Behavior of Glulam in Compression Perpendicular to Grain in Different Strength Grades and Load Configurations

COST E55
Eindhoven / Netherlands

M. Augustin (Speaker)
A. Ruli
R. Brandner
G. Schickhofer

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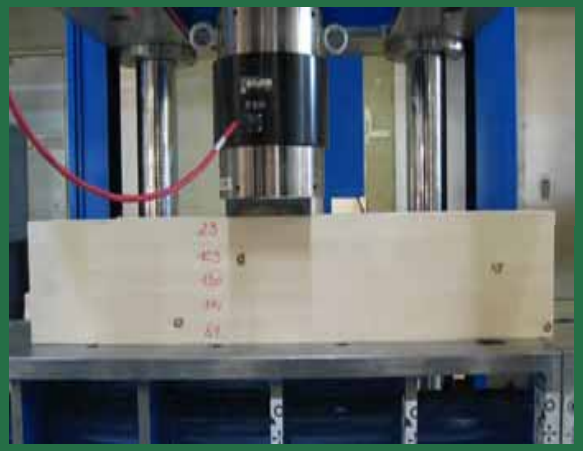
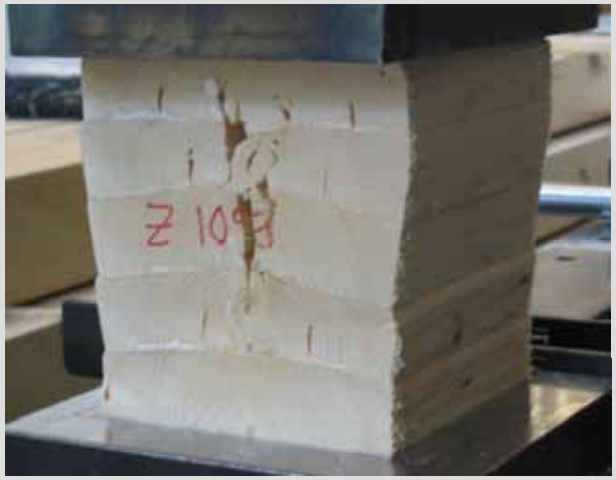
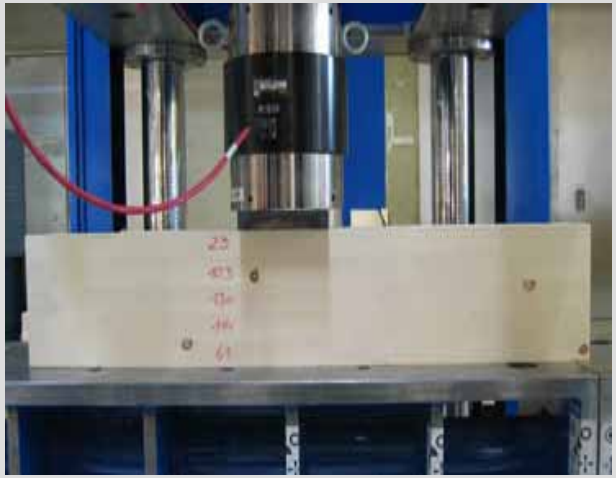


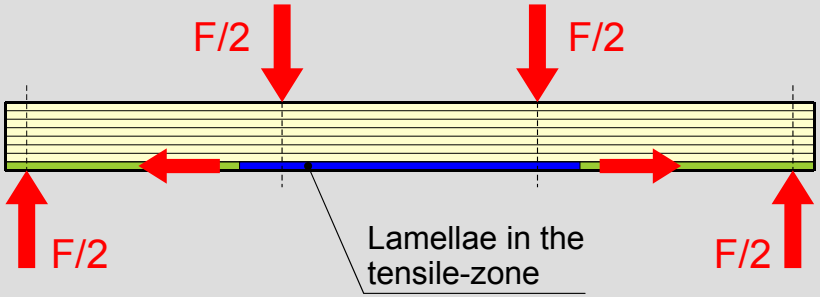
Outline





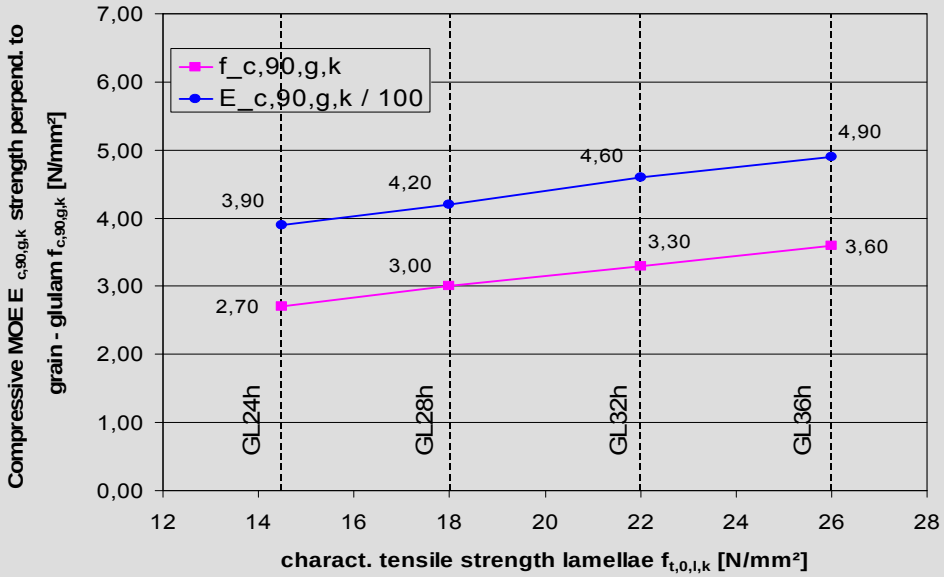
- Basic situation:
  Regulations of EN 1194:1999
- Testing configuration series I
- Results and correlations in compression perpendicular to grain –
  cubic specimens I
- Testing configuration series II
- Results and correlations in compression perpendicular to grain –
  cubic specimens II
- Results and correlations - tests on sills
- Conclusion and discussion

In the specifications of EN 1194:1999 (“Glulam – Strength classes and determination of characteristic values“) mechanical properties are dependent from the tensile properties of the used boards (“beam-model“).



Correlation charact. bending strength glulam – charact. tensile strength lamellae:

$$f_{m,g,k} = 7 + 1{,}15 \cdot f_{t,0,l,k}$$



- Modulus of Elasticity perpendicular to grain:

$$E_{90,g,mean} = 0{,}035 \cdot E_{0,l,mean}$$

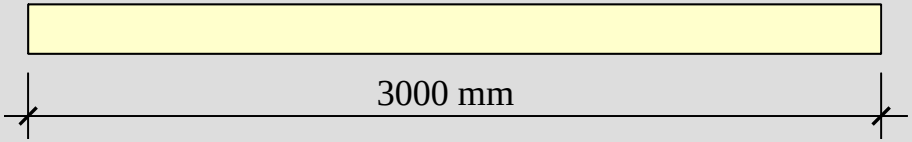
- Characteristic compressive strength perpendicular to grain:

$$f_{c,90,g,k} = 0{,}7 \cdot f_{t,0,l,k}^{\;0{,}5}$$

160 boards (l/b/h = 4000/174/40 mm)

Classification into 3 groups by means of ultrasonic measurement

Tensile tests



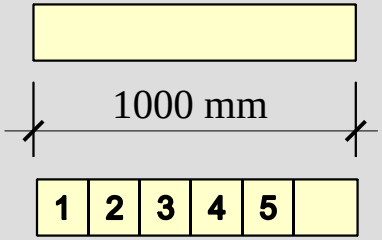
Tensile tests

Tests in accord. to EN 408:2005

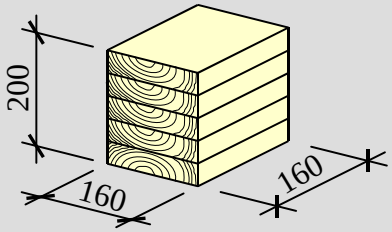
Analysis in accord. to EN 384:2004 resp. prEN 14358:2006

Tests compression perp. to grain

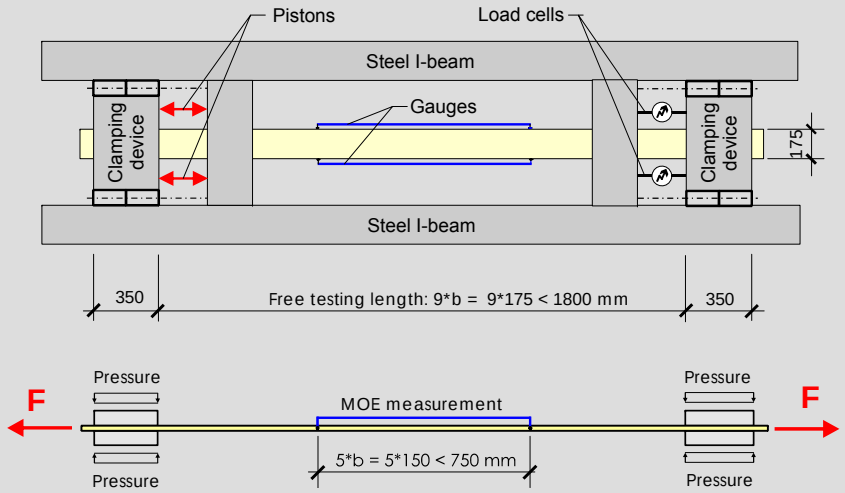
Tests in compression perpendicular to grain



3 x 20 Tests



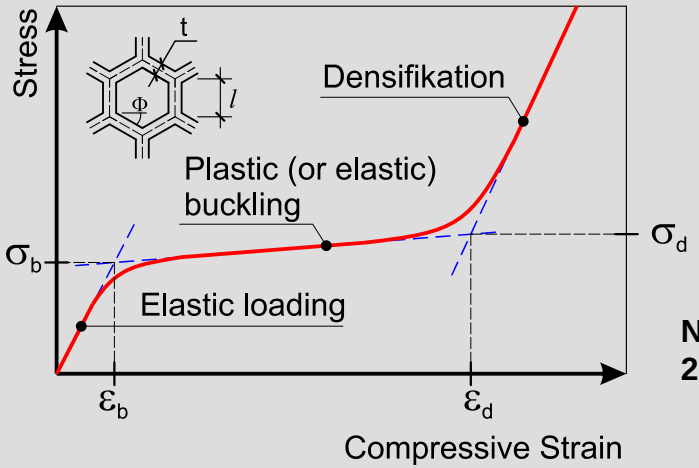
Tensile tests in accord. to EN 408:2005



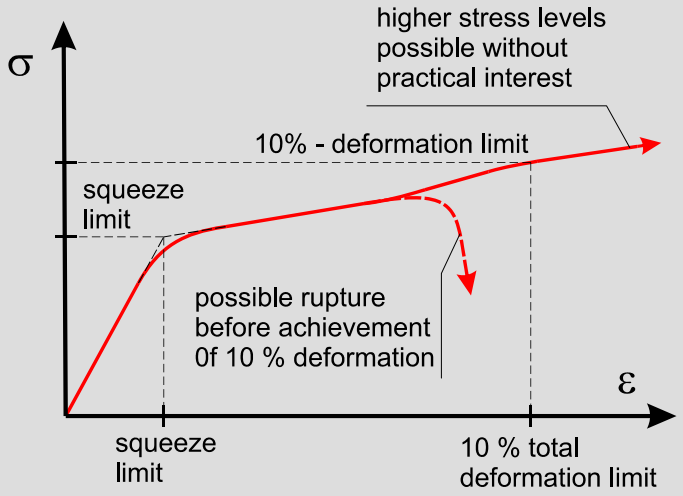
Results

Stiffness class	Threshold values E_{dyn}	Number of specimen	Density $\rho_{l,k}$ ($\rho_{l,mean}$)	(Tensile-) MOE $E_{t,0,l,k}$	Tensile strength boards			
					Mean	Stand.-Dev.	COV	$f_{t,l,0,k}$ (EN 14358)
	[N/mm²]	[-]	[kg/m³]	[N/mm²]	[N/mm²]	[N/mm²]	[%]	[N/mm²]
K1	> 17.000	30	446 (481)	14.730	49,54	11,82	23,87	29,31
K2	15.500 < MOE_{dyn} < 17.000	30	416 (450)	12.290	33,70	8,79	26,07	18,75
K3	< 15.500	30	372 (408)	10.340	27,60	9,36	33,87	12,32

Test configuration compression perpendicular to grain

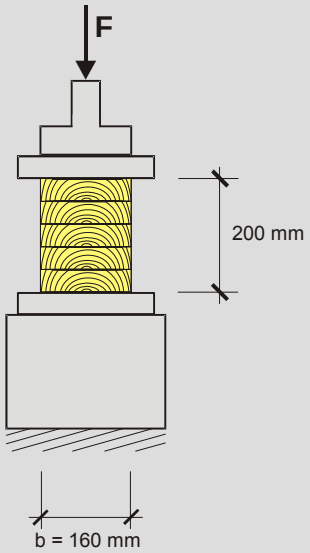


Nairn, 2005

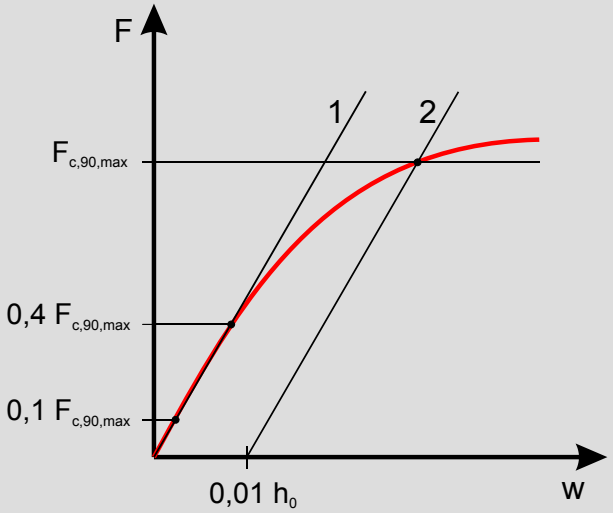


Gehri zit. A. Föppl, 1904

Definition maximum compressive load perp. to grain (EN 408:2005): $F_{c,90,max}$



- Standardized specimens (h = 200 mm, A = 25000 mm²)
- Estimation of a force $F_{c,90,max}$
- Straight line between 0,1 - 0,4 $F_{c,90,max}$ (Line 1)
- Parallel shift by a distance 0,01 h_0 (Line 2)
- Repeat until the intersection point is within a tolerance limit of ± 5%



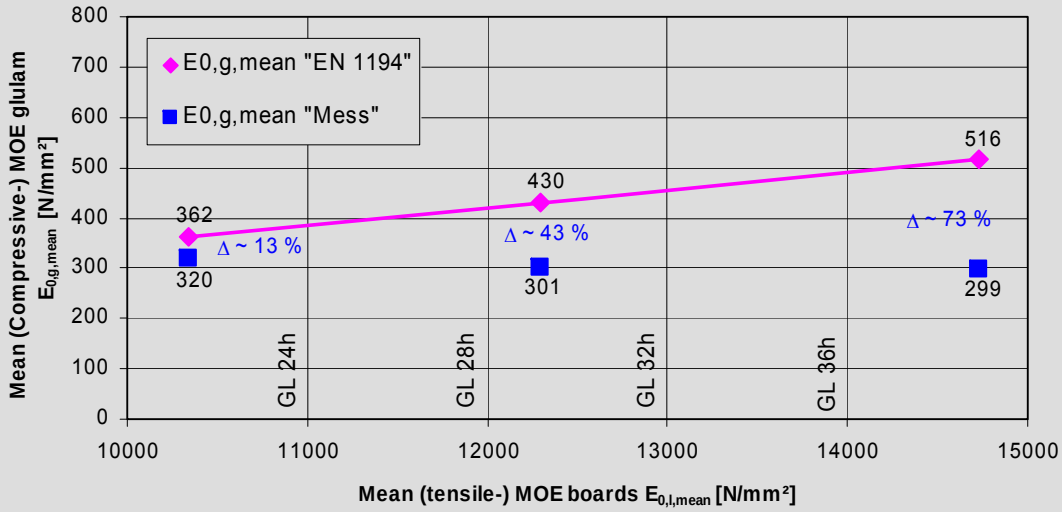
Tests in compression perpendicular to the grain in accord. with EN 408:2005 (h_0 = 200 mm)

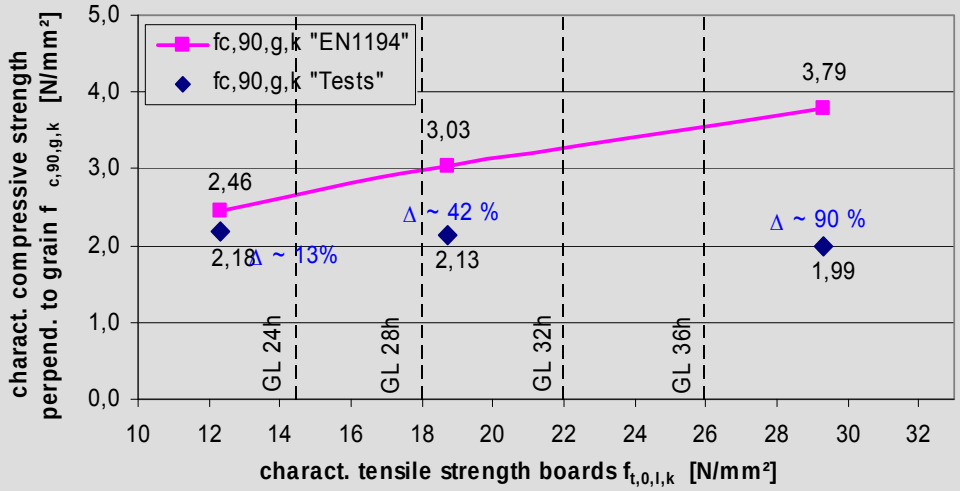
Stiff-ness class	Speci-men number	Density boards $\rho_{l,k}$ ($\rho_{l,mean}$)	Density specimen $\rho_{g,k}$ ($\rho_{g,mean}$)	(Tensile-) MOE boards $E_{t,0,l,k}$	MOE perp. EN 1194	MOE perp. Tests	Percen-tage of EN 1194	Tensile strengt h	Comp. stress perp. Norm	Comp. stress perp. Tests	Percen-tage of EN 1194
					$E_{90,g,k}$	$E_{90,g,k}$		$f_{t,l,0,k}$ EN 14358	$f_{c,90,g,k}$ EN 1194	$f_{c,90,g,k}$ EN 14358	
	[-]	[kg/m³]	[kg/m³]	[N/mm²]	[N/mm²]	[N/mm²]	[%]	[N/mm²]	[N/mm²]	[N/mm²]	[%]
K1	19	446 (481)	449 (490)	14730	516	299	58	29,31	3,79	1,99	53
K2	22	416 (450)	403 (439)	12290	430	301	70	18,75	3,03	2,13	70
K3	21	372 (408)	335 (418)	10340	362	320	88	12,32	2,46	2,18	89

Statement

- **Both the mean value of compression MOE and the characteristic compression strength perpendicular to grain indicate NO dependence on the tensile strength of the used boards.**
- **In particular for the higher stiffness grades of the used boards considerable deviations in relation to the function specified in EN 1194:1999 could be verified.**

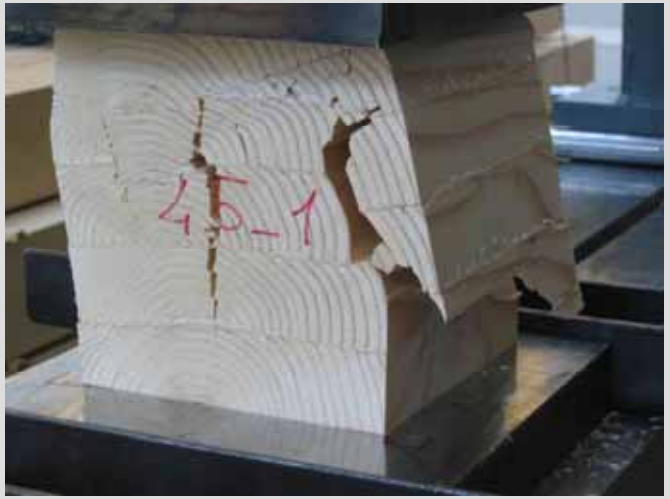
Correlation mean (tensile) MOE board – (Compression-) MOE perpendicular to the grain glulam





Correlation characteristic tensile strength board – charact. compression strength perpendicular to the grain glulam

Tests
cubic specimens



Material

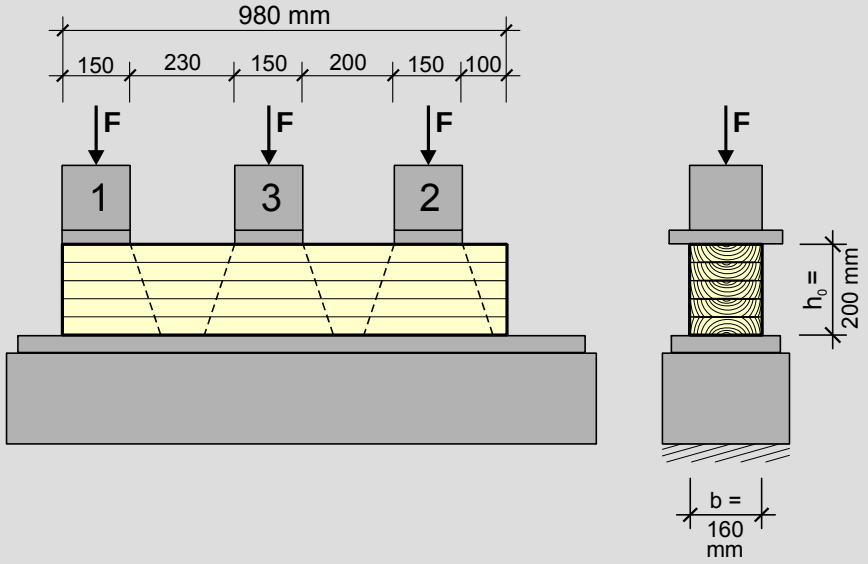
- Machine graded boards in grades MS10, MS13 and MS17 (per grade 135 specimens)
- Cut analog to series I resp. sills (see left)

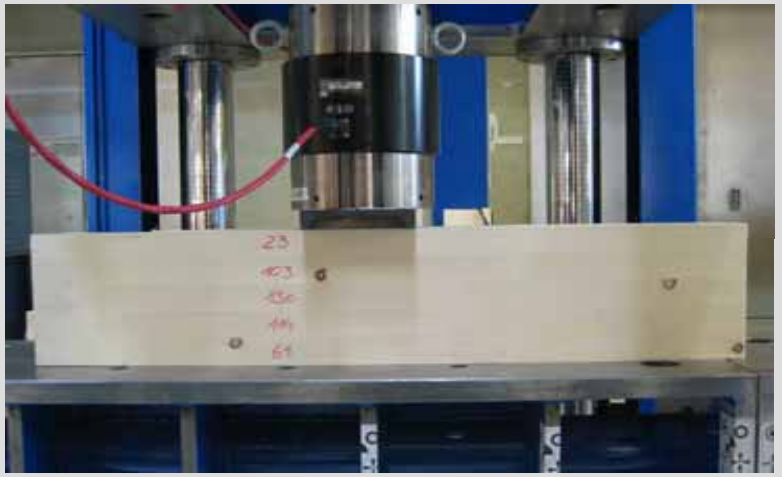
Conducted tests

Per grading class (GC):

- Tensile tests (per GC 135 specimens)
- Verification results of series I (cubic specimens h_0 = 200 mm) per GC about 40 specimens
- Verification of specimens height influence (cubic specimens h_0 = 480 mm) per GC 6 specimens
- Tests on sills with 3 different loading situations (h_0 = 200 mm) per GC 18 specimens
- Verification of specimens height influence on sills (h_0 = 480 mm) per GC 5 specimens

Test configuration sills





Results cubic specimens

Tensile tests in accordance to EN 408:2005

Grading class	Speci-mens number	Density $\rho_{l,k}$ ($\rho_{l,mean}$)	(Tensile-) MOE $E_{t,0,l,k}$	Tensile strength				
				Mean	Standdev.	COV	$f_{t,l,0,k}$ EN 14358	$f_{t,l,0,k}$ EN 384
	[-]	[kg/m³]	[N/mm²]	[N/mm²]	[N/mm²]	[%]	[N/mm²]	[N/mm²]
MS10 (C24M)	131	375 (419)	9.690	22,05	6,49	31	11,98	11,40
MS13 (C35M)	134	404 (452)	11.830	30,32	6,03	23	19,21	19,32
MS17 (C40M)	127	433 (489)	14.400	43,21	13,69	32	23,39	24,03

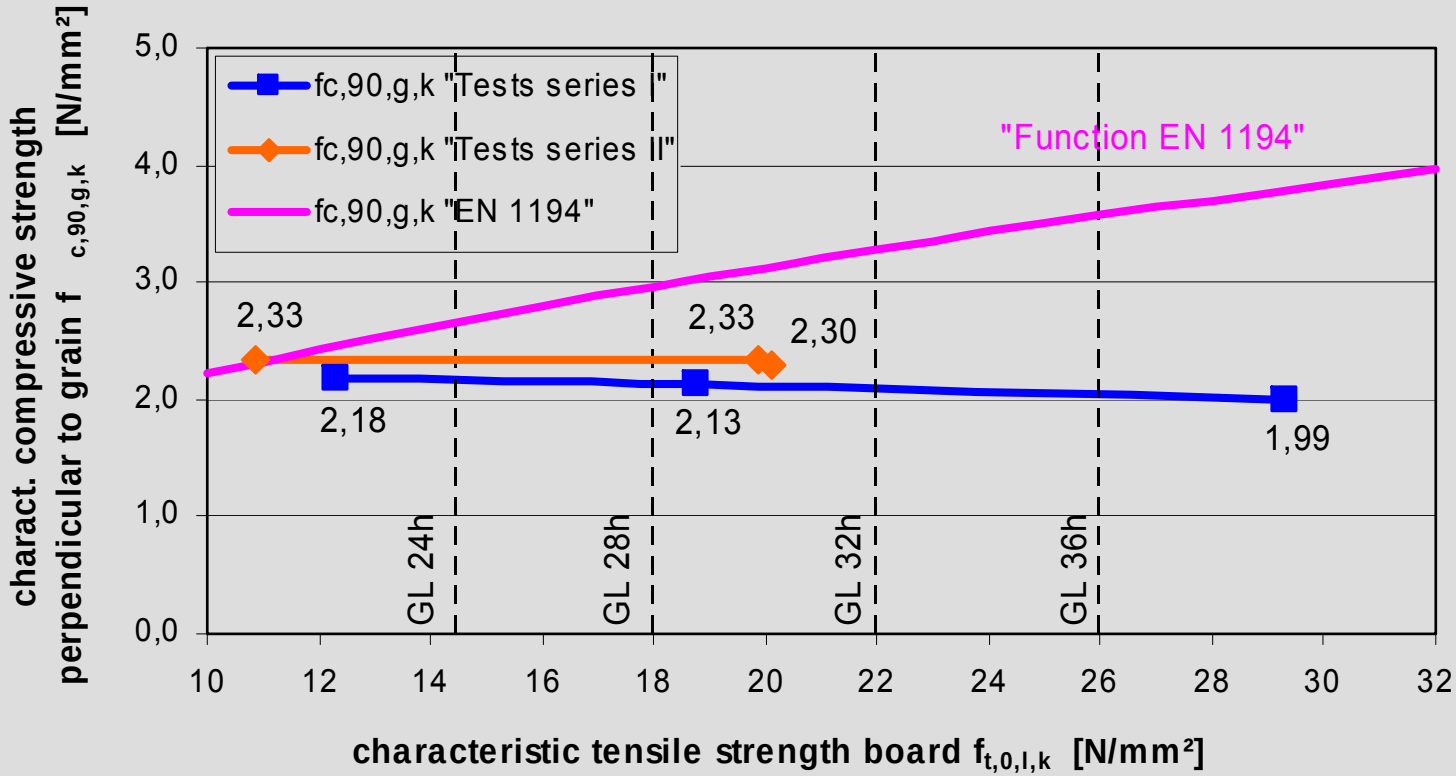
Comp. tests perp. to grain in accord. to EN 408:2005 (h_0 = 200 mm)

Grad-ing class	#	MOE comp. perp. to grain EN 1194	MOE comp. perp. to grain Tests	Percen-tage of EN 1194	Comp. strength perp. to grain EN 1194	Comp. strength perp. to grain Tests	Percen-tage of EN 1194
		$E_{90,g,k}$	$E_{90,g,k}$		$f_{c,90,g,k}$ EN 1194	$f_{c,90,g,k}$ EN 14358	
	[-]	[N/mm²]	[N/mm²]	[%]	[N/mm²]	[N/mm²]	[-]
MS10	41	339	265	78	2,31	2,33	101
MS13	40	414	292	71	3,12	2,33	75
MS17	41	504	318	63	3,14	2,30	73

Comp. tests perp. to grain in accord. to EN 408:2005 (h_0 = 480 mm)

Grad-ing class	#	MOE comp. perp. to grain EN 1194	MOE comp. perp. to grain Tests	Percen-tage of EN 1194	Comp. strength perp. to grain EN 1194	Comp. strength perp. to grain Tests	Percen-tage of EN 1194
		$E_{90,g,k}$	$E_{90,g,k}$		$f_{c,90,g,k}$ EN 1194	$f_{c,90,g,k}$ EN 14358	
	[-]	[N/mm²]	[N/mm²]	[%]	[N/mm²]	[N/mm²]	[-]
MS10	6	339	272	80	2,31	2,10	91
MS13	6	414	255	62	3,12	2,11	68
MS17	6	504	312	62	3,14	2,17	69

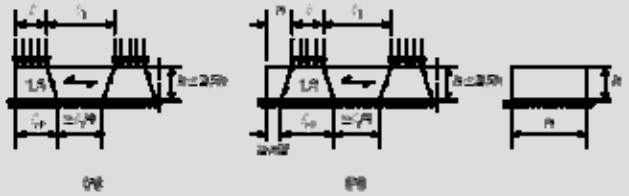
Correlation charact. tensile strength board – charact. compressive strength perpendicular to grain of glulam (cubic specimens)

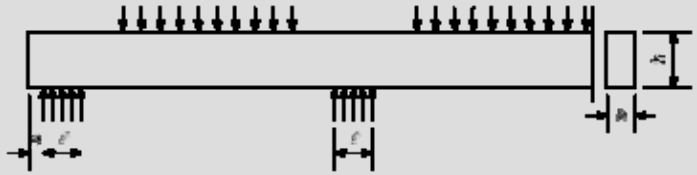


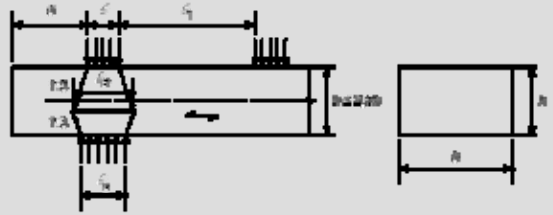
Results of standard test configuration (cubic specimen) have NO practical relevance.

Practical cases:

- Bearing areas
- (Local-) load introduction
- Transmitting loads through members
- Washers







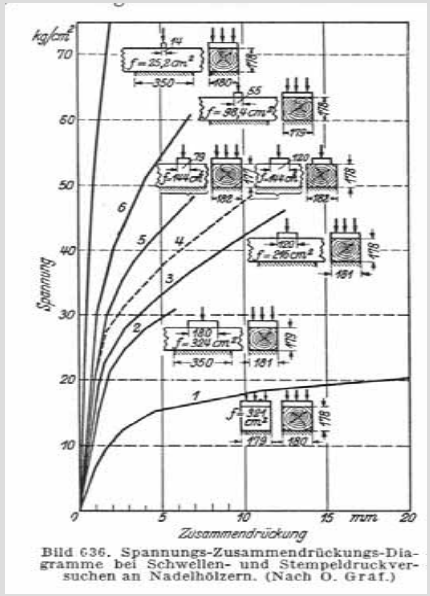
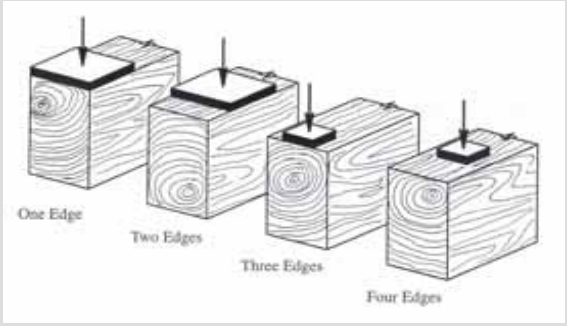


Bild 636. Spannungs-Zusammendrückungs-Diagramme bei Schwellen- und Stempeldruckversuchen an Nadelhölzern. (Nach O. Graf.)

Graf, 1921

Dependence on:

- Used product
- Geometry
  (Distance from the end)
- Loaded area and type of loading perpendicular to grain



Madsen, 2000

Design process (Eurocode):

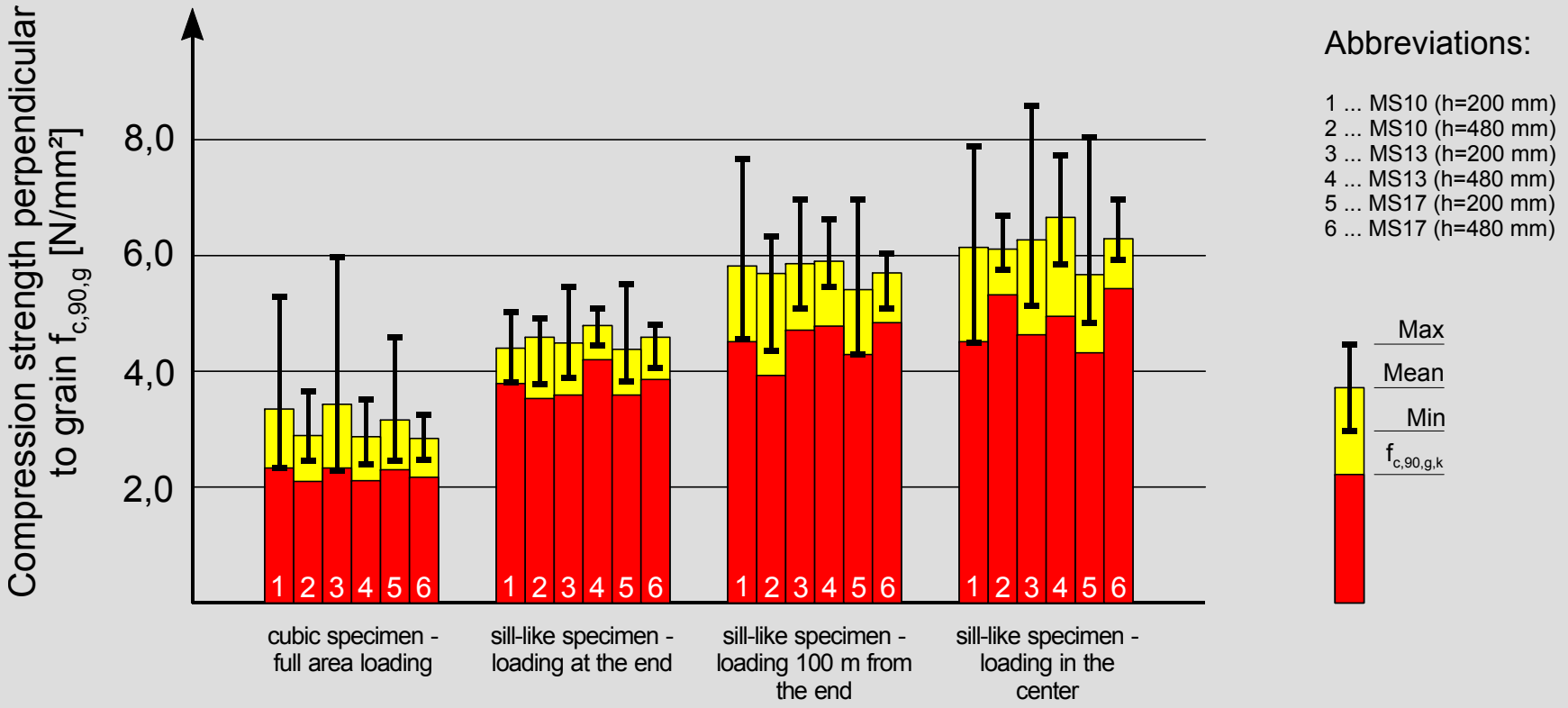
Consideration by means of $k_{c,90}$ - factors

$$f_{c,90,d} = \frac{f_{c,90,k}}{\gamma_M} \cdot k_{mod} \cdot k_{c,90}$$

Type of loading resp. construction	Lumber, Round timber	Glulam, Laminated lumber
loaded at the end with a distance a ≥ 100 mm	**1,3 (1,6)**	**1,5 (2,0)**
loaded in the middle a ≥ 100 mm	**1,5 (1,8)**	**1,8 (2,2)**
stress-laminated deck plates	**1,3**	**1,3**

$k_{c,90}$-factors in accord. to enBR (Stand: Nov 2005)

Charact. compressive strength perpendicular to grain dependent on specimens form, type of loading and specimens height



Conclusions

- The function specified in EN 1194:1999 between the tensile strength of the boards and the compressive strength perpendicular to the grain of glulam could not be confirmed. In particular no increase of the stiffness and strength for higher grading classes has been determined.
- For the specification in EN 1194 a MOE $E_{c,90,g,k}$ = 300 N/mm² and for the strength perpendicular to grain $f_{c,90,g,k}$ = 2,30 N/mm², valid for all glulam strength classes, is recommended.
- If the deformation limit is modified to 0,02 h_0 resp. 0,05 h_0 strength values perpendicular to grain are increasing by 15 % resp. 30 %.
- The only wood technological parameter that is influencing the mechanical behaviour of glulam perpendicular to the grain is the annual ring pattern.
- No dependence of specimens height for cubic specimens could be evaluated.
- Stiffness and strength values perpendicular to grain of sills are strongly dependent on the loading situation. This can be explained by the supporting effect of wood fibers beside the direct loaded areas.
- An increasing factor for the strength and as a conservative approach also for the MOE perpendicular to grain of about 1,50 for loadings at the end and about 1,80 for loadings “in the middle“ could be obtained.
- Stiffness and strength perpendicular to grain of sills are depending on specimens height.

Contact

Univ.-Prof. DI Dr.

Gerhard Schickhofer

Head of the institute and executive manager of hbf

+43 (0) 316 873-4600

gerhard.schickhofer@holzbauforschung.at

Inffeldgasse 24, A-8010 Graz / Austria

DI

Manfred Augustin

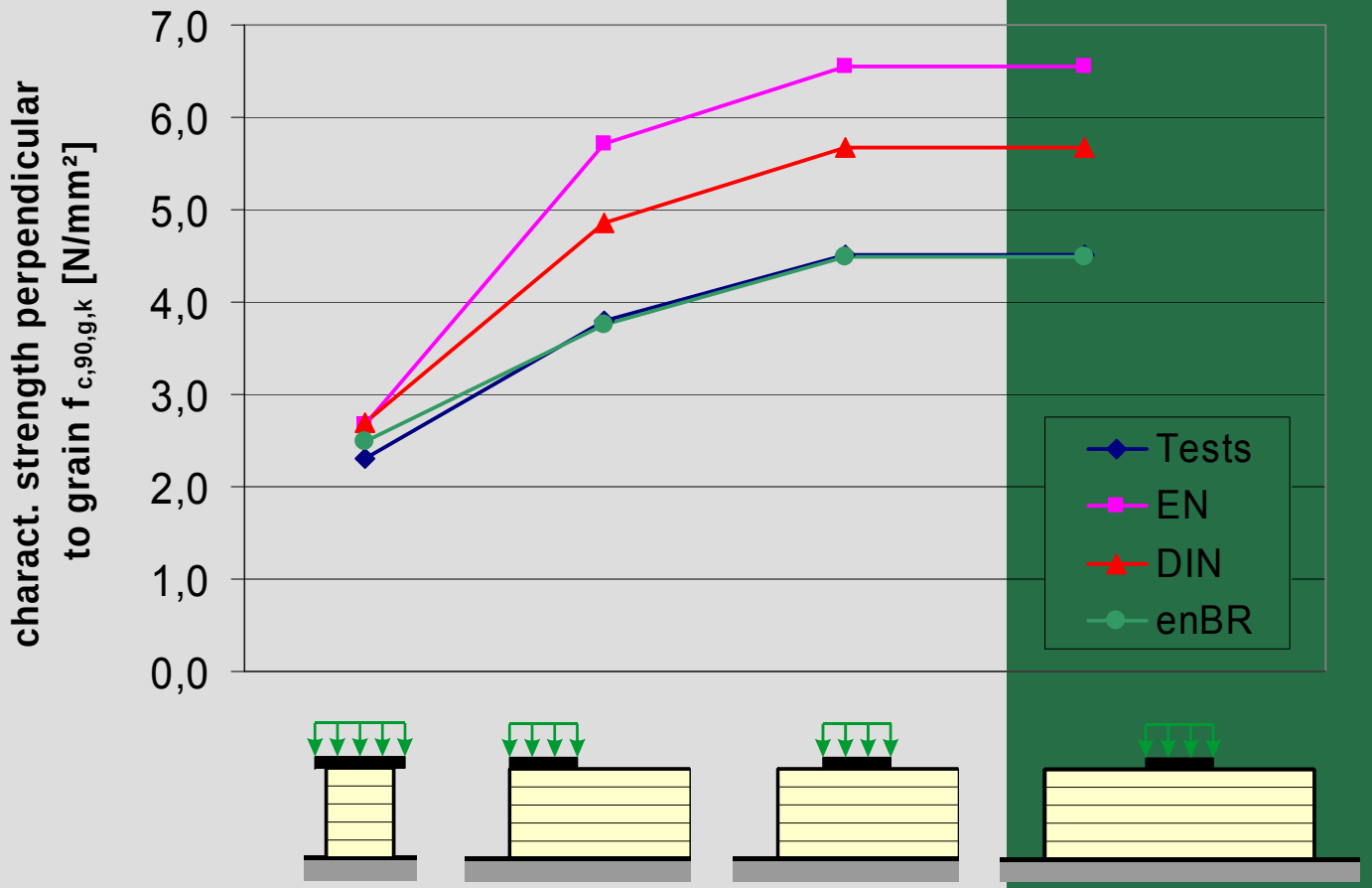
Scientific Assistent

+43 (0) 316 873-4604

manfred.augustin@lignum.tugraz.at

Inffeldgasse 24, A-8010 Graz / Austria

Comparision european standards $f_{c,90,g,k} * k_{c,90}$ for glulam s different loading conditions



Results compression tests perpendicular to grain - sills

Tests perpendicular to grain on sills (h_0 = 200 mm)

Grading class	Specimens number	MOE cubic specimens	MOE sills at the end	MOE sills 10 cm from the end	MOE sills "in the middle"	Comp. strength perp. cubic specimens	Comp. strength perp. sills at the end	Comp. strength perp. sills 10 cm from the end	Comp. strength perp. sills "in the middle"
		$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358
	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]
MS10	18	265	374	574	629	2,33	3,79	4,51	4,51
MS13	18	292	387	580	650	2,33	3,59	4,71	4,63
MS17	18	318	416	609	675	2,30	3,59	4,29	4,32

Tests perpendicular to grain on sills (h_0 = 480 mm)

Grading class	Specimens number	MOE cubic specimens	MOE sills at th end	MOE sills 10 cm from the end	MOE sills "in the middle"	Comp. strength perp. cubic specimens	Comp. strength perp. sills at the end	Comp. strength perp. sills 10 cm from the end	Comp. strength perp. sills "in the middle"
		$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358
	[-]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]
MS10	5	272	399	585	850	2,10	3,53	3,93	5,32
MS13	5	255	400	635	876	2,11	4,20	4,78	4,95
MS17	5	312	398	614	849	2,17	3,86	4,84	5,43

Tests compression perpendicular to grain of the sills – i
to the results of the cubic specimens (h_0 = 200 mm)

Grading class	Specimens number	MOE cubic specimens	MOE perp. to grain at the end	MOE perp. to grain 10 cm from the end	MOE perp. to grain "in the middle"	Comp. strength perp. to gr. cubic specimens	Comp. strength. perp. to gr. at the end	Comp. strength. perp. to gr. 10 cm from the end	Comp. strength perp. to gr. "in the middle"
		$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358
	[-]	[N/mm²]	[-]	[-]	[-]	[N/mm²]	[-]	[-]	[-]
MS10	18	265	1,41	2,17	2,37	2,33	1,63	1,94	1,94
MS13	18	292	1,33	1,99	2,23	2,33	1,54	2,02	1,99
MS17	18	318	1,31	1,92	2,12	2,30	1,56	1,87	1,88

Tests compression perpendicular to grain of the sills – i
to the results of the cubic specimens (h_0 = 480 mm)

Grading class	Specimens number	MOE cubic specimens	MOE perp. to grain at the end	MOE perp. to grain 10 cm from the end	MOE perp. to grain "in the middle"	Comp. strength perp. to gr. cubic specimens	Comp. strength. perp. to gr. at the end	Comp. strength. perp. to gr. 10 cm from the end	Comp. strength perp. to gr. "in the middle"
		$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$E_{90,g,k}$	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358	$f_{c,90,g,k}$ EN 14358
	[-]	[N/mm²]	[-]	[-]	[-]	[N/mm²]	[-]	[-]	[-]
MS10	5	272	1,47	2,15	3,13	2,10	1,68	1,87	2,53
MS13	5	255	1,57	2,49	3,44	2,11	1,99	2,27	2,35
MS17	5	312	1,28	1,97	2,72	2,17	1,78	2,23	2,50

Charact. compressive strength perpendicular to grain dependent on specimens form, type of loading and specimens height