on bending MOE it could be expected that the correlation would have been more pronounced under their presence. However it is likely that MOE and strength would come further down with knots. This was verified by results of preliminary tests. However, regarding the relatively low strength values of the tested samples it is questionable if TMTB with an even lower strength would be an interesting product on the market for structural timber.

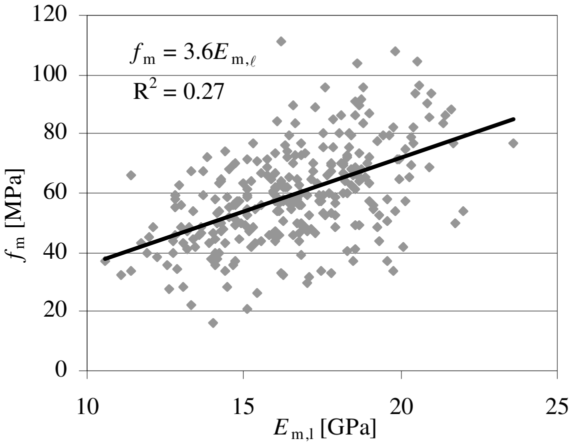

Figure 18: *Linear correlation of measured local MOE $E_{m,l}$ and bending strength f_m (n = 280) as an example for the difficulty to strength-grade TMTB*

Another aspect of timber quality and grading has to be addressed. The thermal treatment of the wood is one more important parameter that must be added to the existing visual and possible machine grading parameters. The great variations of the strength values might also be partly attributed to a more or less inhomogeneous treatment of the specimens within one batch. This however is difficult to verify and therefore it is proposed that grading has to be carried out twice: once before and once after the thermal modification process. It might be even required to apply proof-loading of TMTB members before a safe use in structures.

The quality of TMTB and its big variations in strength have several consequences. On the one hand the big variations of strength question if the known partial factors, e.g. γ_M for solid timber according to EC 5, can be applied unchanged for this material as well. On the other hand a raw material of a superior quality has to be used – and to be paid for– in order to achieve only average strength values. With the tested grading procedures it is not possible to distinguish between low and high strength TMTB which would have been a great contribution for an economical use of this material.

4 CONCLUSIONS

Several samples of TMTB have undergone standard tests in order to investigate their structural behaviour and to assign this timber to a strength class according to EN 338. From the tests executed so far it can be concluded that:

- The stiffness values of TMTB are similar to or slightly exceed those of untreated beech timber and thus could lead to a classification of TMTB into high strength classes, e.g. D50.
- With the exemption of compression parallel to grain the strength values of TMTB are lower than those of untreated beech timber and thus could lead to a classification of TMTB into low strength classes, e.g. D30.
- The conclusions mentioned above suggest not to assign TMTB to existing EN 338 strength classes but to state discrete properties for its structural use.
- The brittle behaviour of the material and the big variation of the test values is the main problem regarding its strength properties. Poor rigidity parallel to grain and great sensitivity to stress concentrations are likely to significantly limit the structural use of TMTB.
- Conversion factors to determine unknown strength and stiffness properties as given in EN 384 for solid wood cannot be used for TMTB.
- The TMTB tested up to now was of a high visual grade. It can be assumed that in particular the strength properties of TMTB of a lower visual grade (timber containing knots and other defects) might further decrease compared to the material tested so far.
- The prediction of the static MOE of TMTB by ultrasonic together with density measurements works well. However, the possibility of (bending) strength prediction is only limited.
- A strict quality management for the thermal modification process has to be installed in order to obtain a reliable quality of the structural TMTB products.

Overall it looks like the application of TMTB that underwent a strong thermal modification (like the one used for this study) as a structural material in an important quantity will be difficult to realize. Good stiffness properties (that are often decisive for the design of a timber structure) face relatively low strength properties which in addition vary strongly. The brittleness of the material and it's susceptibility to stress concentrations and multidimensional stresses are other important downsides that will come into play when it gets to the load-bearing behaviour of joints. Therefore it is suggested to use intensively treated TMTB only for low loaded structural members.

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REFERENCES

[1] Hill, C.A.S.: Wood Modification: chemical, thermal and other processes, Southern Gate, John Wiley & Sons, 2006.

[2] EN 338 (2003): Structural timber - Strength classes. CEN European Committee for Standardization.

[3] EN 384 (2004): Structural timber - Determination of characteristic values of mechanical properties and density. CEN European Committee for Standardization.

[4] DIN 4074-5 (2003): Strength grading of wood - Part 5: Sawn hard wood. DIN German Institute for Standardization.

[5] EN 1912+A2 (2008): Structural timber - Strength classes - Assignment of visual grades and species. CEN European Committee for Standardization.

[6] Mitteramskogler: Thermoholz Kurzinformation. www.mirako.at, 2009

[7] EN 408 (2003): Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties. CEN European Committee for Standardization.

[8] EN 13183-1 (2002): Moisture content of a piece of sawn timber - Part 1: Determination by oven dry method. CEN European Committee for Standardization.

[9] EN 1995-1-1 (2004): Eurocode 5 - Design of timber structures - Part 1-1: General - Common rules and rules for buildings. CEN European Committee for Standardization.

[10] Goens, E: The determination of the elasticity module of rods with the help of bending fluctuation. Annalen der Physik 11 (6): 649 – 678, 1931.

[11] National Institute of Standards and Technology NIST: Percentile, Engineering Statistics Handbook. www.itl.nist.gov/div898/handbook/prc/section2/prc252.htm, 2010

[12] Ravenshorst G.J.P, van de Kuilen, J.W.G., Relationship between local, global and dynamic modulus of elasticity for Soft- and hardwoods, *Proceedings of the Meeting 42*, CIB-W18, paper 42-10-1, Duebendorf, Switzerland, 2009