The influence of the grading method on the finger joint bending strength of beech

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Abstract

During the last meeting in Karlsruhe the authors presented a paper [1] providing background information about the determination of the characteristic bending strength of beech glulam. A design proposal was derived to calculate the characteristic bending strength depending on the characteristic tensile strength of the lamellae and the characteristic finger joint bending strength. It was experimentally and numerically proved that visual strength grading of beech provide for strength class GL36 and mechanical grading for GL48.

The current paper gives now more detailed information about the influence of the strength grading method on the characteristic finger joint bending strength with regard to beech glulam requirements. Therefore 108 bending tests on finger joints manufactured from visually graded beech boards were performed. A further 319 tests on finger joints manufactured from mechanically graded beech boards were carried out. All the bending tests were conducted flatways according to EN 408 with a span of 15 times the height. The test results confirm a characteristic finger joint bending strength of 56 N/mm² in case of visual and 70 N/mm² in case of mechanical grading.

1 Introduction and background

The bending strength of glulam depends on the tensile strength of the lamellae and of the finger joints which may correlate. If the correlation is known, it is possible to determine the characteristic bending strength of glulam (= $f_{m,g,k}$) depending only on the characteristic tensile strength of the lamellae (= $f_{t,\ell,k}$). In the case of softwood this led to the calculation model in EN 1194, where a linear relation between the two values is given, see equation (1). Therein and in the following equation (2) the unit of the strength values is N/mm².

$$f_{m,g,k} = 7 + 1{,}15 \cdot f_{t,\ell,k} \tag{1}$$

The high tensile strength of beech (*fagus silvatica L.*) raises the question, whether the common relation (1) is also valid for a characteristic tensile strength exceeding 26 N/mm² or if a different relation more accurately describes the laminating effect for beech glulam. It was the aim of the investigations [2], [3] and [4] to answer this question and to provide a design model for beech glulam. As a result equation (2) was derived. Therein the characteristic glulam bending strength is calculated from both the characteristic tensile strength of the boards and the characteristic finger joint bending strength (= $f_{m,j,k}$). For a better understanding equation (2) is evaluated in Fig. 1. The six curves represent different characteristic tensile strength values of beech boards, which correspond in part to the strength classes D35 – D70 in EN 338. Actually in DIN 1052 visual strength grading in class LS10 and LS13 as per DIN 4074-5 corresponds to strength class D35 and D40. In [4] it is numerically proved that visual strength grading of boards being free from knots enables even a characteristic tensile strength up to 32 N/mm² (D50) and mechanical strength grading up to 48 N/mm² (≥D60).

In the current paper the authors report on an extensive experimental investigation to determine the characteristic finger joint bending strength, which is necessary to establish beech glulam strength classes. They intend to give a basis for further standardisation of glulam made of hardwood e.g. birch or ash.

$$\begin{aligned} f_{m,g,k} &= -2,87 + 0,844 \cdot f_{m,j,k} - 0,0103 \cdot f_{m,j,k}^2 \\ &-0,192 \cdot f_{t,\ell,k} - 0,0119 \cdot f_{t,\ell,k}^2 + 0,0237 \cdot f_{m,j,k} \cdot f_{t,\ell,k} \end{aligned} \qquad (2)$$

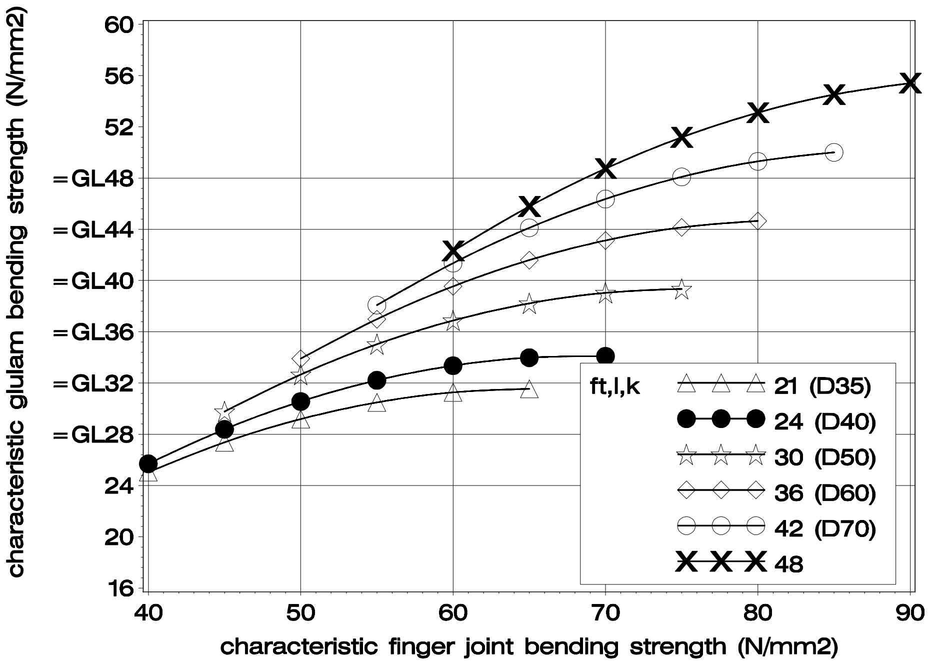

Fig. 1 Characteristic glulam bending strength depending on characteristic finger joint bending strength; evaluation of equation (2); comparison of characteristic tensile strength values corresponding to strength classes in EN 338

2 Finger joint bending strength

2.1 Material and methods

The boards to industrially manufacture the finger joint connection were delivered from three sawmills located in Germany (Nordhessen, Schönbuch and Spessart). The moisture content of the boards amounts to nearly 10%. The ends of the boards were prepared according to EN 385. The finger profile has a length of 15 mm and a division of 3,8 mm. A Melamine-Urea-Formaldehyde adhesive (Kauramin® adhesive 681 liquid and Kauramin® hardener 686 liquid) was used. 108 finger joint specimens differing in terms of source were manufactured from visually strength graded boards, see Table 1. The boards meet at least the criteria of LS10 as per DIN 4074-5 (compare Fig. 2). The MOE of the jointed boards was arbitrary, see Fig. 3 left. It is assumed that grading in LS10, LS13 or grading of boards being free from knots does not really affect the finger joint bending strength. This assumption is justified by the uniform requirements to the board ends in EN 385 and the missing grading criterion fibre deviation in case of beech in DIN 4074-5. A further 319 specimens were produced to study the influence of mechanical strength grading on the finger joint bending strength. Therefore the dynamic MOE (= E_{dyn}) as grading parameter of each board was calculated from (3).

$$E_{dyn} = (2 \cdot f \cdot \ell_{board})^2 \cdot \rho_{gross} \tag{3}$$

Therein f denotes the frequency of a longitudinal vibration, ℓ_{board} the board length and ρ_{gross} the gross density (= air dry mass/volume). The boards were graded according to the system in Table 2. Each specimen was manufactured from two boards belonging to a single grade, see Fig. 3. The 20 samples differing in terms of source and grade are assorted in Table 3. The flexural MOE of the finger joint specimens obtained by vibration methods is the bending strength reference parameter, see Fig. 4 and [6]. In Fig. 3 and Fig. 4 ℓ_j denotes the specimen length of about 20 times the height.

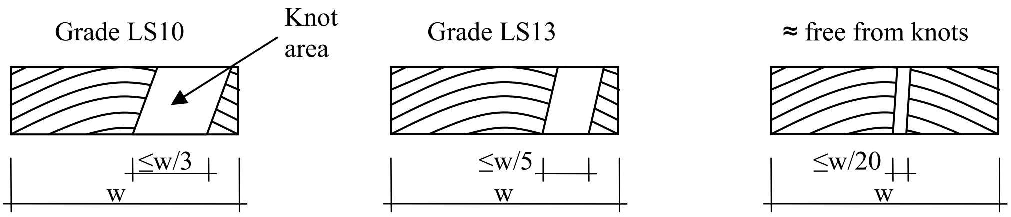

Fig. 2 Visual strength grading exemplified by the single knot: grades LS10 and LS13 according to DIN 4074-5 (left, middle) and recommended additional grade (right)

Table 1 Sample size and cross-sectional dimensions – visual grading

source	Nordhessen	Schönbuch	Spessart
N	56	21	31
width/height (mm)	100/30	105/36	110/34

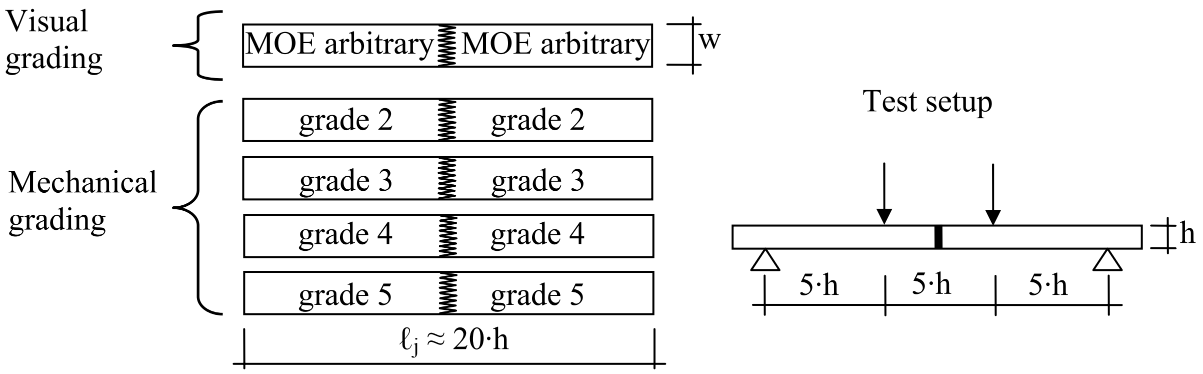

Fig. 3 Finger joint specimen manufacture (left) and test setup (right)

Table 2 Mechanical grading according to dynamic MOE; range in N/mm²

grade	2	3	4	5
range	$13000<E_{dyn}\leq 14000$	$14000<E_{dyn}\leq 15000$	$15000<E_{dyn}\leq 16000$	$16000<E_{dyn}$

Table 3 Sample size N and cross-sectional dimensions – mechanical grading

source	Nordhessen I[1]	Schönbuch	Spessart	Nordhessen II[1]
grade 2	20	22	21	12
grade 3	22	22	25	22
grade 4	22	22	18	12
grade 5	19	22	24	14
width/height (mm)	100/29	105/34	110/33	100/28
[1] first sample coming from Nordhessen; [2] second sample coming from Nordhessen				

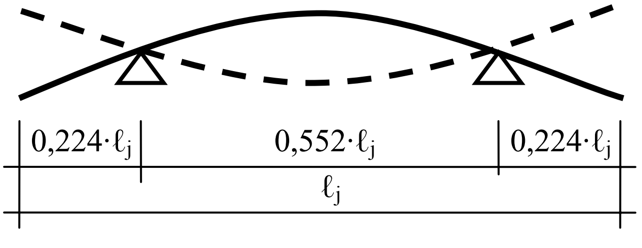

Fig. 4 Flatways flexural vibration; The connection is in the middle of the specimen.

2.2 Results

2.2.1 Visual grading of boards

The relation between bending strength and flexural MOE is shown in Fig. 5. The regression line confirms the influence of stiffness on the bending strength. Considering all specimens the 5th percentile is 56 N/mm². The range of the three 5th percentile values in terms of board source is from 50 up to 69 N/mm². This confirms in a single case a very high characteristic finger joint bending strength. The mean moisture content varies from 9,9% to 11% and the mean density from 684 kg/m³ to 695 kg/m³, see Table 4.

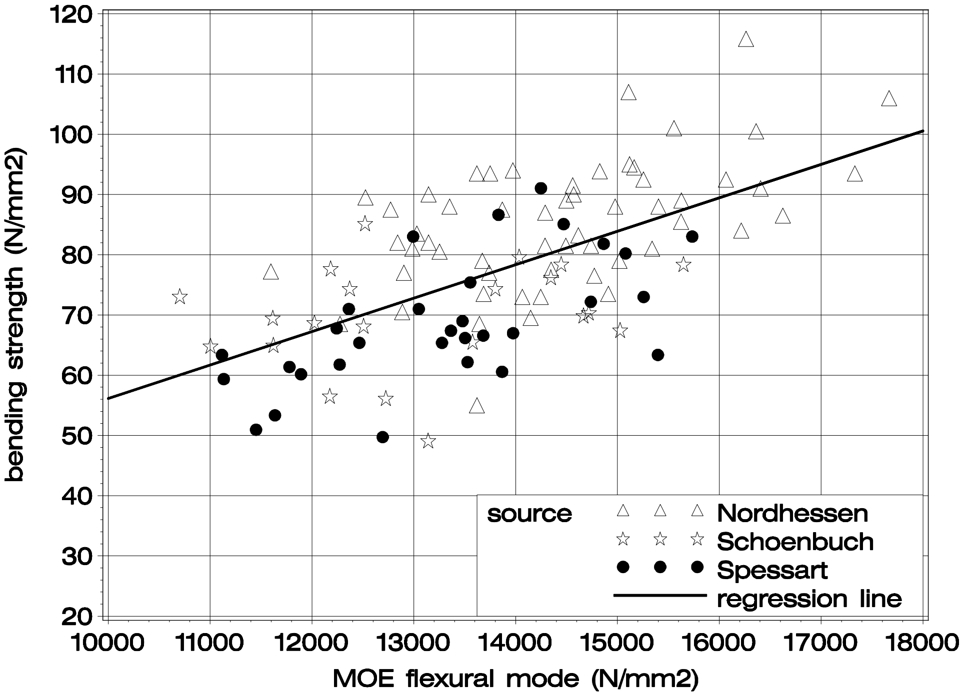

Fig. 5 Bending strength depending on reference parameter flexural MOE

2.2.2 Mechanical grading of boards

Fig. 6 shows the relation between bending strength and reference parameter flexural MOE. The symbols represent the grade of the connected boards. A correlation between the dynamic MOE of the boards determined by longitudinal vibrations and the dynamic flexural MOE of the specimens can be assumed. Hence specimens manufactured from boards of grade 2 and 3 lie on the left and those from boards of grade 4 and 5 on the right side of the diagram. The nonlinear regression curve and the 90% confidence limits indicate an upper limit for the mean and characteristic bending strength. For a better understanding of the influence of board grade and source on the mean and characteristic values Fig. 7 and Fig. 8 show the trend of these values (compare Table 6). It is remarkable that no increase of bending strength between grades 4 and 5 can be observed. Hence the specimens belonging to grade 4 and 5 were merged: The 5th percentile value amounts to 69,3 N/mm². In terms of technical feasibility mechanical grading of grades 4 and 5 can lead to a 5th percentile value exceeding 70 N/mm². Concerning the 4 grades the mean bending strength values in the sample Nordhessen II is in part significantly higher than in the remaining samples. This may be caused by better steel of the finger joint cutter used only during the manufacture of this sample. This steel provides higher rigidity and longer tool life. The 5th percentile value (56 N/mm²) in case of visual grading is nearly equal to the 5th percentile value of specimens belonging to grade 3 (58,8 N/mm²). Hence the advantage of mechanical grading begins when grading boards which exceed a dynamic MOE of about 14000 or 15000 N/mm². The mean moisture content of the specimens in the four samples varies from 8,2% to 9,8% and the density from 672 kg/m³ to 681 kg/m³, see Table 5.

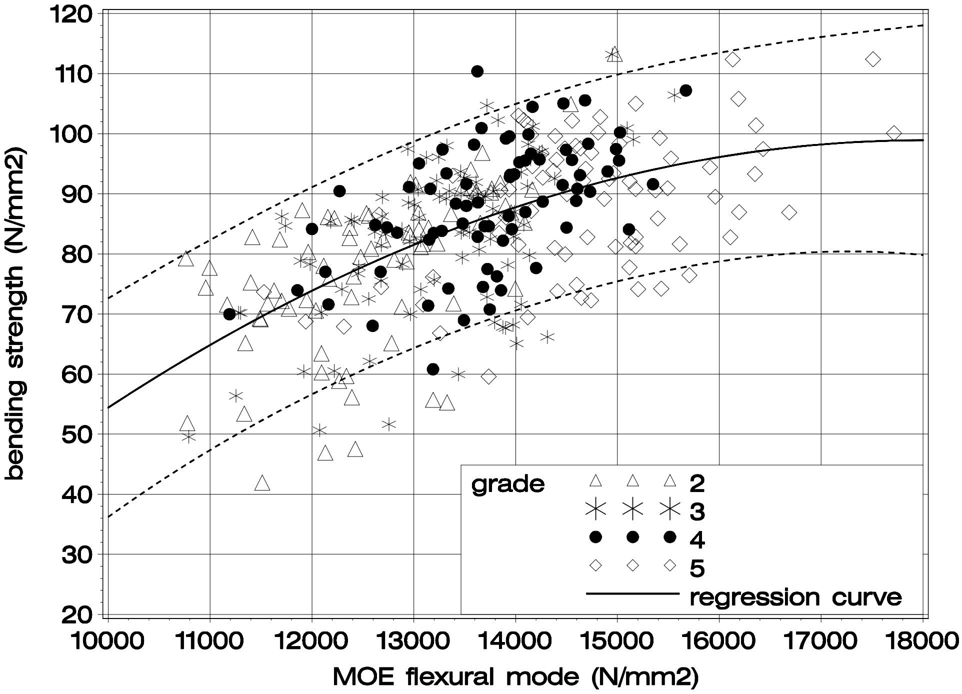

Fig. 6 Bending strength depending on reference parameter flexural MOE

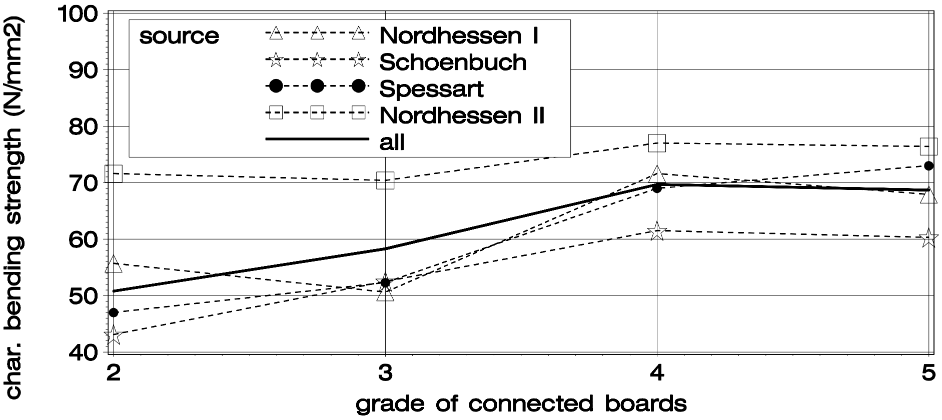

Fig. 7 5th percentile bending strength over grade of connected boards

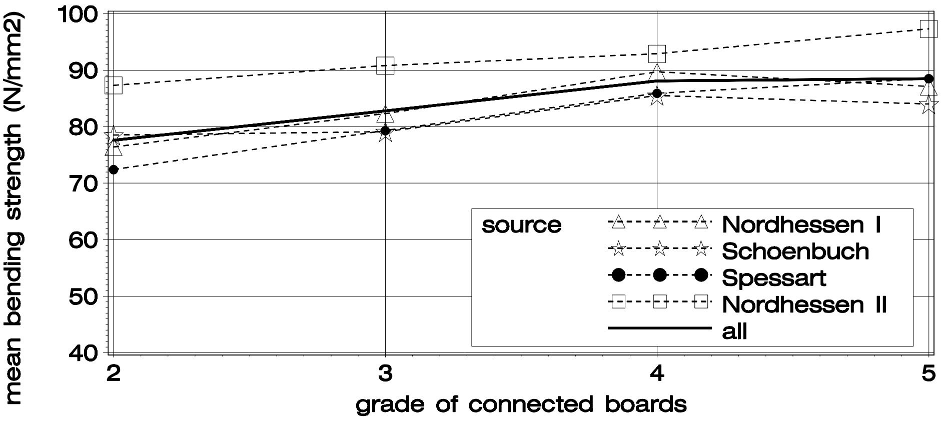

Fig. 8 Mean bending strength over grade of connected boards

3 Conclusions

On the basis of Fig. 1 and the experimental data the following conclusions can be drawn:

- In DIN 1052 visual strength grading of beech in class LS10 and LS13 corresponds to the strength classes D35 and D40, respectively. The characteristic finger joint bending strength of such visually graded boards amounts to nearly 56 N/mm². Hence it is possible to establish GL28 and GL32 with standard visual strength grading methods.

- Assuming that visual strength grading of beech boards being free from knots corresponds to D50 and that finger joint manufacture provides a characteristic bending strength of 58 N/mm² it is even possible to produce GL36.

- Mechanical strength grading of beech boards having a dynamic MOE determined from longitudinal vibrations of at least 15000 N/mm² and additional demands on knots are precondition for strength classes equal to or greater than D60. For those boards a characteristic finger joint bending strength amounts to nearly 70 N/mm². Under optimised production conditions in terms of finger joint manufacture higher values are even possible. Hence strength classes up to GL52 are imaginable.

4 References

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5 Appendix

Table 4 Bending strength, moisture content and density statistics in terms of source; specimens manufactured from visually graded boards

	Nordhessen	Schönbuch	Spessart	all
bending strength (N/mm^2)				
n	56	21	31	108
$\bar{x}$	85,2	70,0	68,8	78
s	10,6	8,7	10,4	13
5%	68,5	49,5	50,4	56
CL_{95}[1]	62,6-71,5	47,9-60,4	44,5-56,4	52-60
moisture content[2] (%)				
$\bar{x}$	9,85	10,1	11	-
s	0,579	0,519	0,681	-
min-max	8,85-11,9	9,14-11,0	8,15-13,4	-
density[2] at given moisture content (kg/m^3)				
$\bar{x}$	695	687	684	690
s	44,1	34,6	47,7	44
min-max	575-822	616-752	584-816	575-822

[1 and 2] see Table 6

Table 5 Moisture content and density statistics in % in terms of source; specimens manufactured from mechanically graded boards

source	Nordhessen I	Schönbuch	Spessart	Nordhessen II
moisture content[2] (%)				
$\bar{x}$	8,88	9,84	9,64	8,24
s	0,345	0,432	0,822	0,228
min-max	7,98-9,70	8,95-10,6	8,80-12,1	7,69-8,85
density[2] at given moisture content (kg/m^3)				
$\bar{x}$	672	681	681	672
s	39,2	32,3	33,8	38,9
min-max	583-817	606-786	595-781	588-786

[2] see Table 6

Table 6 Bending strength and density statistics in terms of board grade; specimens manufactured from mechanically graded boards

source		grade				
		2	3	4	5	4+5
bending strength (N/mm^2)						
Nordhessen I	n	20	22	22	19	41
	$\bar{x}$	76,4	82,3	89,7	87,1	88,5
	s	9,73	13,2	10,1	10,6	10,3
	5%	55,7	51,2	71,6	67,9	71,4
Schönbuch	n	22	22	22	22	44
	$\bar{x}$	78,5	79,1	85,5	84,0	84,7
	s	13,3	12,2	11	12,3	11,6
	5%	43,1	52,5	61,5	60,3	62
Spessart	n	21	25	18	24	42
	$\bar{x}$	72,4	79,3	85,9	88,5	87,4
	s	14,7	12,5	9,42	9,15	9,24
	5%	47	52,3	69,0	73,0	71,0
Nordhessen II	n	12	22	12	14	26
	$\bar{x}$	87,3	90,8	92,9	97,3	95,3
	s	12,5	10,6	10,2	9,47	9,87
	min/5%	71,6	70,4	77	76,4	76,6
all	n	75	91	74	79	153
	$\bar{x}$	77,6	82,8	88,1	88,5	88,3
	s	13,4	12,9	10,4	11,3	10,8
	5%	50,8	58,3	69,7	68,7	69,3
	CL$_{95}$[1]	50,2-59,7	57,0-65,3	66,8-74,2	65,6-73,4	67,6-72,9
density[2] (kg/m^3)						
	$\bar{x}$	661	671	678	699	-
	s	37,6	28,7	36,4	31,5	-
	min-max	583-770	605-752	589-786	621-817	-

[1] 95% Confidence limits of the characteristic value assuming normal distributed data

[2] determined at both ends of the specimens as per EN 408