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BEECH GLULAM STRENGTH CLASSES

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Beech Glulam Strength Classes

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1 Abstract

The following paper contains essential background information to provide an insight into the intended determination of characteristic values of the bending strength of beech glulam and of strength classes for beech glulam, respectively. The basis of this investigation is a research project performed at the Universität Karlsruhe [1].
Mechanical grading according to the dynamic MOE of 1888 beech boards for the production of 47 combined test beams is described. The results of bending tests of glulam beams according to EN 408 are presented. They confirm that mechanical grading using the dynamic MOE is an effective step towards high strength glulam beam production. These test results were used to verify a newly developed calculation model. It is suitable to determine both the characteristic tensile strength of boards and the characteristic bending strength of combined glulam beams. Using the calculation model, five different grading methods were numerically derived. They are based on visual and/or mechanical grading. Combined test beams are simulated taking into account the different grading methods and the beam load-carrying capacity was numerically determined depending on variable characteristic finger joint bending strength. The results of 235 bending tests on finger joints are presented. The specimens were produced from both, visually and mechanically graded boards. The results clarify the evident influence of the grading method on the characteristic strength values. They render possible strength classes up to GL48.

2 Background

2.1 Testing material and bending tests on beech glulam beams

Three sawmills located in Germany (Nordhessen, Schönbuch and Spessart) each delivered one third of the 1888 boards which were used to produce the test beams. The boards were graded using the dynamic MOE (= E_{dyn}) according to the scheme shown in Table 1. [2] gives the basis of the applicability of machine strength grading based on dynamic MOE from longitudinal vibration. The division based on MOE allowed a combined lay-up with lamellae of high stiffness in the outer zones of the test beams. Fig. 1 depicts the yield in the different grades. Table 2 and Table 3 give details of the beam lay-up. The total amount of 1888 boards was used to produce the beams. This confirms the economical aspect of the proposed grading scheme. Three strength classes and two beam heights were realised.

Fig. 2 shows the relation between the experimental data and the fitted normal density function of the beam bending strength. To provide a wider base to the statistical values the strength classes "very high" and "high" were merged for each beam height. Grading boards having a dynamic MOE over 15000 N/mm² ensures a characteristic bending strength of about 46,1 N/mm² (43,6 N/mm²) at a beam height of 340 mm (600 mm).

Table 1 Grading scheme according to dynamic MOE

grade	range of dynamic MOE (N/mm²)
1	$E_{dyn} \leq 13000$
2	$13000 < E_{dyn} \leq 14000$
3	$14000 < E_{dyn} \leq 15000$
4	$15000 < E_{dyn} \leq 16000$
5	$16000 < E_{dyn}$

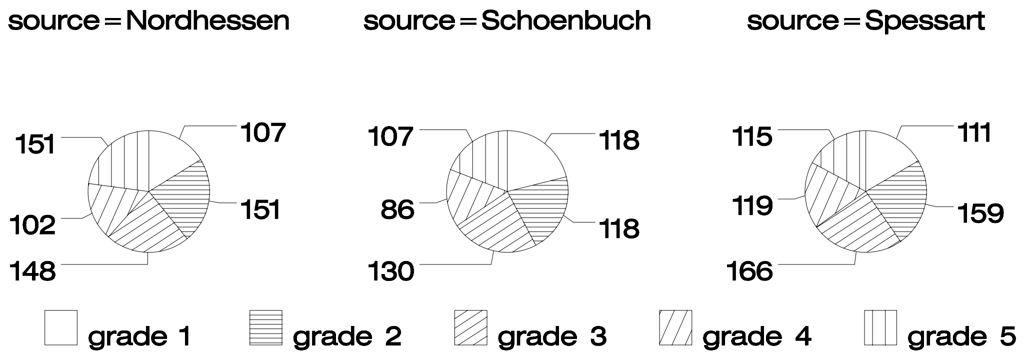


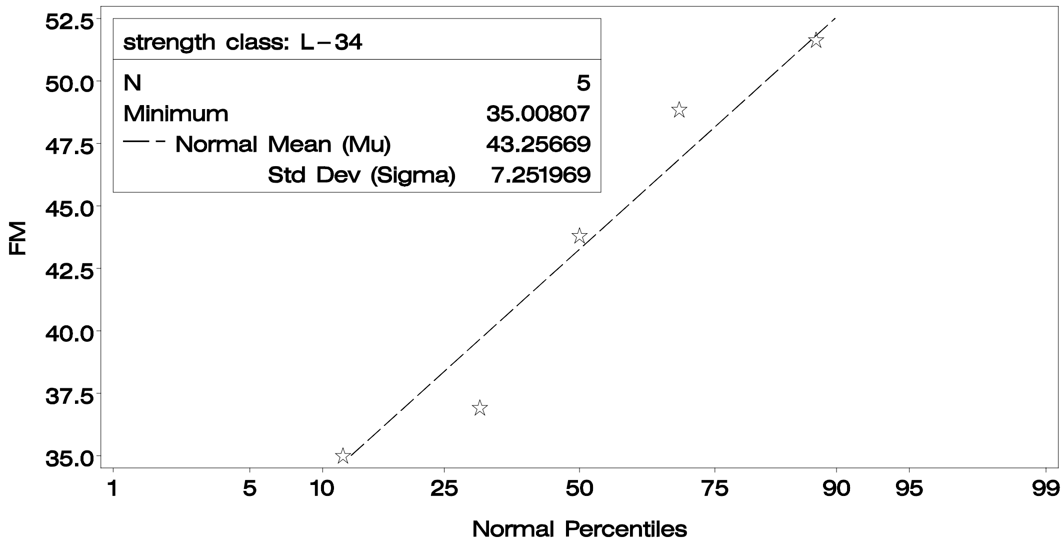
Fig. 1 Absolute yield in the 5 grades

Table 2 Acronym of strength class/sample size of the series and beam span

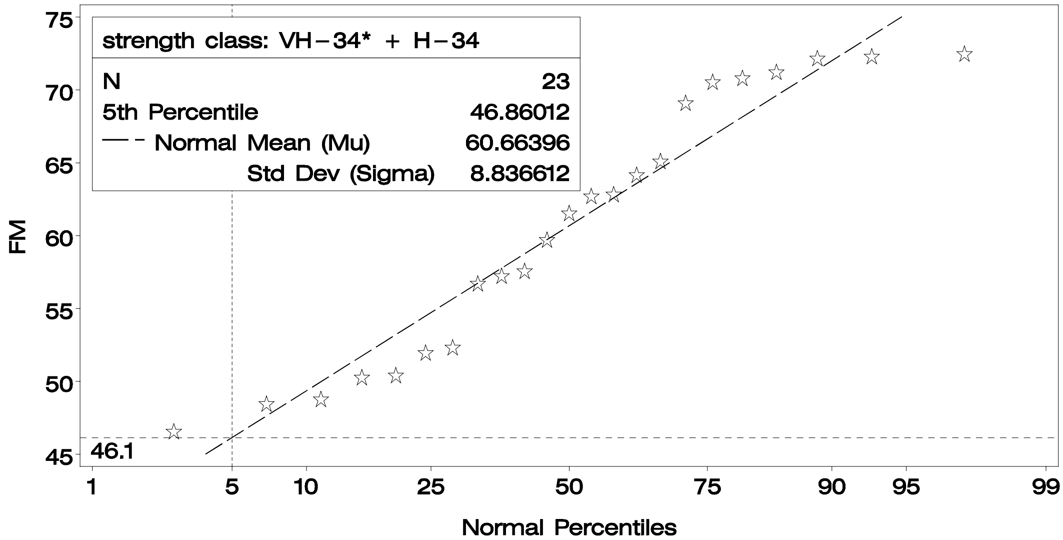
height h (mm)	340	600
strength class		
very high	VH-34 / 12	VH-60 / 10
high	H-34 / 12	H-60 / 8
low	L-34 / 5	-
span ℓ(m)	5,10	9,00

Table 3 Strength class and combined beam lay-up

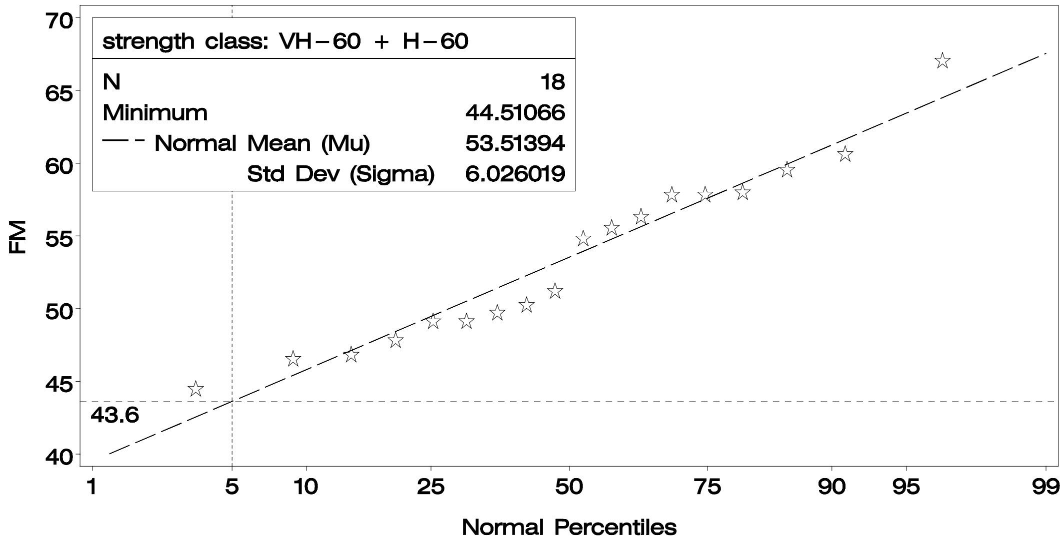
strength class	grade of lamellae according Table 1	
	outer zone 1 (h/6)	inner zone 2 (4h/6)
very high	5	3
high	4	2
low	1	1



a)



b)



c)

Fig. 2 experimental data versus fitted normal density function;
strength class L-34 (a), VH-34 + H-34 (b) and VH-60 + H-60 (c)
*A poorly manufactured finger joint in the outermost lamella caused a strength value of 32,7 N/mm². Hence this value is disregarded.

2.2 Calculation model

The calculation model is divided into a simulation and a finite element programme. The simulation programme works similarly as the real glulam production. A continuous lamella is generated consisting of simulated boards and finger joints. The mechanical properties are determined in steps of 150 mm. The autocorrelation of the mechanical properties is taken into account. The results are boards of low up to high quality. The activation of different density functions which describe the structural properties of the boards enables the simulation of a grading process according to the scheme in Table 1 as well as the grading proposals in Table 4 with regard to practical application. In general beams with combined lay-ups are simulated taking into account the economical use of the higher grade boards. The beam bending strength and MOE are calculated using a commercial finite element programme. Fig. 3 shows the mechanical model. Instead of a load a stepwise displacement Δu is applied in the middle of the loading equipment. Hence the unknown ultimate load is the sum of the forces in the links. The ultimate load is achieved when a crack is modelled in the outermost lamination. In this way the test concerning the EN 408 is suitably substituted.

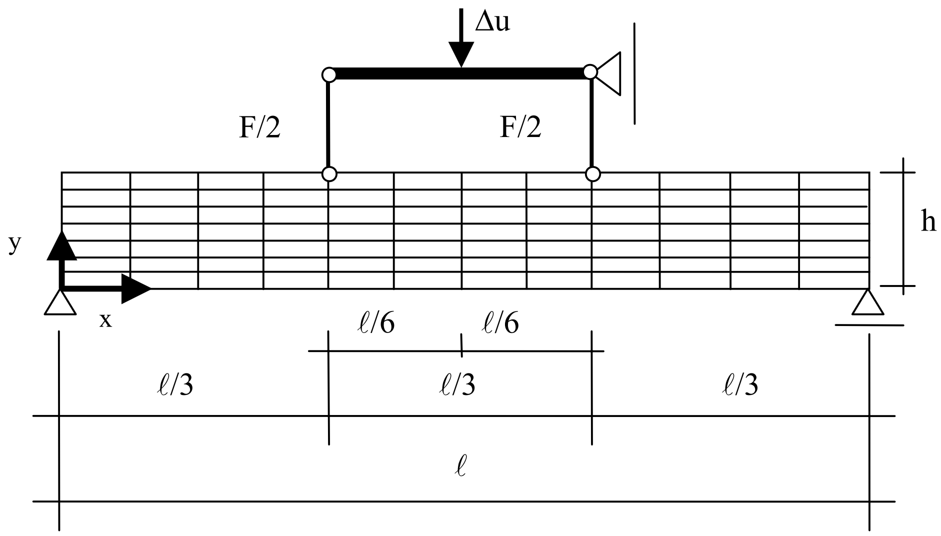


Fig. 3 Finite element model

2.3 Grading models

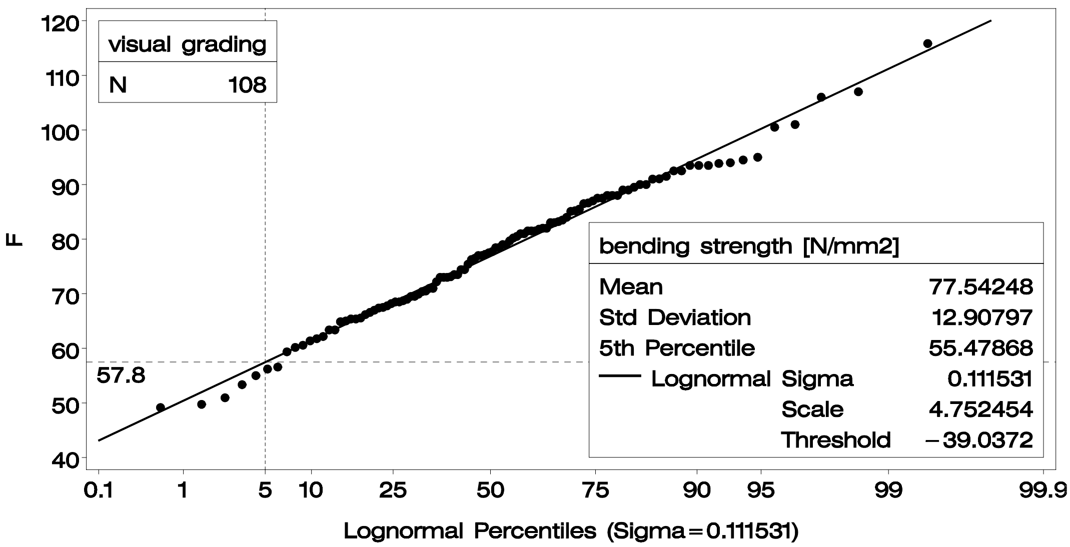
A large database describing the structural properties of the 1888 boards was used to develop the grading models. The mechanical grading using the dynamic MOE was only applied to simply and effectively divide the boards into classes to produce the combined test beams. Therefore it was not possible to produce multiple test series of beams considering different grading methods. This was performed with the calculation model taking into account the grades given in Table 4. The DEB value quantifies the single knot according to DIN 4074. More details concerning the determination of characteristic tensile strength of the boards as shown in the last column of Table 4 can be found in [3].

Table 4 Grades

No.	Model	knots	MOE (N/mm²)	characteristic tensile strength EN 408 (N/mm²)
1	LS10	DEB ≤ 0,33	-	22
2	LS13a	DEB ≤ 0,20	-	27
3	LS13b	DEB ≤ 0,042	-	31
4	MSa	DEB ≤ 0,20	15000 < E_{dyn}	40
5	MSb	DEB ≤ 0,042	15000 < E_{dyn}	48

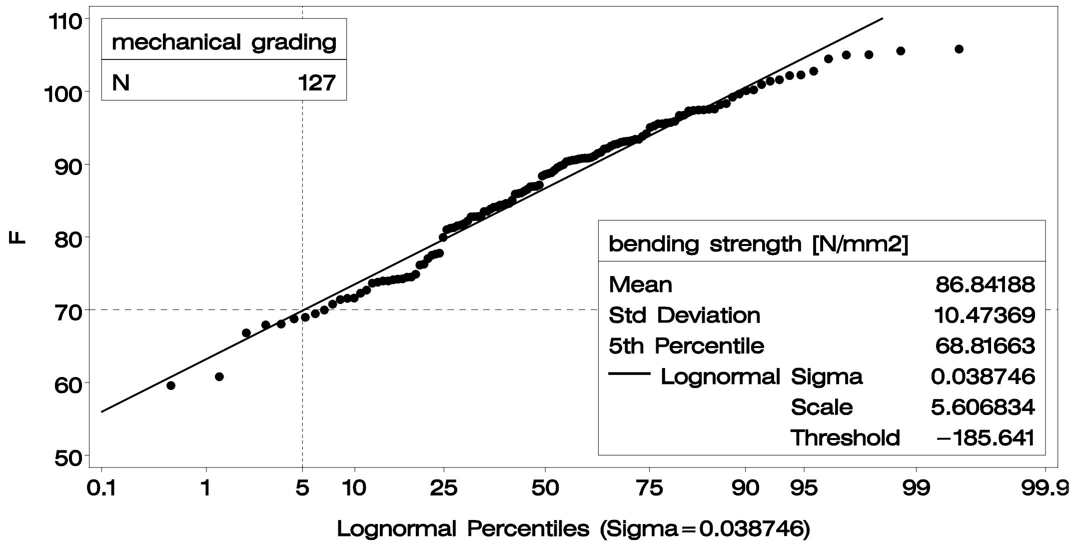
2.4 Bending tests on finger joints

108 bending tests on finger joints manufactured from visually graded boards were performed. A further 127 tests were carried out to study the influence of mechanical grading on the bending strength of finger joints. These specimens were manufactured in the laboratory from the undamaged parts of tested beams. The clearly defined lay-up of the beams, see Table 3, made it possible to assign the specimens to the grades of the connected boards. All the bending tests were conducted flat wise according to EN 408 with a span of 15 times the height. The 5th percentile is 55,5 N/mm² in case of visual grading (Fig. 4 a). No increase of bending strength between grades 4 and 5 can be observed. Therefore the 127 specimens belonging to grades 4 and 5 were merged. The 5th percentile amounts to 68,8 N/mm² (Fig. 4 b). In terms of technical feasibility mechanical grading of grades 4 and 5 allows a 5th percentile value exceeding 70 N/mm². The continuous distribution of the experimental data is confirmed by the fitted lognormal curve in Fig. 4 a and b. A comparison of both visual and mechanical grading is depicted in Fig. 5.



a)

Fig. 4 Experimental data versus fitted lognormal density function; visual grading (a)



b)

Fig. 4 (Continuation) experimental data versus fitted lognormal density function; mechanical grading (b)

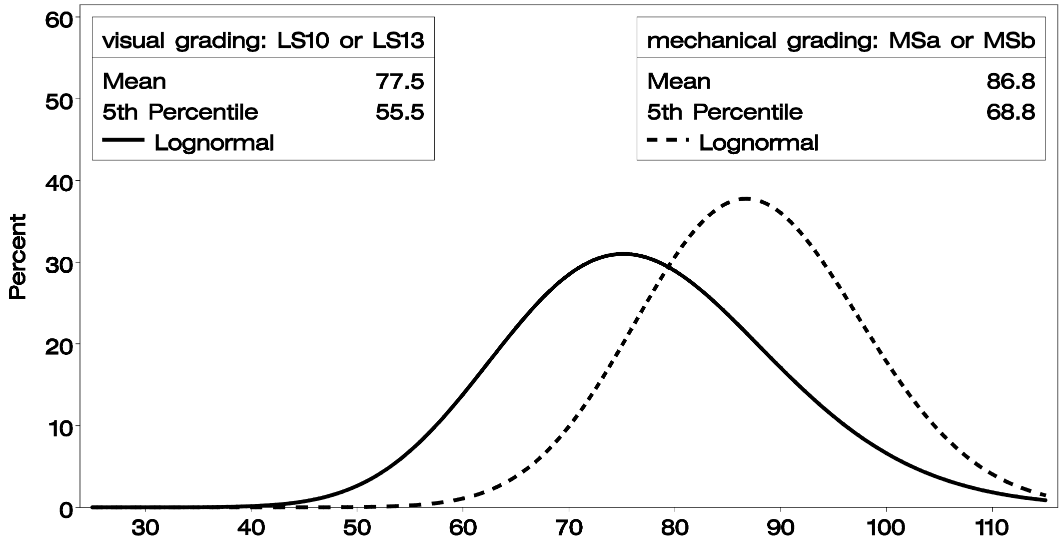


Fig. 5 lognormal density curve of finger joint bending strength (N/mm²); visual grading in comparison with mechanical grading

3 Strength classes

3.1 Proposals for strength classes

The influence of the grading method can be demonstrated in two ways. 1.: Fig. 6 displays the classification depending on grading model and variable finger joint bending strength. 2.: Using the data shown in Fig. 6 together with the characteristic tensile strength of boards as shown in Table 4, equation (1) can be derived. In this equation the characteristic glulam bending strength (= $f_{m,g,k}$) is calculated from both the characteristic tensile strength of the boards (= $f_{t,l,k}$) and the characteristic finger joint bending strength (= $f_{m,j,k}$). Considering the upper limits of the characteristic finger joint bending strength two further equations can be derived. Incorporating the values of 56 N/mm² (visual grading) and 70 N/mm² (mechanical grading) in equation (1) leads to the equations (2) and (3). The beech glulam design proposals in comparison with the current model in EN 1194 referring to softwood, see equation (4), are shown in Fig. 7. There, the model according to equation (3) seems to be an adequate continuation of the model according to equation (4).

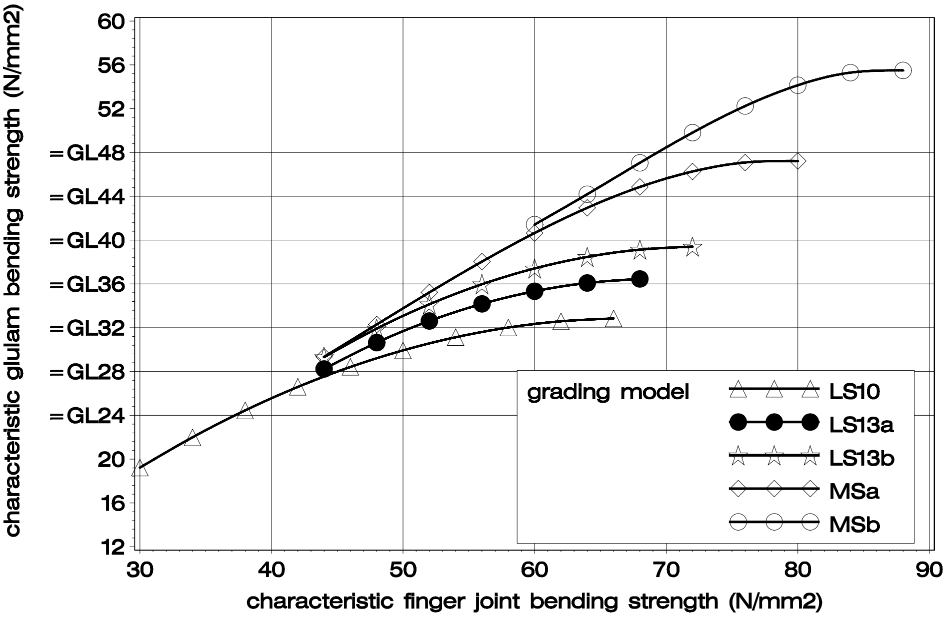


Fig. 6 Characteristic bending strength of glulam depending on characteristic finger joint bending strength

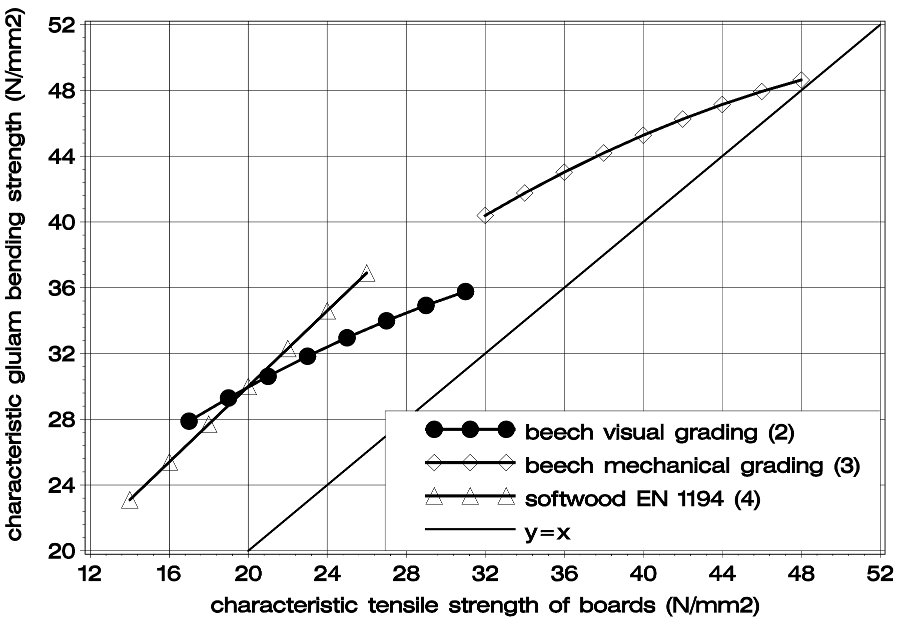


Fig. 7 Design models in comparison

$$f_{m,g,k} = -2,87 + 0,844 \cdot f_{m,j,k} - 0,0103 \cdot f_{m,j,k}{}^2 \\ -0,192 \cdot f_{t,l,k} - 0,0119 \cdot f_{t,l,k}{}^2 + 0,0237 \cdot f_{m,j,k} \cdot f_{t,l,k} \qquad (1)$$

$$f_{m,g,k} = 12,0 + 1,13 \cdot f_{t,l,k} - 0,0119 \cdot f_{t,l,k}{}^2 \qquad (2)$$

$$f_{m,g,k} = 5,66 + 1,47 \cdot f_{t,l,k} - 0,0119 \cdot f_{t,l,k}{}^2 \qquad (3)$$

$$f_{m,g,k} = 7 + 1{,}15 \cdot f_{t,l,k} \quad (4)$$

3.2 Size effect

It is expected that the length of boards or the size of the beam, respectively, affects the characteristic bending strength of the beams. Assuming that the mean length of boards of about 2600 mm keeps constant, the influence of beam size on the bending strength is studied using the calculation model. The result of the study is shown in Fig. 8. Therein the beam height was varied from 300 mm up to 1500 mm in steps of 300 mm. The regression curve describing the height factor (= k_h) was calculated from a total of 6400 single calculations. During the calculations the relation of beam height and beam span is 1/18. The thickness of lamellae is 30 mm and the width 100 mm. The low influence of board width on the beam strength is reported in [1]. The value of the exponent (= 0,143) in equation (5) is very close to the value used in DIN 1052 (= 0,14). In EN 1194 an exponent of 0,10 is assumed. Since no further decrease in bending strength above h = 1200 mm was observed in the simulations, the decrease in bending strength is limited to 10 %. Consequently, equation (6) describes the size effect.

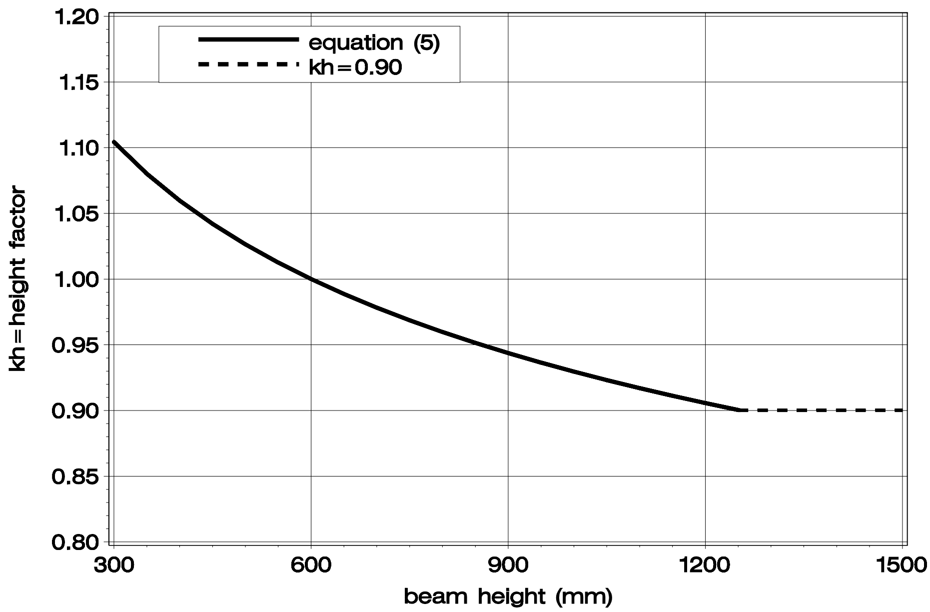


Fig. 8 Size effect

$$k_h = \left(\frac{600}{h}\right)^{0,143} \quad (5)$$

$$k_h = \begin{cases} 1{,}10 & h < 300\,\text{mm} \\ \left(\frac{600}{h}\right)^{0,14} & 300 \le h \le 1200\,\text{mm} \\ 0{,}90 & h > 1200\,\text{mm} \end{cases} \quad (6)$$

4 Conclusions

Table 5 gives a survey of the results. The most important findings are:

- Using beech glulam, it is possible to establish three further strength classes exceeding the strength class GL36. The maximum increase of bending strength is 33% comparing GL48 with GL36.
- The proposed strength grading techniques provide a remarkable 5th percentile MOE value of 12700 N/mm² and 14700 N/mm², respectively. The low difference between the mean values concerning GL36 made of softwood and GL48 made of beech could be extended by higher dynamic MOE limits for beech lamellae.
- Visual grading enables glulam producers to offer GL36.
- The increase in bending strength with decreasing beam height is as expected. Beam heights exceeding 600 mm cause a reduction of bending strength up to 10%.
- Further investigations are necessary to provide for factors from which more characteristic values can be calculated.

Table 5 Strength and stiffness values and requirements; reference beam height 600 mm

	GL28c	GL32c	GL36c	GL40c	GL44c	GL48c
strength values (N/mm²)						
$f_{m,k}$	28	32	36	40	44	48
stiffness values (N/mm²)						
$E_{0,mean}$	13500	13500	13500	15100	15100	15100
$E_{0,05}$	12700	12700	12700	14700	14700	14700
requirements outer zone 1						
DEB	≤0,33	≤0,20	≤0,042	≤0,20	≤0,20	≤0,042
E_{dyn}	-	-	-	>15000	>15000	>15000
$f_{m,j,k}$	≥45	≥50	≥56	≥59	≥66	≥70
requirements inner zone 2						
DEB	≤0,50	≤0,50	≤0,50	≤0,50	≤0,50	≤0,50
	-	-	-	≥14000	≥14000	≥14000

5 References

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