Tensile Strength and Stiffness of Low Quality Beech (Fagus Sylvatica) Sawn Timber

Westermayr, Maximilian; Stapel, Peter; Van De Kuilen, J. W.

Publication date
2018

Document Version
Final published version

Published in
WCTE 2018 - World Conference on Timber Engineering

Citation (APA)
Westermayr, M., Stapel, P., & Van De Kuilen, J. W. (2018). Tensile Strength and Stiffness of Low Quality Beech (Fagus Sylvatica) Sawn Timber. In *WCTE 2018 - World Conference on Timber Engineering* World Conference on Timber Engineering (WCTE).

WCTE 2018
2018 World Conference on Timber Engineering
August 20 - 23, 2018 | Seoul, Republic of Korea

Tensile strength and stiffness of low quality beech (*Fagus sylvatica*) sawn timber

Maximilian Westermayr[1], Peter Stapel[1], Jan Willem van de Kuilen[1,2]

ABSTRACT: This paper investigates the tensile strength and stiffness of low quality beech sawn timber. In addition, the influences of visual and physical characteristics of the beech boards on the mechanical performance were analysed. Visual characteristics like knots, pith or fibre deviation as well as density and dynamic modulus of elasticity were examined regarding their influence on the tensile strength and stiffness of the beech boards. The subsequent destructive testing was performed according to EN 408on 214 beech boards with two different cross sections. Correlation analyses regarding non-destructive and destructive parameters indicate possibilities and limits of strength grading in terms of beech sawn timber. This paper complements many investigations of the last years focusing mainly on the mechanical behaviour of middle and high quality beech sawn timber and glulam. As a large proportion of beech sawn timber is low quality material, a better understanding of its behaviour may lead to higher yield in combination with economic benefits as well as to more reliable strength grading and more efficient material use.

KEYWORDS: Visual grading, Machine grading, Strength characteristics, Beech, Hardwood

1 INTRODUCTION

The results of the German National Forest Inventories 2 and 3 show an increasing amount of the species beech (*Fagus sylvatica*) in German forests. At the same time, the forest areas covered by the economically important softwood species spruce (*Picea abies*) are decreasing [1]. The effects of climate change will probably intensify this development within the next decades. As a result, a growing proportion of hardwood can be expected in future. A quantitatively interesting market for the growing proportion of hardwood is timber construction. Some hardwood species, such as beech, show favourable strength and stiffness properties for the application in timber structures [2].

Before the material can be used in structural applications, either as structural members, or in glued products such as GLT or CLT, the mechanical properties of timber need to be assessed. In order to make efficient use of the material, the variation in properties need to be controlled by grading of the raw material.

The harmonized European standard for strength grading of structural timber with rectangular cross section EN 14081-1 [3] defines general requirements. Specific visual grading rules in Europe are given in national standards, like the DIN 4074-5 [4] in Germany for hardwood. Depending on strength reducing characteristics, like for example knots, fibre deviation or pith, hardwood is allocated into the different grading classes LS7, LS10 and LS13. These visual grades are assigned to the strength classes according to DIN EN 338 [5]. Concerning machine grading of beech, no approved machine settings are available.

Currently, the use of beech sawn timber in structural applications is limited to middle and high qualities. Regulations for the production of beech glulam define for example a minimum visual grade for beech lamellas of LS10. As only middle and high quality beech lamellas are approved for glulam production, the yield is heavily decreasing during the production process of lamellas. Torno et al. [6] showed, that only ~20 % of the total beech stem volume are lamellas, which fulfil the requirements for glulam production. In the mentioned investigation, a large proportion of lamellas were rejected due to pith, as it is currently a reject criterion for beech lamellas. As a result of the low yield, beech glulam becomes expensive and thus often less attractive for architects and planners. If a higher yield could be achieved by approving for example lamellas with pith or lamellas of grade LS7, beech glulam may find wider use in timber construction. But research of the past years focused mainly on middle and high quality beech sawn timber and glulam, showing considerable higher strength and stiffness properties than spruce (e.g. [7]-[10], [14], [16]).

This paper examines the tensile strength and stiffness of low quality beech sawn timber in combination with an identification of visual and physical strength indicating characteristics.

2 MATERIALS AND METHODS

2.1 MATERIALS

The investigation is based on 214 beech boards from Central Germany. The sample consists of the lowest

[1] Maximilian Westermayr, TU Munich, Germany, westermayr@hfm.tum.de
[1] Peter Stapel, TU Munich, Germany, stapel@hfm.tum.de
[1,2]Jan Willem van de Kuilen, TU Munich, Germany/ TU Delft, The Netherlands
vandekuilen@hfm.tum.de

sawn timber quality of the sawmill *Pollmeier* called *Common Shop*, which includes a large variety of growth defects like large knots, fibre deviation and pith. The boards were lightly steamed and technically dried by the producer. The ordered material was not graded according to strength, but only according to company-internal visual aspects.
109 of the 214 beech boards had a cross section of 100x24 mm², the other 105 beech boards had a cross section of 150x24 mm². Length of all boards was 3050±20 mm. Before testing, the boards were stored in normal climate (20 °C/65 %rh) according to DIN EN 408 [11] until constant mass was reached. The moisture content of each board at the time of testing was determined according to DIN EN 13183-1 [12]. Mean moisture content of all boards at the time of testing was 10.4 % with a standard deviation of 0.8 %.

2.2 METHODS

Before tensile testing, non-destructive measurements were performed in order to identify characteristics, which may indicate the tensile strength of the boards. Beside visual characteristics such as knots, fibre deviation and pith, the dynamic modulus of elasticity (dyn. MoE) was determined. Subsequently, the boards were tested in tension.

2.2.1 Non-destructive measurements

Knots

The positions and geometrical characteristics of all knots larger than 4mm were measured. Bark inclusions were treated like knots. The recorded data allowed the calculation of different knot parameters. This paper focuses on the three knot parameters DEB, DAB and tKAR.
The DEB and DAB are knot parameters according to the German strength grading standard for sawn hardwood DIN 4074-5 [4]. The DEB-value divides the sums of the visible widths of a knot on the flat and edge faces by two times the width of the board. The DAB-value regards accumulation of knots by taking into account all knots within a board section of 150 mm, whereby overlapping widths are only counted once.
The tKAR desribes the knot area within a maximum length of 150 mm projected on the end grain divided by the cross section, whereby overlapping areas are counted once.
It is mentioned, that the geometrical data of knots in beech were sometimes difficult to measure properly. Especially sound knots are often not clearly distinguishable to the surrounding wood, as no change in colour or a sharp change in fibre orientation can be found. Further on, bark inclusion turned out to be a demanding characteristic as they mainly appear numerous with uneven, not circular geometries.

Pith

According to the regulations given in DIN 4074-5 [4], hardwood boards with pith are generally rejected for structural applications. In contrast, the German strength grading standard for sawn softwood DIN 4074-1 [13] allows pith in boards of the lower and middle grades S7 and S10. As the rejection of beech boards with pith show negative impact on the yield [6], this study included boards with and without pith to investigate its influence on the tensile strength. The presence and location of the pith were documented. 100 of 214 boards included pith partly or completely, 67 of 214 boards included pith in the section that was tested in tension. It is mentioned, that the correct identification of the pith was challenging in many cases. Discoloured brown drying cracks often looked deceptively similar to the pith, as the pith also has a very small diameter in beech and no soft core compared to many softwoods like spruce. Further on, the pith entered and left the same board several times due to curved growth of the trees in some of the specimens.

Fibre deviation

In the German strength grading standards for sawn hardwood and softwood DIN 4074-5/DIN 4074-1[4, 13], slope of grain forms a grading characteristic. An exception concerning the mentioned regulation is the species beech, as literature confirms, that a visual estimation of fibre deviation is difficult for beech [14, 16]. Nonetheless, past investigations outlined the important role of the grain angle on the tensile strength of beech [8, 15]. In consequence, slope of grain was recorded in the range of the testing length. For this, the maximum grain angle was estimated with a protrector, as it shown in Figure 1.

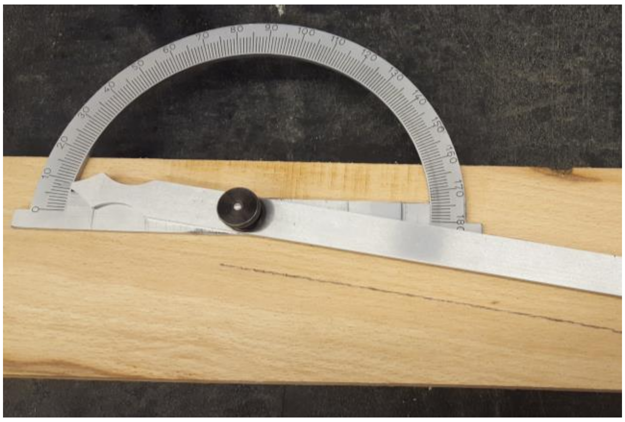

Figure 1: *Measurement of the grain angle with a protrector.*

The grain angle was measured before testing and after testing, following the fracture lines. High local fibre deviations, for example around knots, were ignored. It was clearly noticeable, that the measurement of the grain angle before testing was difficult due to redheart and discoloration. Both phenomena gave a wrong impression of the real grain angle in many cases. Hence, it is clearly mentioned, that the measurement of the grain angle before testing only allowed a rough estimation of the real grain angle.

Other characteristics

All characteristics given in DIN 4074-5 [4] were registered. Drying cracks in longitudinal direction were numerous as well as redheart and other colour errors. Both characteristics were recorded qualitatively. None of the specimens included wane, as the boards were cut from the inner part of the stems. Curvature was very little and fulfilled at least the threshold values of grade LS 13 of DIN 4074-5 [4].

In total, quality of the investigated beech boards was very low and wood defects were numerous. Some typical wood defects of the investigated material are compiled in Figure 2.

Figure 2: *Typical wood defects: a) knots, pith and fibre deviation, b) cracks, c) slope of grain, pith and discoloration*

Dynamic modulus of elasticity

Eigenfrequency and ultrasound measurements were performed on all beech boards.

To determine the dyn. MoE by using eigenfrequency, an impulse was induced by a simple hammer, causing a longitudinal wave. The resulting first eigenfrequency was detected by a highly sensitive microphone as well as by an acceleration sensor. The dyn. MoE was calculated by equation (1):

$$E_{dyn} = 4 \cdot l^2 \cdot f^2 \cdot \rho \qquad (1)$$

where l = length of the board, f = first eigenfrequency, ρ = density

As the frequencies recorded by microphone and acceleration sensor showed negligible differences, the microphone frequency was used in the following analysis.

The dyn. MoE calculated on basis of ultrasound runtime showed weaker correlation with strength and stiffness, than the dyn. MoE calculated with frequency. Hence, the following analysis was performed on frequency based dyn. MoE. The dyn. MoE got moisture corrected according to Unterwieser and Schickhofer[17].

2.2.2 Destructive testing

Testing was performed according to DIN EN 408 [11]. The tensile testing device is shown in Figure 3. The testing length of *9 x width* was 900 mm for the boards with a cross section of 100x24 mm² and 1350 mm for the boards with a cross section of 150x24 mm². Deformation got measured on both edge faces over a length l_1 of *5 x width*, which were 500 mm and 750 mm depending on the cross section. As far as possible, the weakest section of the board got estimated and positioned in the testing length between the clamps. The force was increased continuously until failure. The tensile strength $f_{t,0}$ was calculated using equation (2), the tensile stiffness $E_{t,0}$ was calculated using equation (3).

$$f_{t,o} = \frac{F_{max}}{A} \qquad (2)$$

$$E_{t,0} = \frac{l_1(0.4 \cdot F_{max} - 0.1 \cdot F_{max})}{A \cdot (w_{0.4} - w_{0.1})} \qquad (3)$$

where F_{max} = maximum force, A = cross section, $w_{0.4}$ and $w_{0.1}$ are the deformations corresponding to the stress levels of 40% and 10% of F_{max}.

Figure 3: *Testing device according to DIN EN 408 [11].*

The moisture content and density measurements of each board were carried out on small samples, free of defects and close to failure location, using oven dry method according to DIN EN 13183-1 [12]. Tensile stiffness and density were moisture corrected according to DIN EN 384 [18]. Characteristic values were calculated according to DIN EN 14358 [19].

3 RESULTS AND DISCUSSION

3.1 Basic test results

Table 1 compiles the basic test results.

Table 1: *Basic test results.*

	Cross section [mm²]	Mean value	Standard deviation	COV [%]
Strength [N/mm²]	100x24	35,9	15,9	44
	150x24	31,8	14,5	46
Static MoE [N/mm²]	100x24	11582	2876	25
	150x24	11330	2451	22
Density [kg/m³]	100x24	767	42	5
	150x24	759	40	5

Mean tensile strength of both cross sections are similar between 35.9 and 31.8 N/mm². Also, stiffness show almost congruent values of ~11500 N/mm². Standard deviations are high, which lead to coefficients of variation of ~45 % concerning strength and ~24 % concerning stiffness. As both cross sections did not show significant differences regarding mechanical characteristics as well as density, the following analysis was mainly performed on one dataset combining both cross sections.
The mean tensile strength and stiffness values of the tested boards are substantially lower, than the corresponding values given in literature. Erhart et al. [10] found a mean tensile strength of 66.7 N/mm² and a mean tensile stiffness of 14540 N/mm² for beech boards with comparable cross sections. Frühwald and Schickhofer [14] determined a mean tensile strength of 62.3 N/mm² and a mean stiffness of 13930 N/mm². Blaß et al. [7] found a mean tensile strength of 68.1 N/mm² and a mean stiffness of 13000 N/mm². All mentioned investigations applied the same testing method according to DIN EN 408 [11] or slightly modified methods. It can be summarized, that here, the mean tensile strength of the ungraded material is about 50 % lower than the tensile strength given in literature. The tensile stiffness is about 20 % lower. Remarkable is the high density of the tested material. The frequency distribution of the strength values is shown in Figure 4.

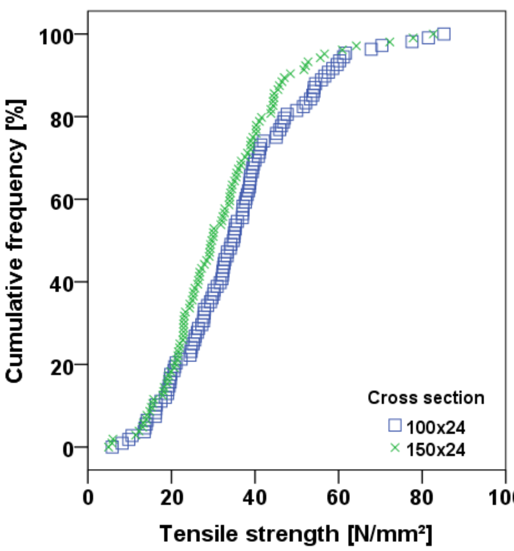

Figure 4: *Cumulative frequency distribution of tensile strength values.*

The gained strength values reach from 4.9 N/mm² to 85.2 N/mm². The distribution shows positive skewness concerning the high strength values. Statistical analysis yield that the data are not normally distributed. Same results are obtained regarding stiffness values. This indicates that middle and especially high quality boards are missing in the tested collective.

3.2 Visual strength indicators

This chapter describes the correlation between selected visual parameters and the mechanical potential of the investigated beech boards.

Knots

Figure 5, Figure 6 and Figure 7 show the relation between tensile strength and the single knot parameter DEB and the parameter for knot clusters DAB according to the German strength grading standard for Hardwood DIN 4074-5 [4] as well as the knot value tKAR.

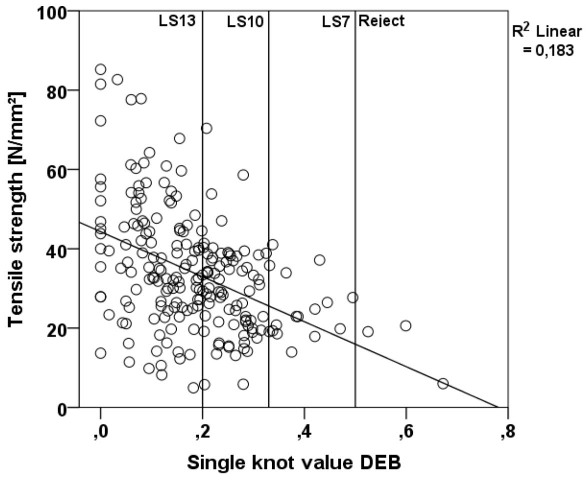

Figure 5: *Relation between DEB and tensile strength.*

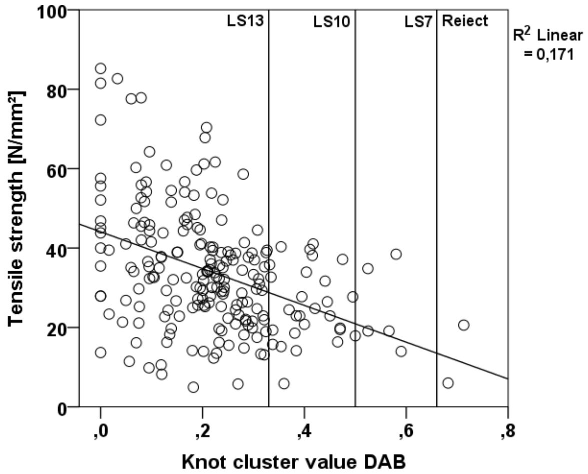

Figure 6: *Relation between DAB and tensile strength.*

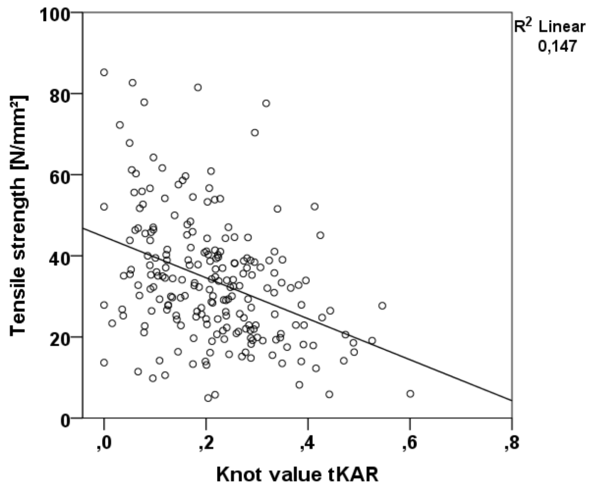

Figure 7: *Relation between tKAR and tensile strength.*

All knot values show low correlation with the tensile strength resulting in R^2 values between 0.15 and 0.18. This stands in contrast to research considering higher quality beech timber. Erhart et al. [10] found correlations of R^2=0.52 for DEB/DAB and R^2=0.53 for tKAR concerning tensile strength. Frühwald and Schickhofer [14] identified similar correlations. Glos and Lederer [8] determined correlations between tensile strength and DEB/DAB of 0.63/0.64.

As knots are significant weak points in high quality material, the strength of low quality material is mainly governed by various overlapping wood defects, like local fibre deviations and pith. As a result, single knots or knot clusters show less correlation with the tensile strength as they represent only one characteristic of various wood defects. In addition, strength values covering a wider range of values also lead to higher R^2 values. Table 2 compiles the number of beech boards in the visual grading classes of DIN 4074-5 [4] and the corresponding mean tensile strength values applying DEB and DAB knot criterion for grading.

Table 2: *Number and mean tensile strength of boards in visual grading classes of DIN 4074-5 considering DEB+DAB value.*

	Reject	LS7	LS10	LS13
Number	3	16	71	124
Mean strength [N/mm²]	-	24,9	29,6	37,9
Char. strength [N/mm²]	-	16.9	14.5	12.4

Only three boards are rejected during 58 % of the boards reach grade LS13. This confirms the results of knot measurements, which showed numerous but small knots around or close to the pith for many boards. Mean tensile strength is increasing with increasing visual grading class, characteristic strength shows opposite behaviour. This can be explained by the higher number of specimens in LS10 and LS13 including also a higher proportion of low strength boards. It shows, that knot size as a single criterion for strength grading may lead to distorted results on characteristic value level.

Pith

Out of 214 boards, 100 boards included pith and 67 boards included pith in the range of the testing length. All results in this chapter are referring to boards, which include pith in the range of the testing length. The influence of the pith on the mechanical properties is shown in Table 3.

Table 3: *Mean value and standard deviation (SD) of the tensile strength and stiffness depending on pith.*

	n	Strength [N/mm²]		Static MoE [N/mm²]	
		Mean	**SD**	**Mean**	**SD**
With pith	67	26,3	11,3	10513	2316
Without pith	147	37,3	15,7	11889	2720

It can be observed, that the beech boards with pith exhibit about ~30 % lower mean tensile strength and ~10 % lower stiffness than the boards without pith. Thus, the findings of Glos and Lederer [8] can be confirmed. They mentioned in particular that pith causes cracks and curvature, which lead to lower strength values. In addition, boards including pith showed much higher local and global fibre deviation than boards without pith. In 47 of 67 boards including pith, the fracture line followed the pith. A higher proportion of juvenile wood in boards with pith may probably decrease the strength.

Scatter in mechanical properties is high for boards with and without pith. The unequal specimen numbers are indicated. The cross section showed no impact on the mentioned results. A significant difference in density of boards with and without pith was not found.

Fibre deviation

Before destructive testing, the grain angle got estimated in the range of the testing length. After failure, the grain angle got measured along the fracture line. The relation between estimated grain angle before and measured grain angle after testing is shown in Figure 8.

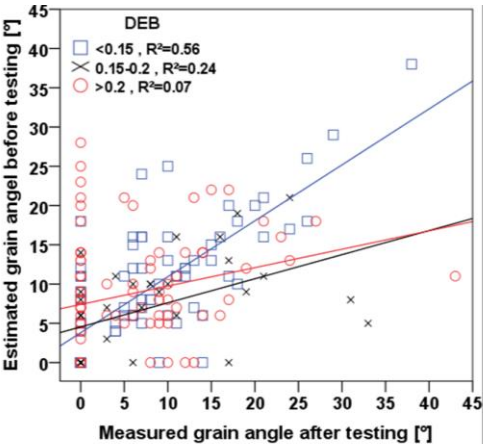

Figure 8: *Correlation between estimated and measured grain angle depending on the DEB knot value.*

The overall correlation between estimated and measured grain angle is R^2=0.25. This outlines the difficult visual assessment of fibre deviations for beech as given in literature [8, 14]. Unexpected high correlations were gained for small knot values, as shown in Figure 8. For DEB values <0.15 and 0.15-0.2, the R^2 values of 0.56 and 0.24 were derived.

Figure 9 shows the relation between tensile strength and estimated grain angle before testing.

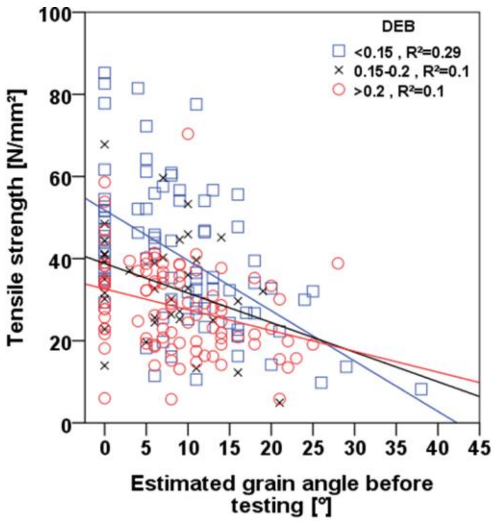

Figure 9: *Correlation between tensile strength and estimated grain angle depending on the DEB knot value.*

As in already seen in Figure 8, small DEB values show better correlation with the tensile strength than bigger knot values. During knots with a DEB <0.15 lead to R^2=0.29, bigger knot values show a R^2=0.1, which is in the range of the overall R^2 of 0.15.
A possible explanation of the phenomena in Figure 8 and Figure 9 is that strength of boards with big knots is mainly governed by local fibre deviation and the knots itself, as strength in boards with small or no knots seem to be mainly influenced by global grain angle. Global grain angle may be detected more reliable in boards with smaller knots, also partly by the, in some cases, visible pith.
Almost congruent results were obtained concerning the relation between tensile strength and measured grain angle after testing. Hereby, even higher correlations were found with R^2=0.31 for DEB<0.15 and R^2=0.21 for DEB=0.15-0.2. Higher knot values also led to low correlations, overall R^2 was 0.11.
It can be summarized, that the reliable identification of the grain angle is challenging and often misleading concerning beech sawn timber. Nonetheless, the estimation of the grain angle led to high correlations with the measured grain angle after testing as well as to a correlation of R^2=0.29 with the tensile strength for small knot values of DEB<0.15.

3.3 Machine strength indicators

This chapter describes the relation of density as well as dynamic modulus of elasticity and the tensile strength.

Density
The tensile strength depending on the density is shown in Figure 10.

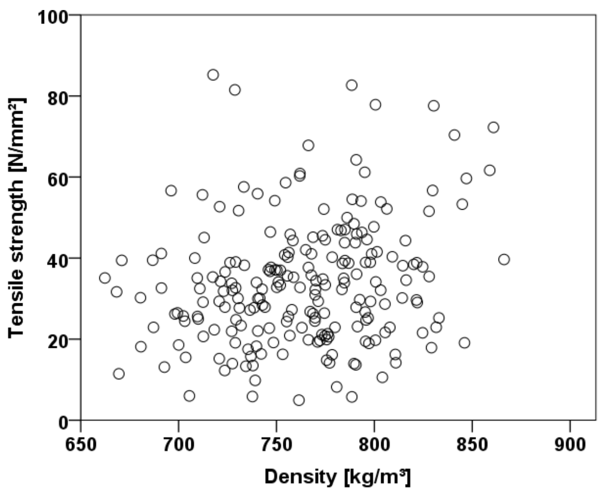

Figure 10: *Relation between tensile strength and density.*

No significant correlation can be found regarding tensile strength and density resulting in a correlation of R^2=0.05. This finding confirms the results given in the investigations of Erhart et al. [10], Frühwald and Schickhofer [14] and Glos and Lederer [8].

Dynamic modulus of elasticity
In Figure 11, the dynamic modulus is plotted against the tensile strength.

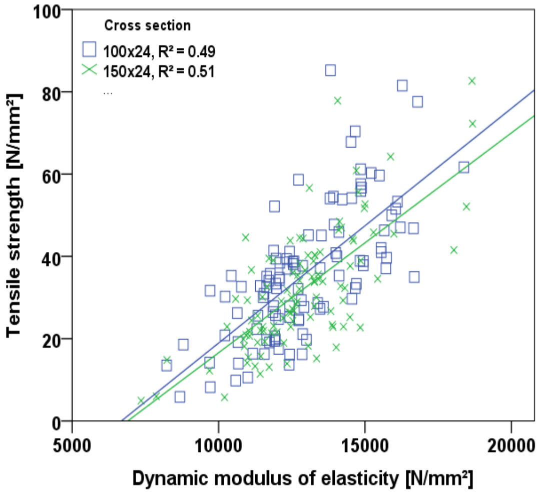

Figure 11: *Relation between dyn. MoE and tensile strength.*

A strong relation between dynamic modulus of elasticity and tensile strength is found. Depending on the cross section, correlations of R^2=0.51 and R^2=0.49 are calculated for the cross sections of 150x24 mm² and 100x24 mm². These findings are contrary to the investigation of Erhart et al. [10], who found a correlation value of R^2=0.22 for higher quality beech timber. It seems that the dynamic modulus of elasticity reacts very sensitive to wood defects like fibre deviations, pith and other characteristics. As a result, the dynamic modulus of elasticity works well as a grading parameter for low quality beech sawn timber. Contrary, the dynamic modulus of elasticity provides only low correlations for straight grained boards and a low number of defects, as the frequency is no more affected by the mentioned characteristics. Applying eigenfrequency as single grading criterion, a correlation of R^2=0.45 is derived. The correlation between dynamic and static modulus of elasticity is high with a value of R^2=0.69.
Finally, Table 4 gives an overview of some selected combined indicating properties (IP).

Table 4: *Correlations of selected IP values.*

IP	R^2
Frequency + density	0.48
Frequency + density + DEB	0.49
dyn. MoE + tKar	0.50
dyn. MoE + DEB	0.51
dyn. MoE + DEB + estimated grain angle before testing	0.55

4 SUMMARY AND CONCLUSIONS

This paper investigates the tensile strength and stiffness of low quality beech sawn timber. In addition, selected non-destructive characteristics are pointed out indicating the mechanical behaviour under tensile stress. The main findings can be summarized as follows:

- Mean tensile strength is with 33.9 N/mm² significantly lower than the strength values gained in literature investigating higher beech sawn timber qualities. Scatter in strength is high with a COV of

45 %. Minimum strength was 4.9 N/mm², maximum strength was 85.2 N/mm².

- Mean tensile stiffness is 11458 N/mm² with a COV of 23 %. This value is also lower than static modulus of elasticity given in literature dealing with higher quality beech sawn timber.
- Measurements and assessments of the visual grading parameters of DIN 4074-5 [4] were challenging due to the bad qualities of the beech boards. Especially grain angle, pith and small knots were difficult to identify doubtless.
- The knot values DEB, DAB and tKAR showed low correlation with the tensile strength and stiffness as tensile failure seemed to be governed by a combination of various wood defects. In addition, knots were mainly small due to the boards originating from the inner part of the stem, which also leads to low rejects caused by knots.
- Beech boards with pith showed significantly lower tensile strength and stiffness than boards without pith. Beside the pith itself, higher fibre deviation and cracks were observed in boards including pith, which reduce strength additionally.
- Visual identification of the grain angle was challenging for beech timber but turned out to allow a rough estimation of the real grain angle as well as the tensile strength for boards with very small knots. Concerning values of DEB>0.15, the estimation of the grain angle and the tensile stiffness was not possible.
- By applying density, no indication regarding tensile strength and stiffness was found.
- The eigenfrequency and the dynamic modulus of elasticity showed high correlation with the tensile strength and stiffness. With dynamic modulus of elasticity, correlations of $R^2=0.49$ concerning strength and $R^2=0.69$ concerning stiffness were derived.

5 OUTLOOK

The gained data are basis for further investigations in the field of strength grading of beech sawn timber for structural applications. The results will be combined with a dataset of middle and high quality beech sawn timber at TU Munich to allow an analysis of the full range of beech qualities. Also, the derivation of machine settings for strength grading in combination with visual characteristics of beech sawn timber for glulam is then possible. Further on, the currently valid visual grading regulations of DIN 4074-5 need to be assessed regarding beech sawn timber. Finally, the interaction between mechanical performance, grading an yield need to be understood and analysed. By this, a more economic and resource efficient use of beech sawn timber could be enabled in future.

ACKNOWLEDGEMENT

We want to thank the *Bavarian Institute of Forestry (LWF).*

REFERENCES

[1] Federal Ministry of Food and Agriculture: The forests in Germany. Selected results of the third national forest inventory, 2015.

[2] Aicher S., Ohnesorge D.: Shear strength of glued laminated timber made from European beech timber. European Journal of Wood and Wood Products 69: 143-154; DOI 10.1007/s00107-009-0399-9, 2011.

[3] DIN EN 14081-1: Timber structures – Strength graded structural timber with rectangular cross section – Part 1: General requirements; German version EN 14081-1:2016.

[4] DIN 4074-5: Strength grading of wood – Part 5: Sawn hard wood; DIN 4074-5:2008.

[5] DIN EN 338: Structural timber – Strength classes; German version EN 338:2016.

[6] Torno S., Knorz M., van de Kuilen J.-W.: Supply of beech lamellas for the production of glued laminated timber, ISCHP Conference , Florence, Italy, 2013.

[7] Blass H.-J., Denzler J. K., Frese M., Glos P., Linsenmann P. : Biegefestigkeit von Brettschichtholz aus Buche. Band 6 der Karlsruher Berichte zum Ingenieurholzbau (in German), 2005.

[8] Glos P., Lederer B.: Sortierung von Buchen- und Eichenschnittholz nach der Tragfähigkeit und Bestimmung der zugehörigen Festigkeits- und Steifigkeitskennwerte. Holzforschung München, TU Munich, Munich (in German), 2000.

[9] Frühwald A., Ressel J.B., Bernasconi A.: Hochwertiges Brettschichtholz aus Buchenholz. Institut für Holzphysik und mechanische Technologie des Holzes, Bundesforschungsanstalt für Forst- und Holzwirtschaft, Hamburg, 2003.

[10] Erhart T., Fink G., Steiger R., Frangi A.: Experimental investigation of tensile strength and stiffness indicators regarding European beech timber. Conference paper WCTE, 2016.

[11] DIN EN 408: Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties; German version EN 408:2010+A1:2012

[12] DIN EN 13183-1: Moisture content of a piece of sawn timber - Part 1: Determination by oven dry method; German version EN 13183-1:2002

[13] DIN 4074-1: Strength grading of wood – Part 1: Coniferous sawn timber; DIN 4074-1:2012

[14] Frühwald A., Schickhofer G.: Strength grading of hardwoods. Proceedings of the 14th International Symposium on Nondestructive Testing of Wood, Hanover, Germany, 2005.

[15] Aicher S.: A study on tension strength of finger joints in beech wood laminations. Otto-Graf-Journal, 12 (in German), 2001.

[16] Glos P., Denzler J. K., Linsenmann P.: Strength and stiffness behavior of beech laminations for high strength glulam. Paper 37-6-3, CIB-W18 Proceedings Edinburgh, Scotland, Meeting 37, August 2004.

[17] Unterwieser H., Schickhofer G.: Influence of moisture content of wood on sound velocity and dynamic MOE of natural frequency- and ultrasound runtime measurement. European Journal of Wood

Products 69: 171-181. DOI 10.1007/s00107-010-0417-y, 2010.
[18] DIN EN 384: Structural timber – Determination of characteristic values of mechanical properties and density; German version EN 384:2016.
[19] DIN EN 14358: Timber structures –Calculation and verification of characteristic values; German version EN 14358:2016.