HOLZ FORSCHUNG AUSTRIA

European Hardwoods for the Building Sector

Reality of today – possibilities for tomorrow

Peter Linsenmann

eu-hardwoods

Motivation for EU Hardwoods

Background

forestry

- missing market or market with low added value for hardwood

building products

- ~~CE marking~~, only national technical approvals
- performance of gluing systems

mechanical data

- only few European hardwood species allocated in EN1912
- missing experience in visual and machine strength grading

research necessity with European dimension

Funding

- 4th joint call within WoodWisdom-Net
  - as part of ERA-Net plus of FP7
  - focussing on topics in the area of interest between forestry and industry
  - with the idea to cofund national initiatives
  - ➔ application within "Industrial processes"
- industrial partners
  - Fa. Černivšek Jože, Fa. Hess, Fa. Noka
- associations
  - Fachverband der Holzindustrie Österreichs
  - Studiengemeinschaft Holzleimbau

Consortium

Holzforschung Austria
Bundesforschungszentrum für Wald
Fachverband der Holzindustrie Österreichs

University of Ljubljana
CBD – Contemporary Building Design

MPA Stuttgart
Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg

FCBA
SIMONIN SAS

Structure

- prerequisites
  - no basic research
  - holistic approach
  - focus on industrial needs

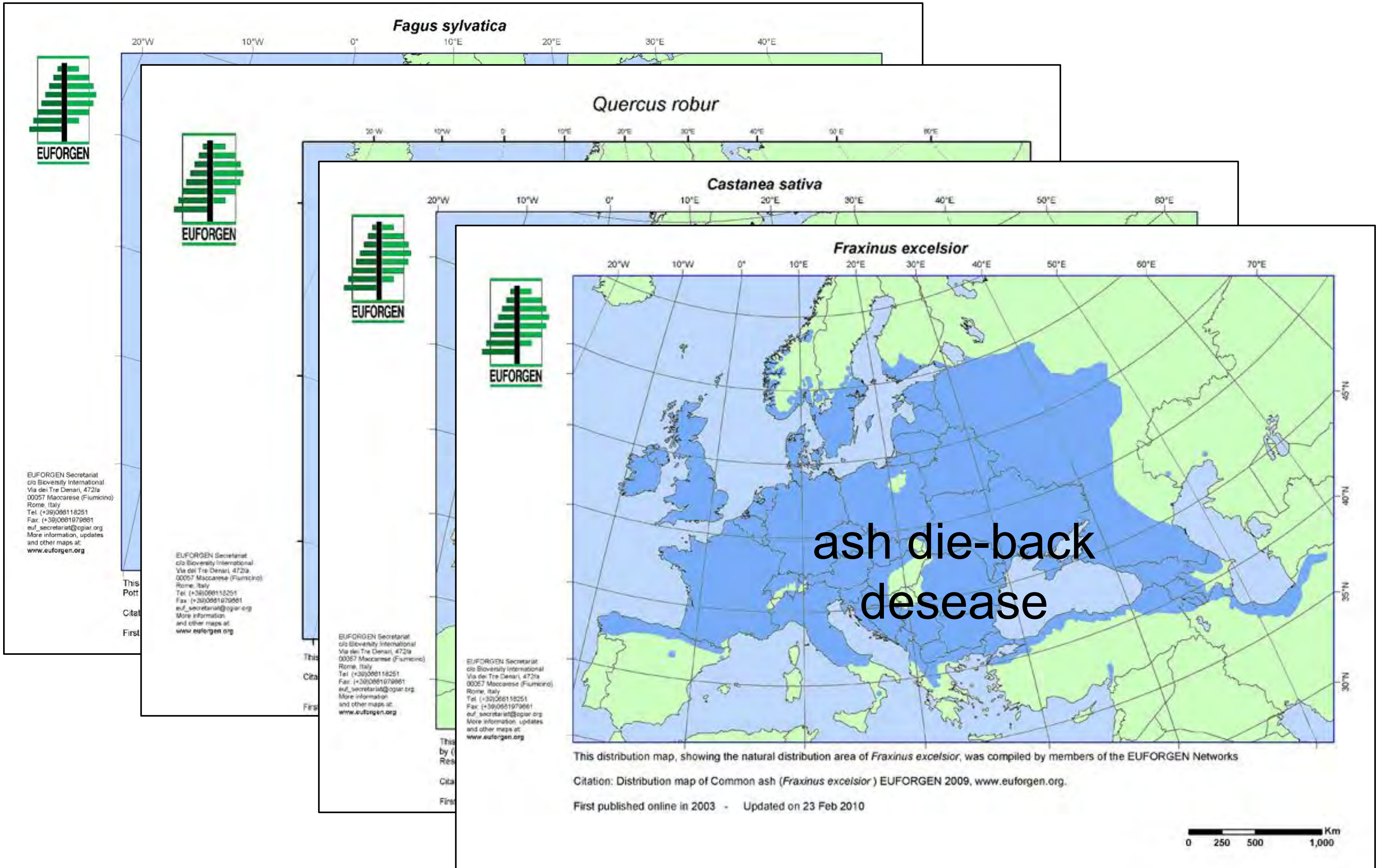
forestry
- stock
- forecast

mechanical data
- testing
- grading
- (data collection)

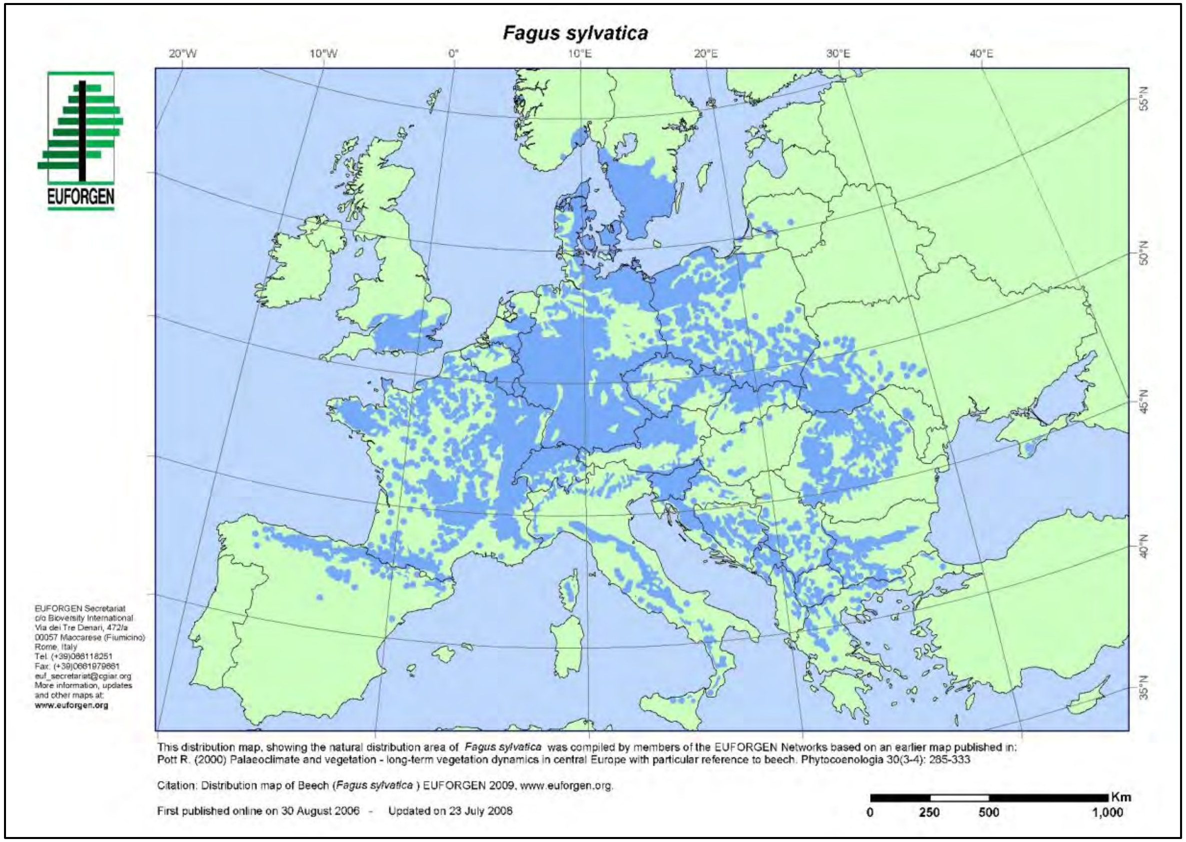
glulam / CLT
- simulating
- verifying
- modelling
- prototyping

dissemination
- workshops
- publications

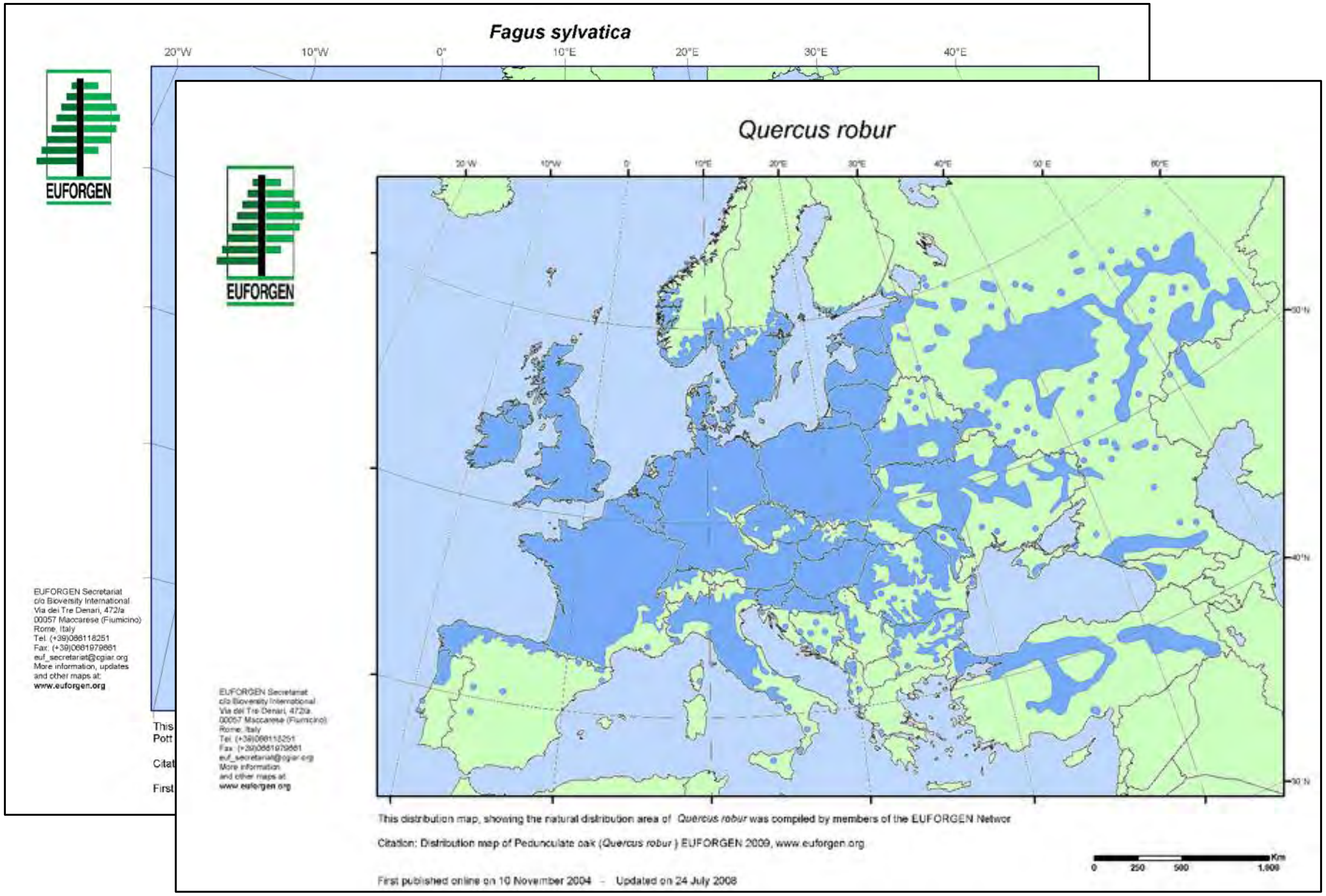
Objectives


Fagus sylvatica
Quercus robur
Castanea sativa
Fraxinus excelsior
EUFORGEN
ash die-back
desease
This distribution map, showing the natural distribution area of Fraxinus excelsior, was compiled by members of the EUFORGEN Networks
Citation: Distribution map of Common ash (Fraxinus excelsior) EUFORGEN 2009, www.euforgen.org.
First published online in 2003 - Updated on 23 Feb 2010
Km
0 250 500 1,000

Objectives


Fagus sylvatica
20°W
10°W
0°
10°E
20°E
30°E
40°E
55°N
50°N
45°N
40°N
35°N
EUFORGEN
EUFORGEN Secretariat
c/o Bioversity International
Via dei Tre Denari, 472/a
00057 Maccarese (Fiumicino)
Rome, Italy
Tel. (+39)066118251
Fax: (+39)0661979661
euf_secretariat@cgiar.org
More information, updates
and other maps at:
www.euforgen.org
This distribution map, showing the natural distribution area of Fagus sylvatica was compiled by members of the EUFORGEN Networks based on an earlier map published in:
Pott R. (2000) Palaeoclimate and vegetation - long-term vegetation dynamics in central Europe with particular reference to beech. Phytocoenologia 30(3-4): 285-333
Citation: Distribution map of Beech (Fagus sylvatica) EUFORGEN 2009, www.euforgen.org.
First published online on 30 August 2006 - Updated on 23 July 2008
Km
0
250
500
1,000

Objectives


Fagus sylvatica
20°W
10°W
0°
10°E
20°E
30°E
40°E
EUFORGEN
EUFORGEN Secretariat
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Via dei Tre Denari, 472/a
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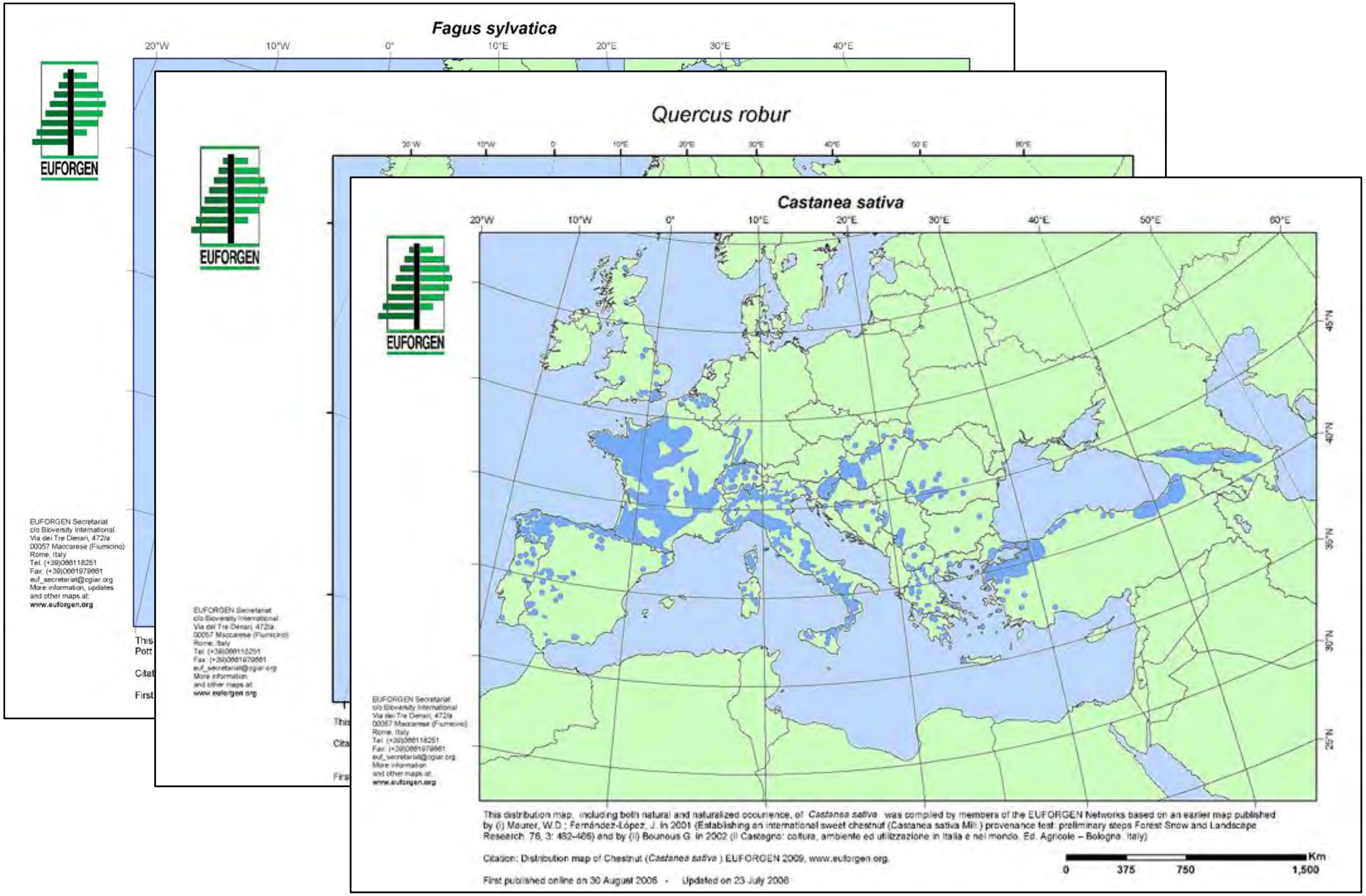
Quercus robur
EUFORGEN
This distribution map, showing the natural distribution area of Quercus robur was compiled by members of the EUFORGEN Networ
Citation: Distribution map of Pedunculate oak (Quercus robur) EUFORGEN 2009, www.euforgen.org
First published online on 10 November 2004 - Updated on 24 July 2008
Km
0
250
500
1,000

Objectives


Fagus sylvatica
Quercus robur
Castanea sativa
EUFORGEN
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°E
45°N
40°N
35°N
30°N
25°N
EUFORGEN Secretariat
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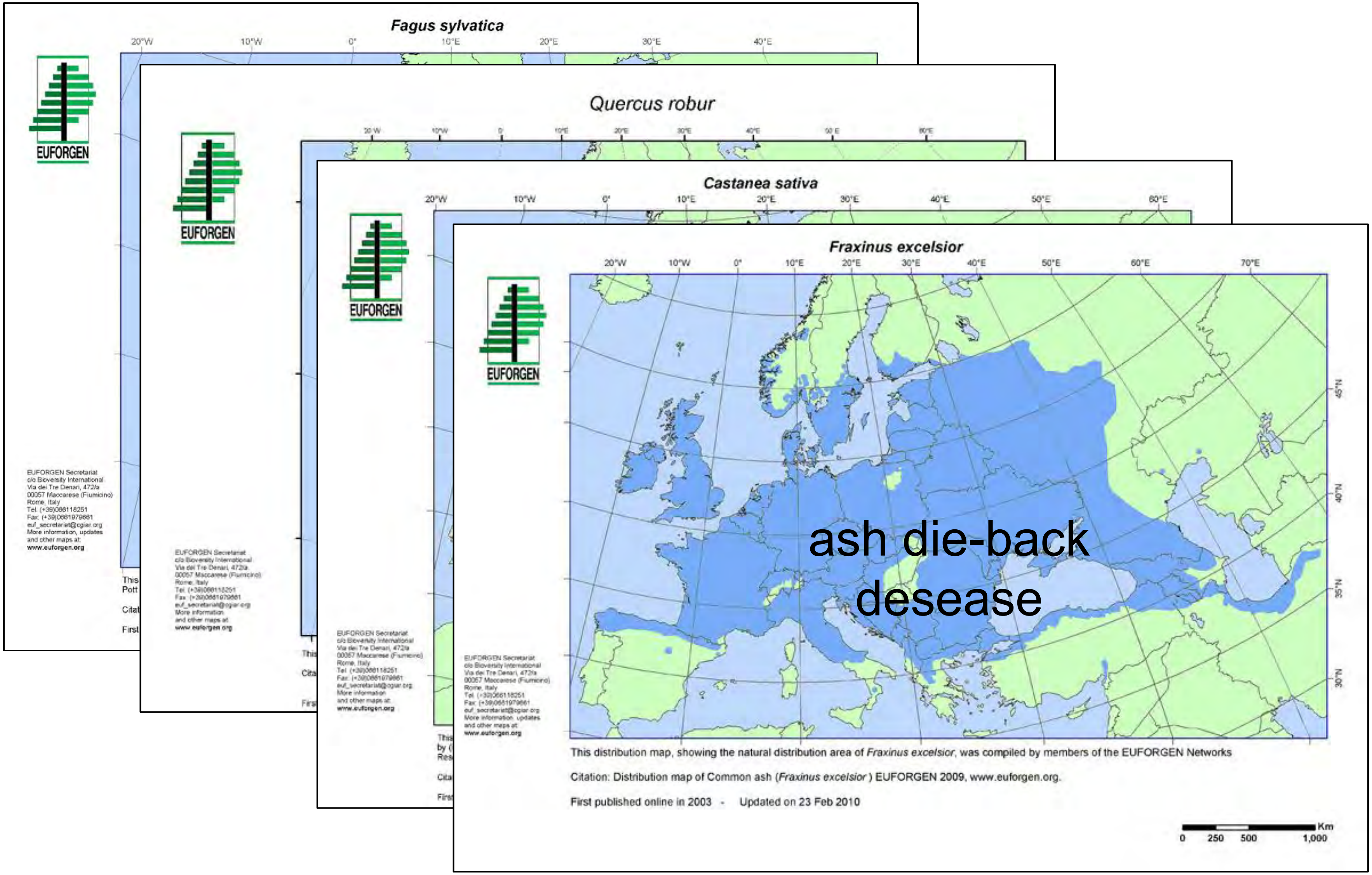
This distribution map, including both natural and naturalized occurrence, of Castanea sativa was compiled by members of the EUFORGEN Networks based on an earlier map published by (i) Maurer, W.D.; Fernández-López, J. in 2001 (Establishing an international sweet chestnut (Castanea sativa Mill.) provenance test: preliminary steps Forest Snow and Landscape Research 76, 3: 482-486) and by (ii) Bounous G. in 2002 (Il Castagno: coltura, ambiente ed utilizzazione in Italia e nel mondo. Ed. Agricole – Bologna. Italy)
Citation: Distribution map of Chestnut (Castanea sativa) EUFORGEN 2009, www.euforgen.org.
First published online on 30 August 2006 - Updated on 23 July 2008
Km
0
375
750
1,500

Objectives



Fagus sylvatica
Quercus robur
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Fraxinus excelsior
EUFORGEN
ash die-back
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Citation: Distribution map of Common ash (Fraxinus excelsior) EUFORGEN 2009, www.euforgen.org.
First published online in 2003 - Updated on 23 Feb 2010

Objectives (2)

- definition of the raw material
  - availability and log quality
  - potential for different roundwood qualities and grades
- characterisation with respect to mechanical properties
  - visual strength grading
  - machine strength grading
- development of new high-tech products
  - hybrid cross laminated timber
  - simulation software for glulam built-ups
  - pre-normative adhesives testing

Agenda

13:00 – 13:20	**Mission and architecture of EU Hardwoods** *Peter Linsenmann (Holzforschung Austria / AT)*
13:20 – 13:40	**Hardwood supply chain** Hardwood potential and availability (present and future) *Udo Sauter (FVA Baden-Württemberg / DE)*
13:40 – 14:10	**Basic hardwood strength data and grading tools** Obstacles and potential of visual and machine grading of hardwoods *Peter Linsenmann (Holzforschung Austria / AT)* *Mitja Plos (University of Ljubljana / SL)*
14:10 – 14:40	**Glulam made of hardwoods** State of the art – species, adhesives and national/European approvals *Simon Aicher (MPA Stuttgart / DE)*
14:40 – 15:10	*Coffee Break sponsored by IHF*

Agenda

15:10 – 15:30	Requirements from a producer's and sawmiller's point of view, prototype production and testing of homogenous and combined oak glulam *Guillaume Legrand (FCBA / FR)*
15:30 – 15:50	Modelling and design equations for hardwood glulam (EN 14080-2) *Cristóbal Tapia Camú (MPA Stuttgart / DE)*
15:50 – 16:05	Glueline integrity verification for glulam made of various hardwood species *Maren Hirsch (MPA Stuttgart / DE)*
16:05 – 16:35	**Hybrid beech-spruce CLT** Production, advantages and design of a novel “hybrid CLT” *Zachary Christian (MPA Stuttgart / DE)* *Iztok Šušteršič (CBD Contemporary Building Design / SL)*
16:35 – 17:00	**Open discussion** Remaining questions, further needs, looking forward

European Hardwoods for the Building Sector (EU Hardwoods)

Workshop Garmisch-Partenkirchen

06/12/2016

WP 1: Hardwood resources in Europe

Standing stock and resource forecasts

Udo H. Sauter und Lorenz Breinig

Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg

Quantification of recent
and
forecast of future hardwood resources
in Europe

Methods

1 Determination standing stock

- Germany
  - Results from the 3rd German national forest inventory (*Bundeswaldinventur*, *BWI*) 2012
  - Total standing stock on the entire forest area, living trees with DBH ≥ 7 cm
  - In cubic meters solid *over* bark (m³ sob)
  - Volumes calculated with the WEHAM model based on the original inventory data: single tree data from variable-size plot sampling
  - Standing stock differentiated by species and diameter class, age class, federal state
- Austria
  - Results from the inventory 2007/09; data provided by BFW (Wolfgang Russ)
  - Standing stock in production forests, living trees with DBH ≥ 7 cm
  - In cubic meters solid *over* bark (m³ sob)

1 Determination standing stock

- France
  - Results from the inventory period 2009 – 2013 (inventory campaigns 2009, 2010, 2011, 2012, 2013); data provided by IGN
  - Standing stock in production forests, living trees
    - Total standing stock (all trees with DBH ≥ 7.5 cm)
    - Standing stock of “construction wood” (timber usable for sawing, *bois d’œuvre*): “sufficiently straight” logs with a minimum top diameter of 20 cm and a minimum length of 2 m
  - In cubic meters solid over bark (m^3 sob)
  - Standing stock differentiated by species and diameter class, age class, region, forest ownership and “accessibility class” (combination of skidding distance, slope, soil bearing strength, etc.; *exploitabilité*)

2 Determination annual cut

- Germany:
  - Data provided by the German ministry of agriculture in the annual report *Holzmarkbericht*
  - In cubic meters solid *under* bark (m³ sub)
- Austria
  - Reported by the Austrian ministry of agriculture (*Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft*)
  - In cubic meters solid *under* bark (m³ sub)

3 Forecast standing stock and annual cut – D, A

The WEHAM model — basic functionality

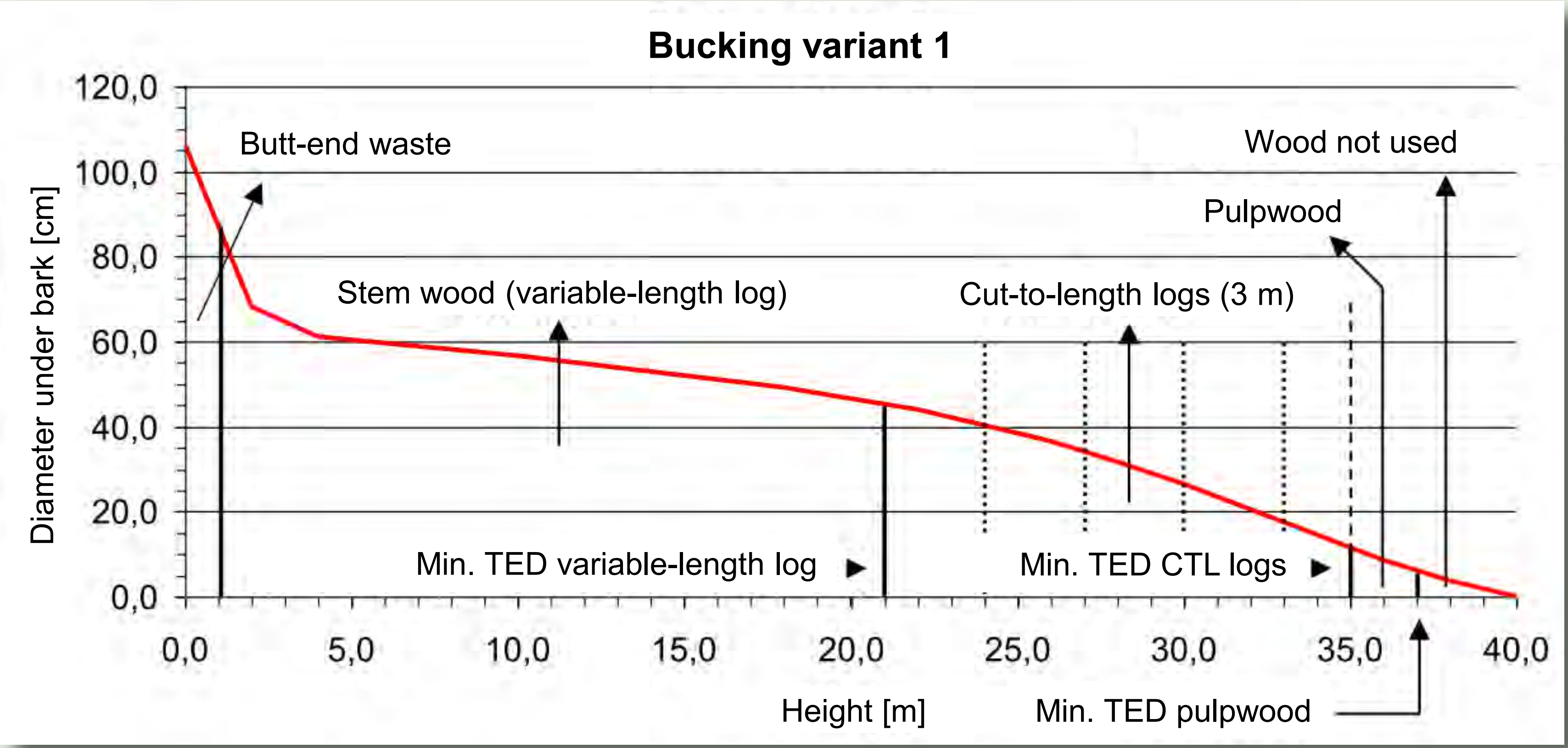
- Specifically adapted to data from the German forest inventory (BWI)
- Single-tree-based simulation of growth and harvest (and mortality); bucking/sorting module
- Input (database): individual trees from forest inventory point sampling; projection to whole forest area
- Simulation governed by a control database containing growth models, parameters of silvicultural treatment, and log bucking/sorting specifications

Restrictions

- Results only valid on a large scale (federal state is the smallest entity for analyses)
- No change of species or change of site conditions modelled
- Bucking/sorting module: standard stem models (diameter/height) used, quality not taken into account (not recorded at inventory)

Forecast of hardwood resources and harvest in Germany

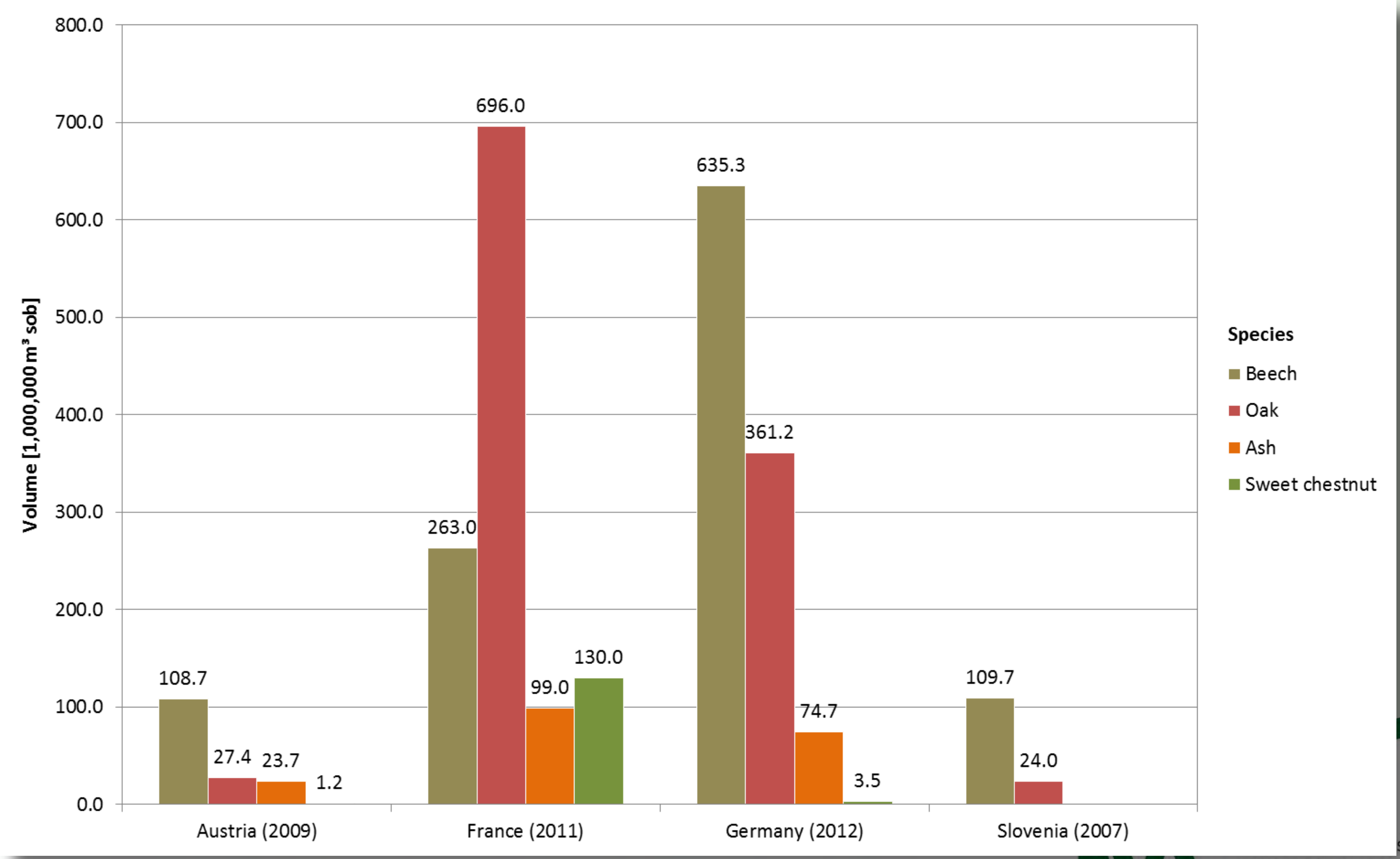
Prediction of roundwood supply: Bucking/sorting variants tested



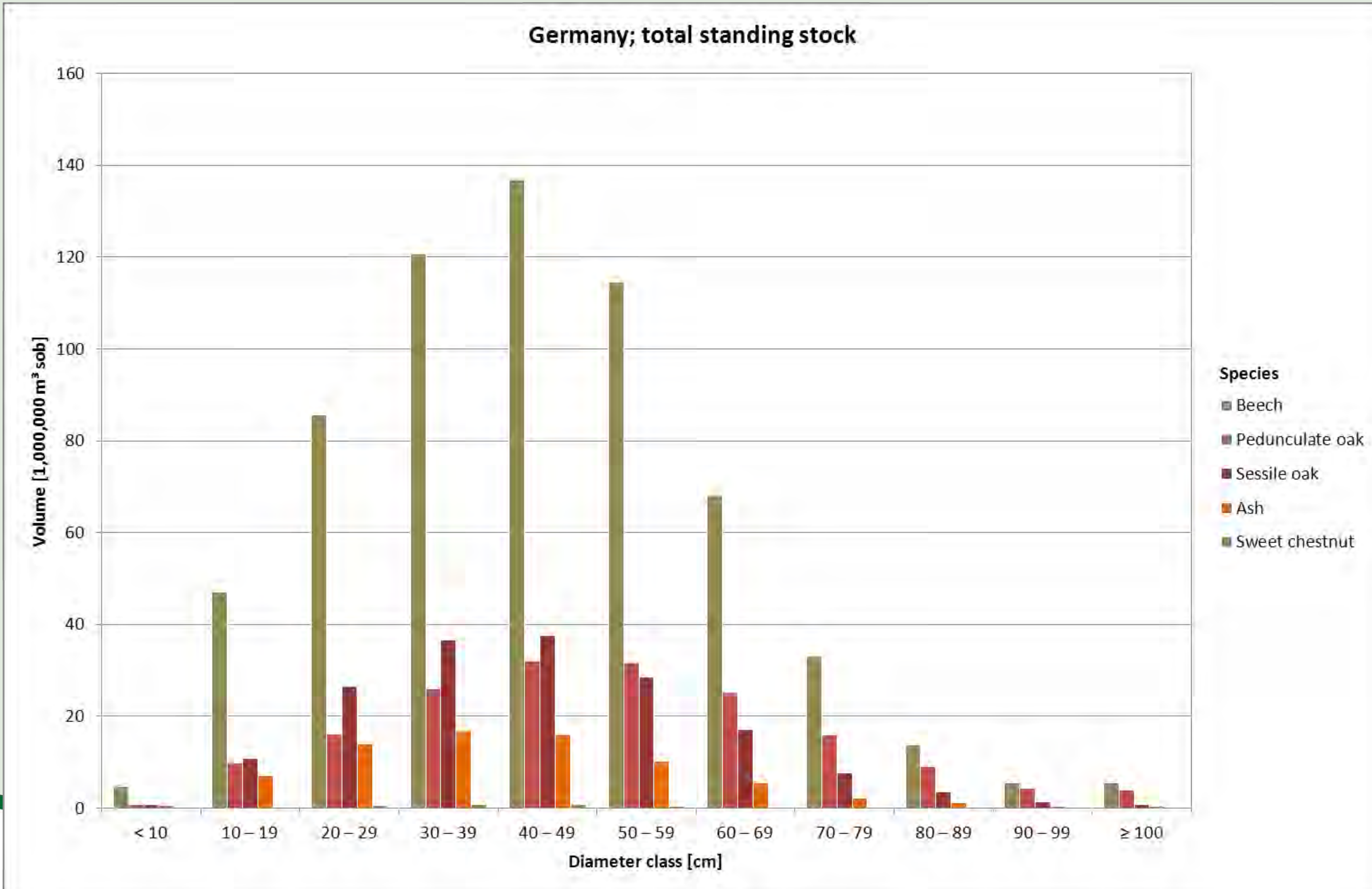
Results

Quantification of recent resources (WP1.1)

Hardwood resources in Austria, France, Germany and Slovenia

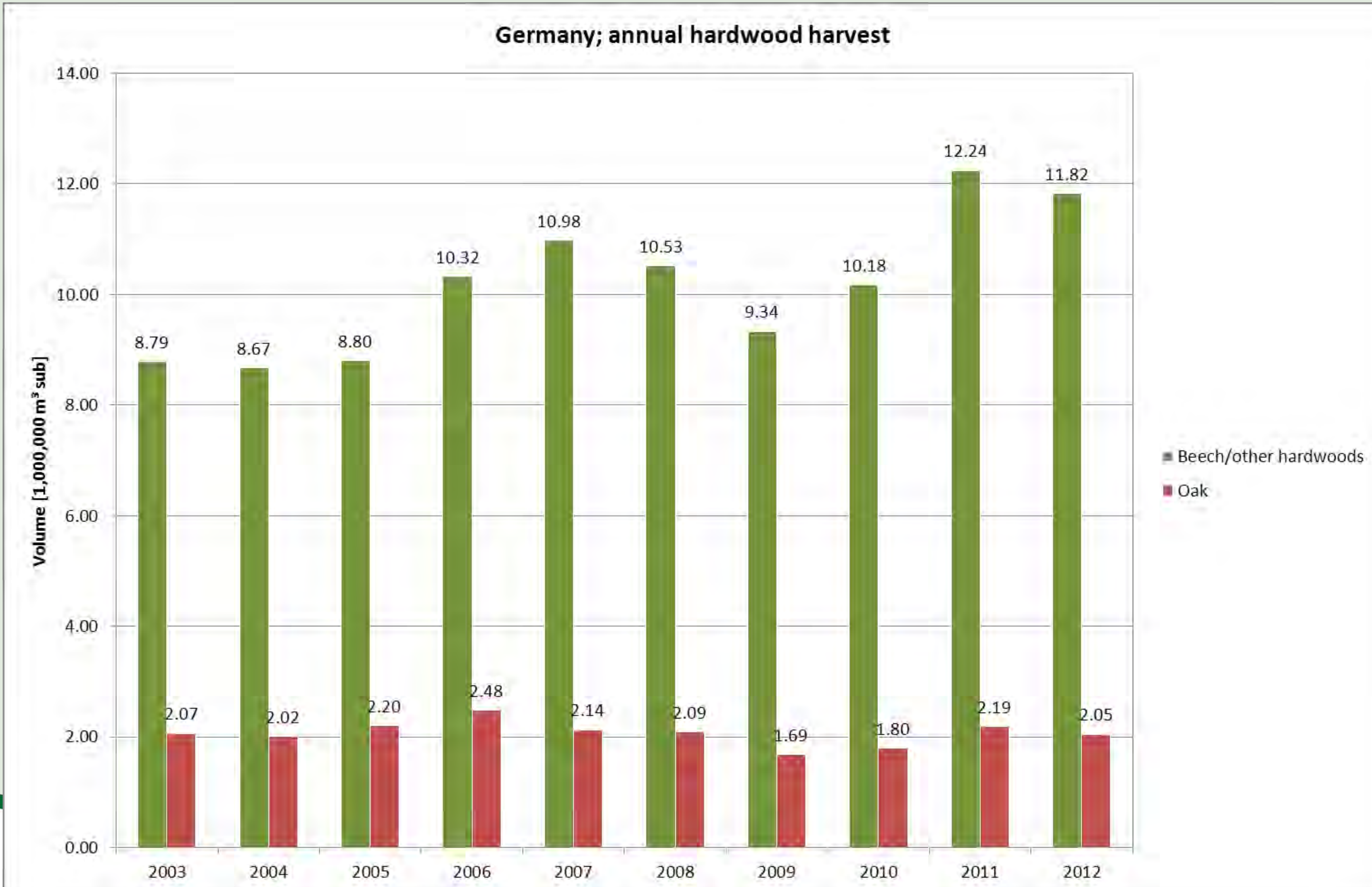


Hardwood resources in Germany

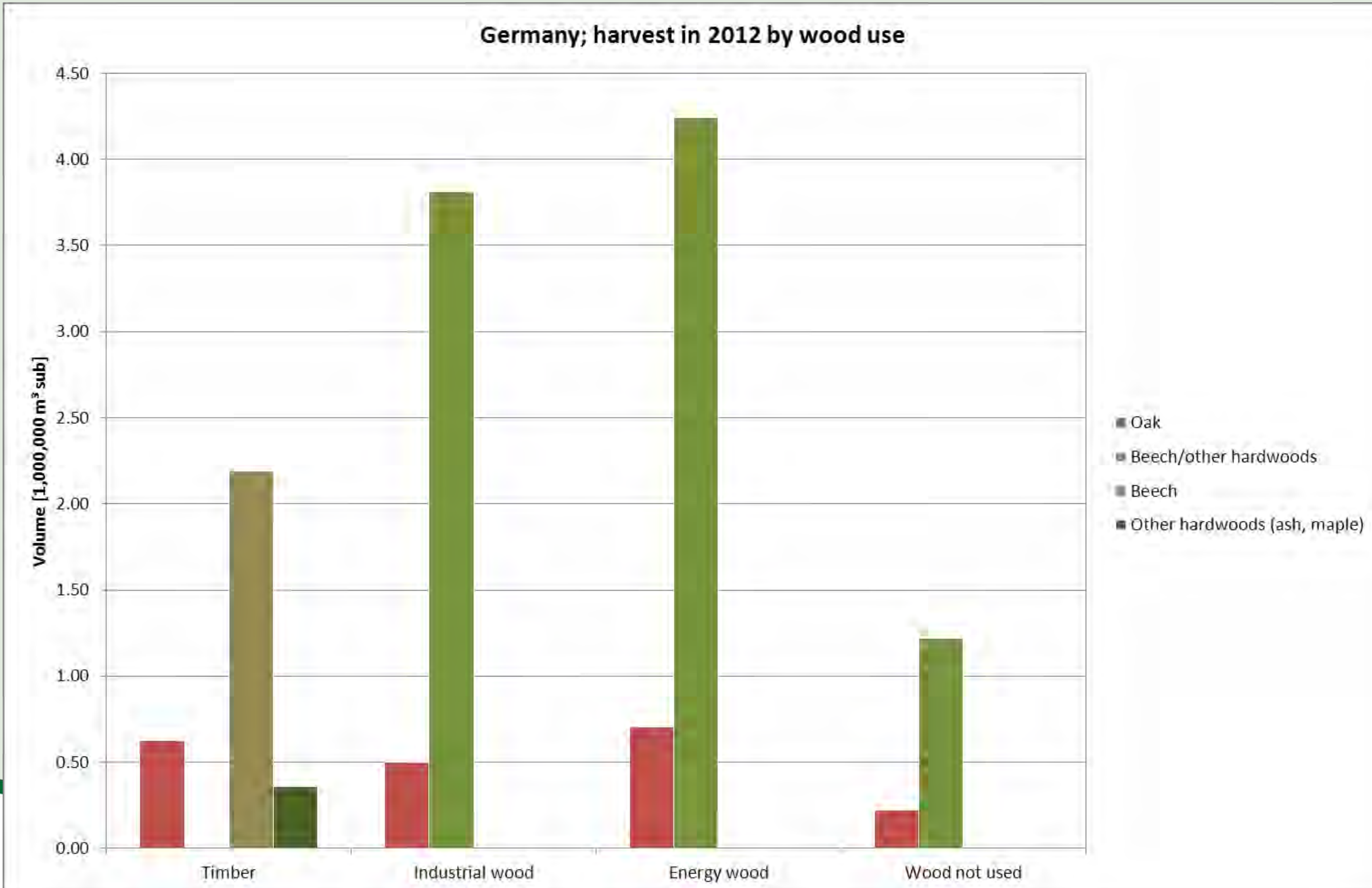


Hardwood resources in Germany

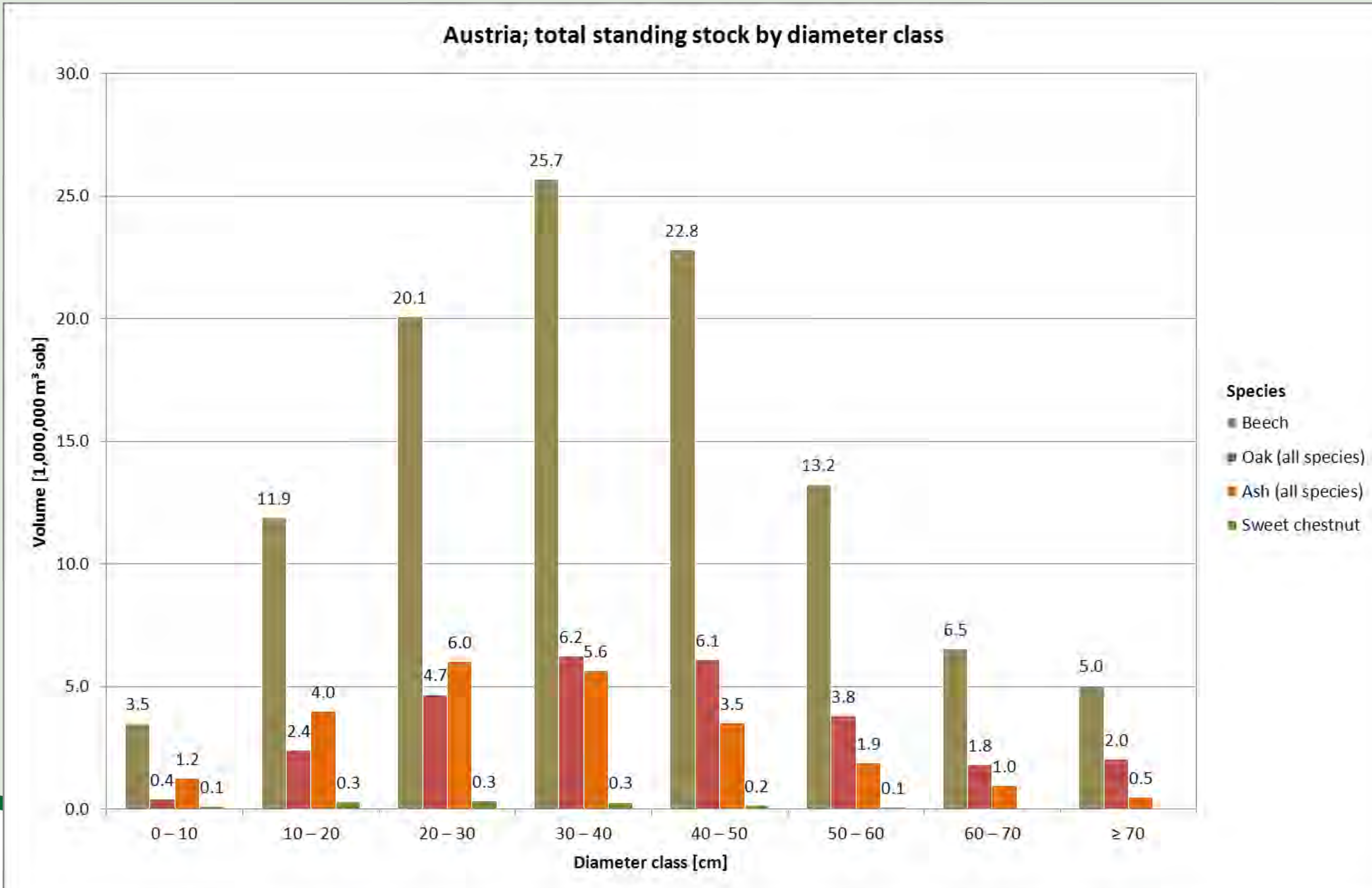
Annual hardwood harvest in Germany



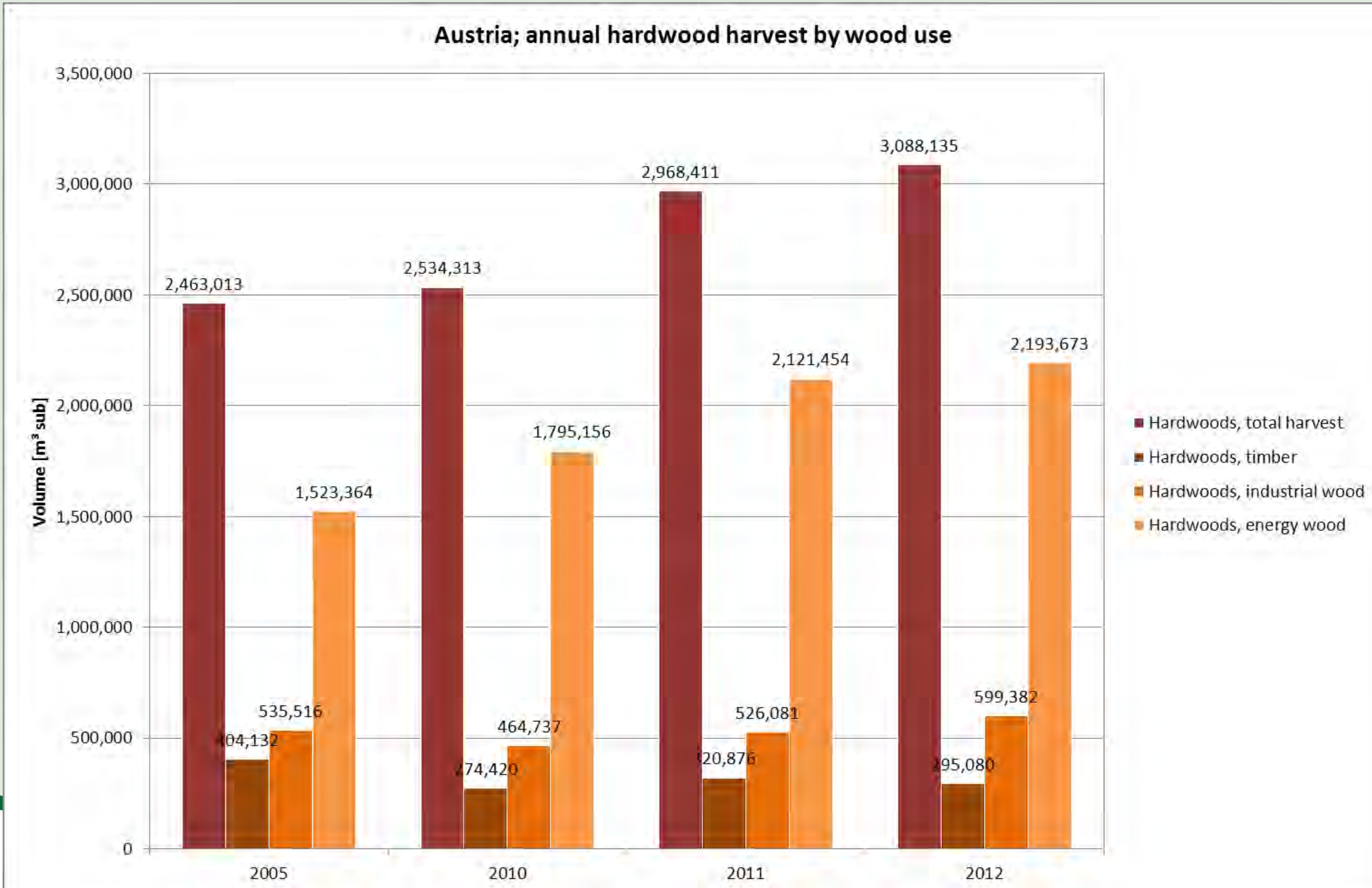
Annual hardwood harvest in Germany



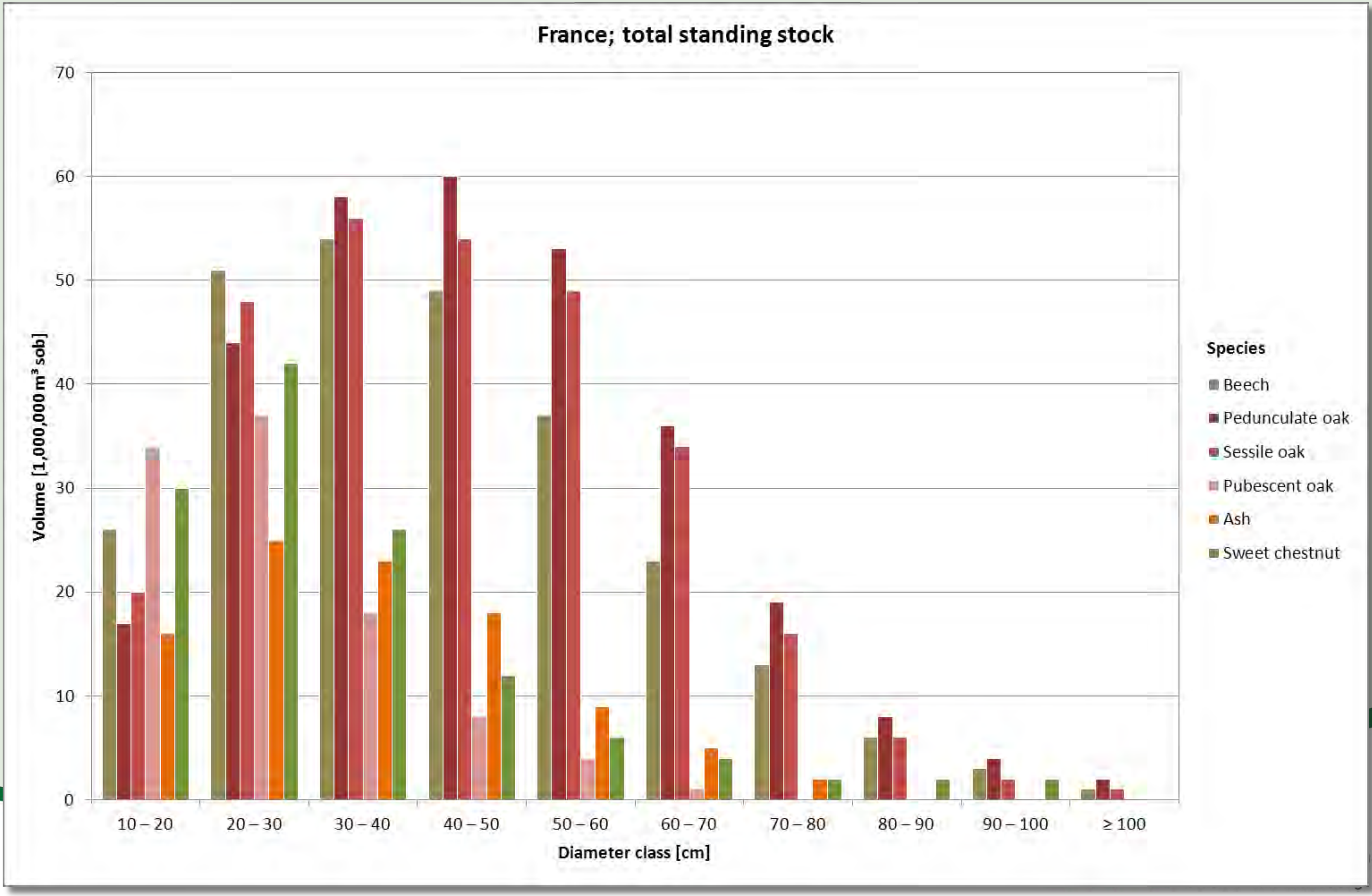
Hardwood resources in Austria



Hardwood resources in Austria



Hardwood resources in France



Hardwood resources in France

Hardwood resources in Austria, France, Germany and Slovenia

Total stocks (all four countries combined; in million m³)

- Beech: 1,116.7
- Oaks: 1,108.7
- Ash: 197.4
- Sweet chestnut: 134.7

For comparison: Softwood stocks in France and Germany (in million m³)

- *Norway spruce: 1,617.6 (Silver fir: 290.4)*
- *Douglas fir: 184.7*
- *Pines (Scots pine and maritime pine): 1,048.8*

In Germany, the stocks of spruce have decreased by 48.6 M m³ since the previous forest inventory (in 2002), while the stocks of beech and oaks have increased by 57.8 and 50.1 M m³, respectively.

Hardwood resources in Europe – Summary

Standing stocks

- Oak has by far the highest share of hardwood standing stock in France (59%), the second highest share in Germany (33%) but only 17% in Austria.
  Oak has the highest total standing stock of the regarded species in the three countries: ~ 1,063,600,000 m³ (sob)

- Beech has the highest share of the hardwood resource in Austria (68%) and Germany (60%) and the second highest share in France (22%).
  In total, beech has a standing stock of ~ 1,007,100,000 m³ (sob)

- Ash has shares between 7% (Germany) and 15% (Austria) → considerably less important than beech and oak.
  High uncertainty in the prediction of future availability: The rapidly spreading ash dieback disease could cause up to 90% loss of ash standing stock in some regions within the next decade

- Sweet chestnut: considerable standing stock in France (11%), only very small stocks in Austria and Germany.
  Estimates for Austria and Germany, especially diameter distribution, have a rather high standard error (± 20% in the case of Austria)

Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg

Hardwood resources in Europe – Summary

Report harvests

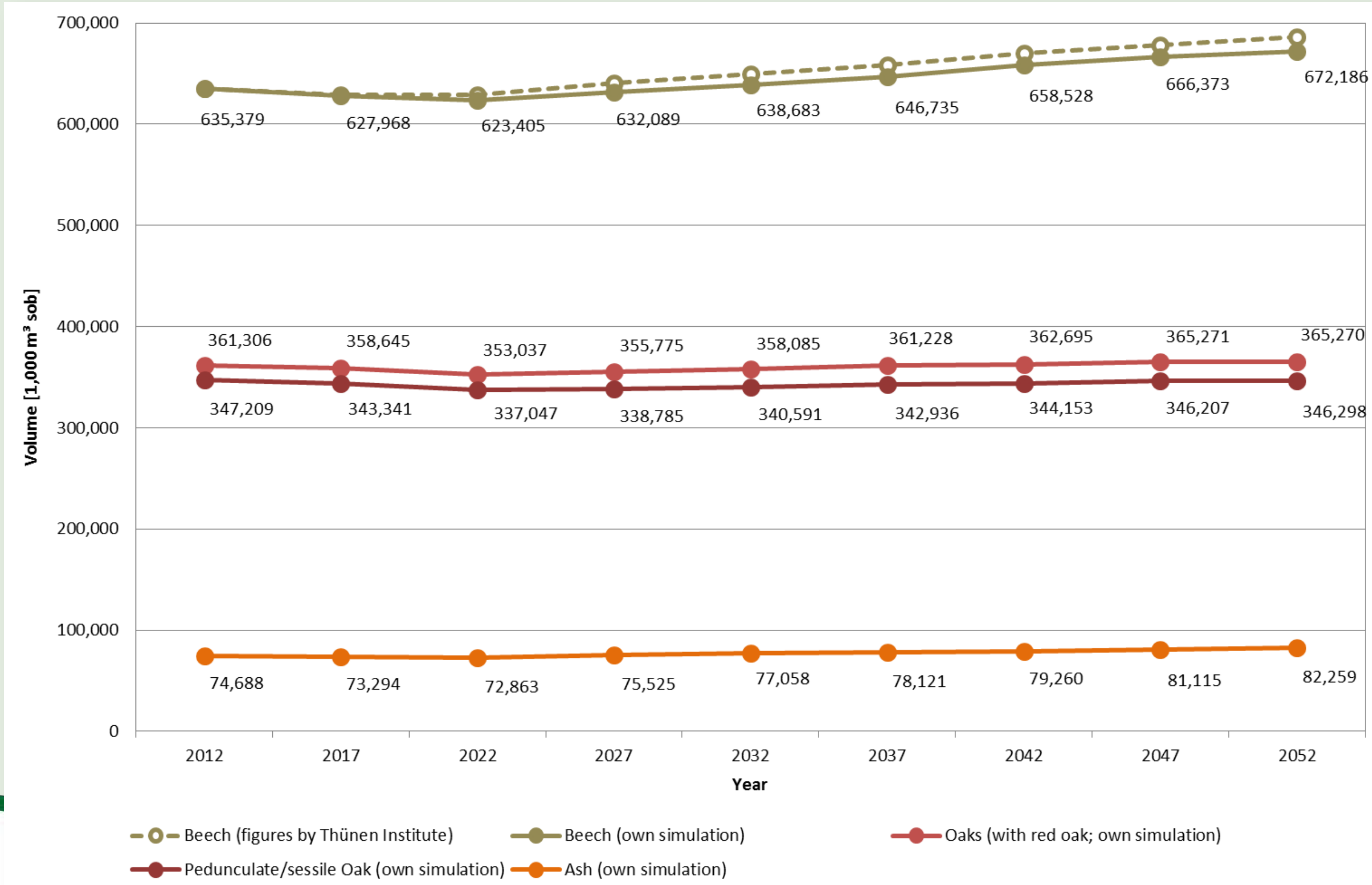
- Austria: Energy wood has a very high share of the annual hardwood harvest (62–72%); beech has the highest share of the annual timber harvest (48–54%)
- Germany: Beech has the highest share of timber harvest (2012: 69%); the share of energy wood is much lower than in Austria (2012: 36%)
- Reported figures on annual harvest can only be seen as a (rather coarse) estimate; especially harvested volumes from small private forest properties are often estimated

Forecast to future resource availability (WP1.2)

Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg

Forecast of hardwood resources and harvest in Germany

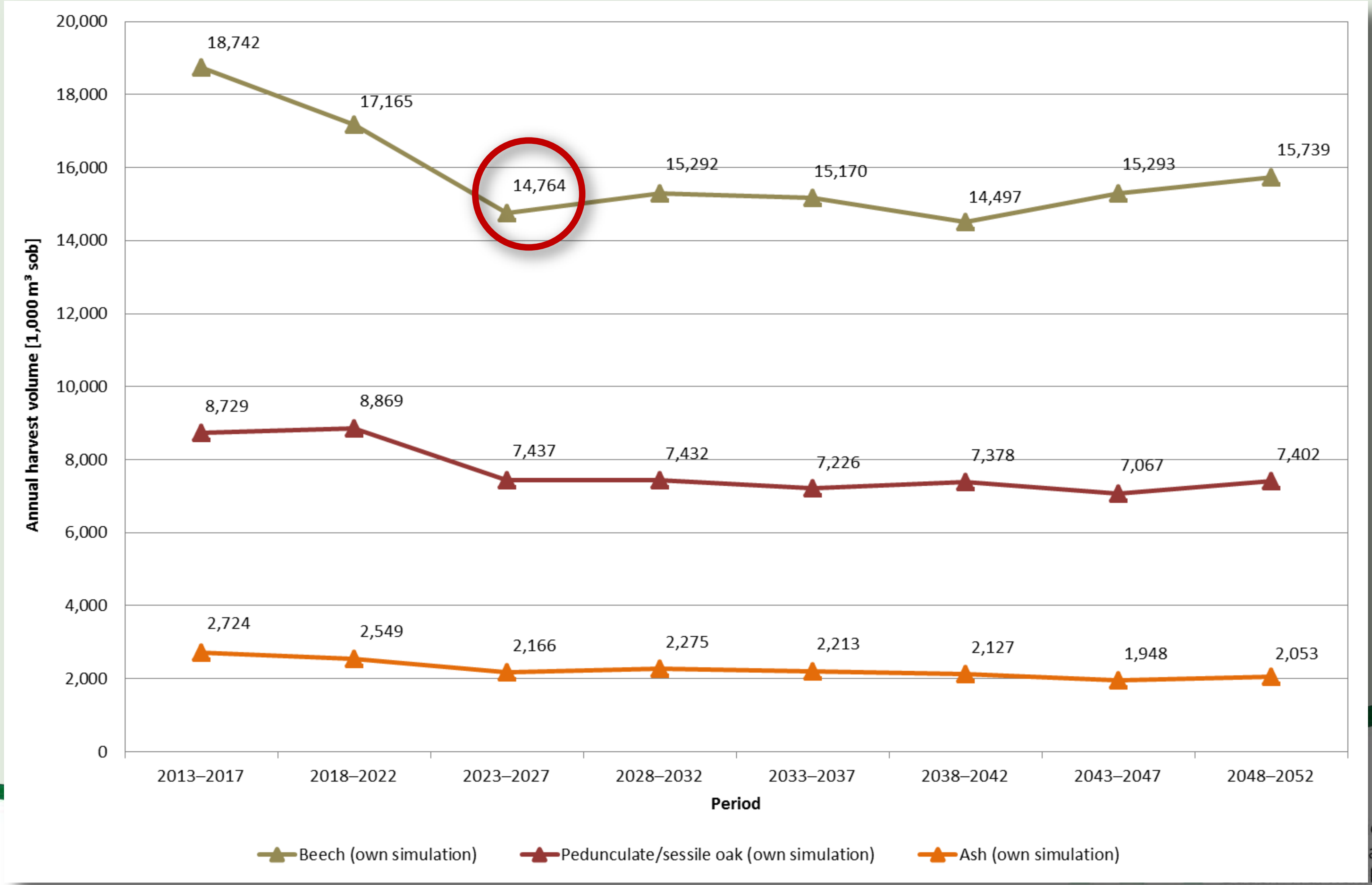
WEHAM prediction of standing stocks according to the official scenario



chs-
anstalt
berg

Forecast of hardwood resources and harvest in Germany

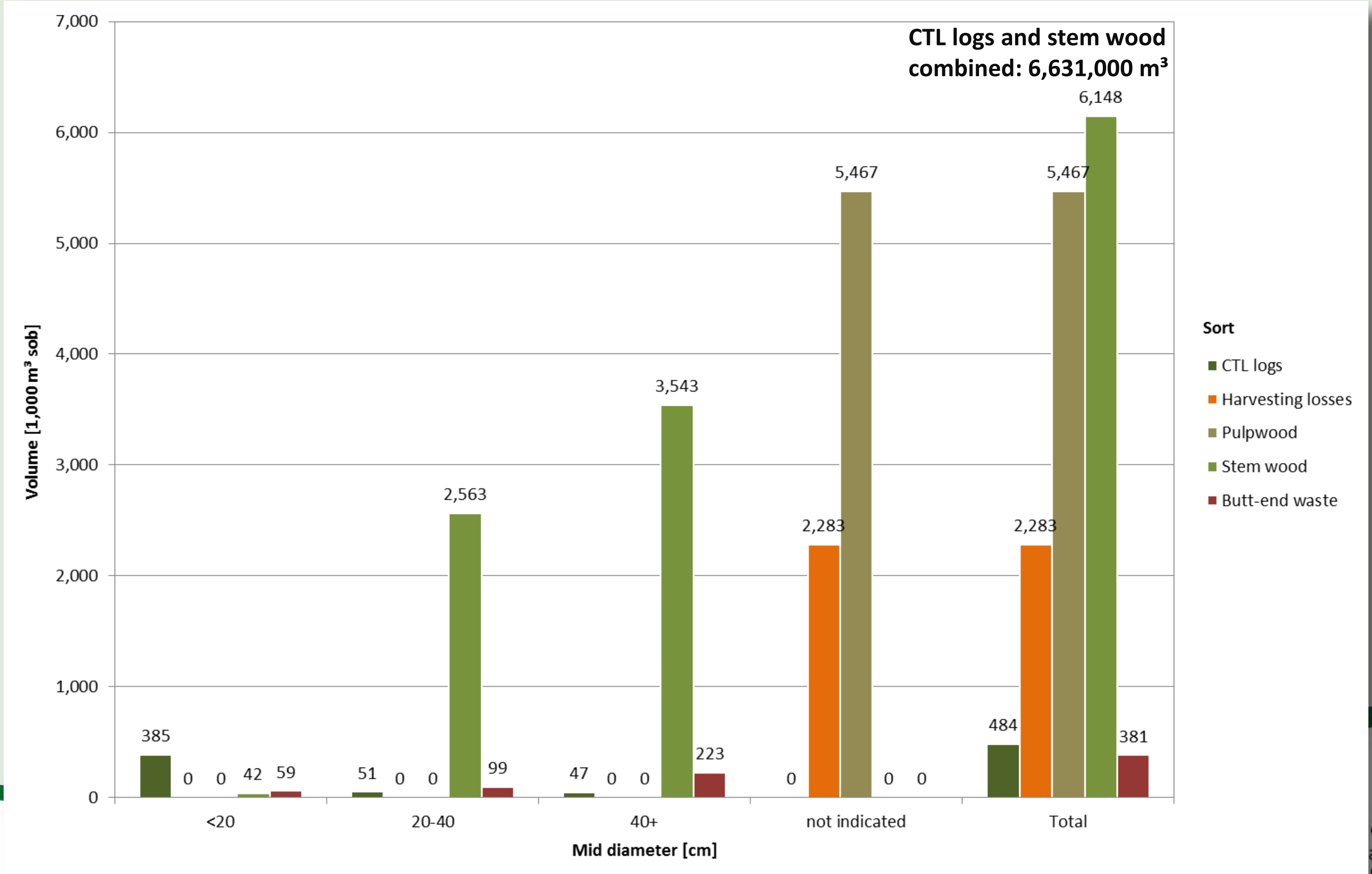
WEHAM prediction of annual harvest volumes according to the official scenario



chs-
anstalt
berg

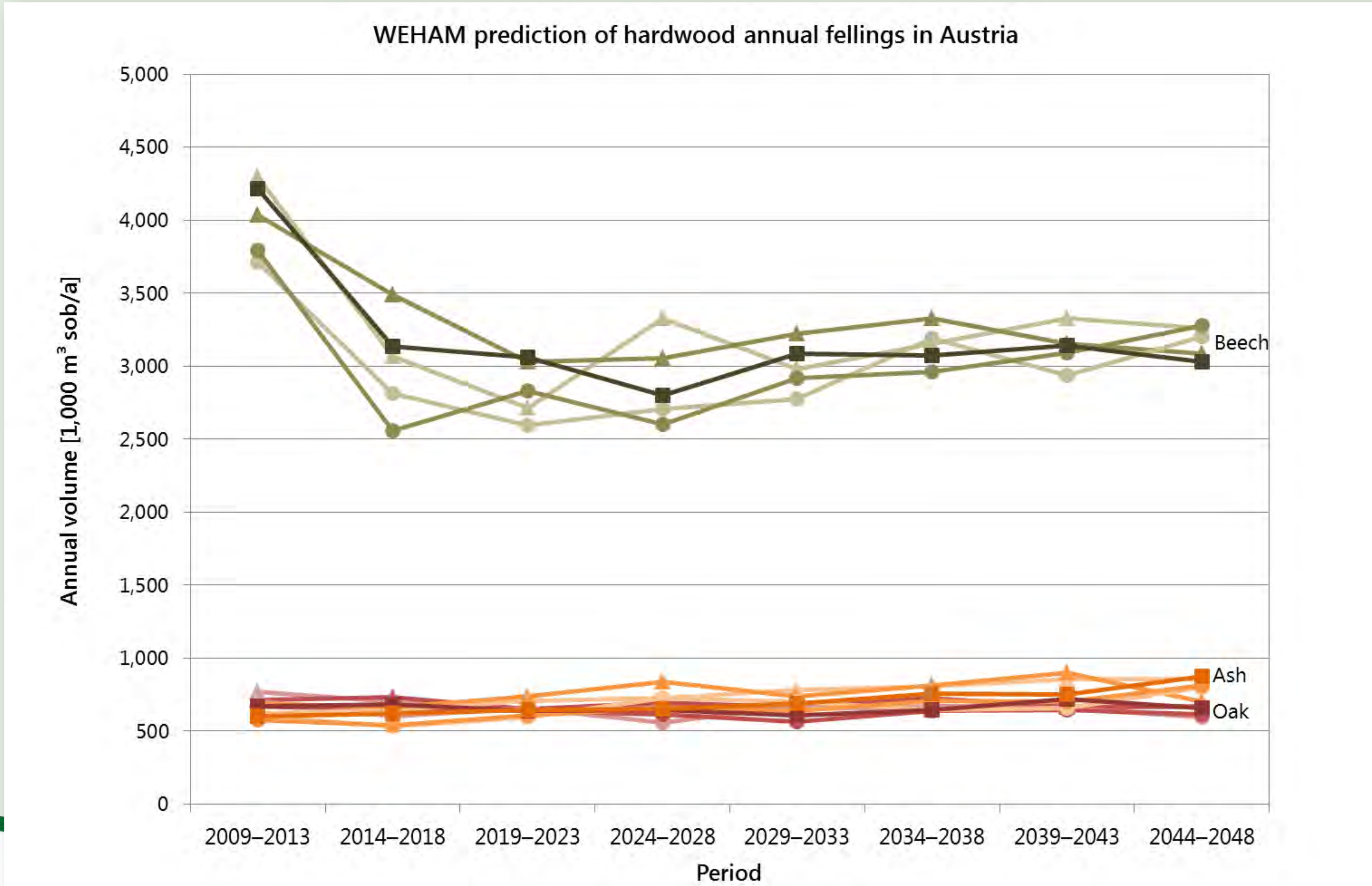
Forecast of hardwood resources and harvest in Germany

Prediction of annual roundwood supply 2023–2027 — Beech; bucking variant 1

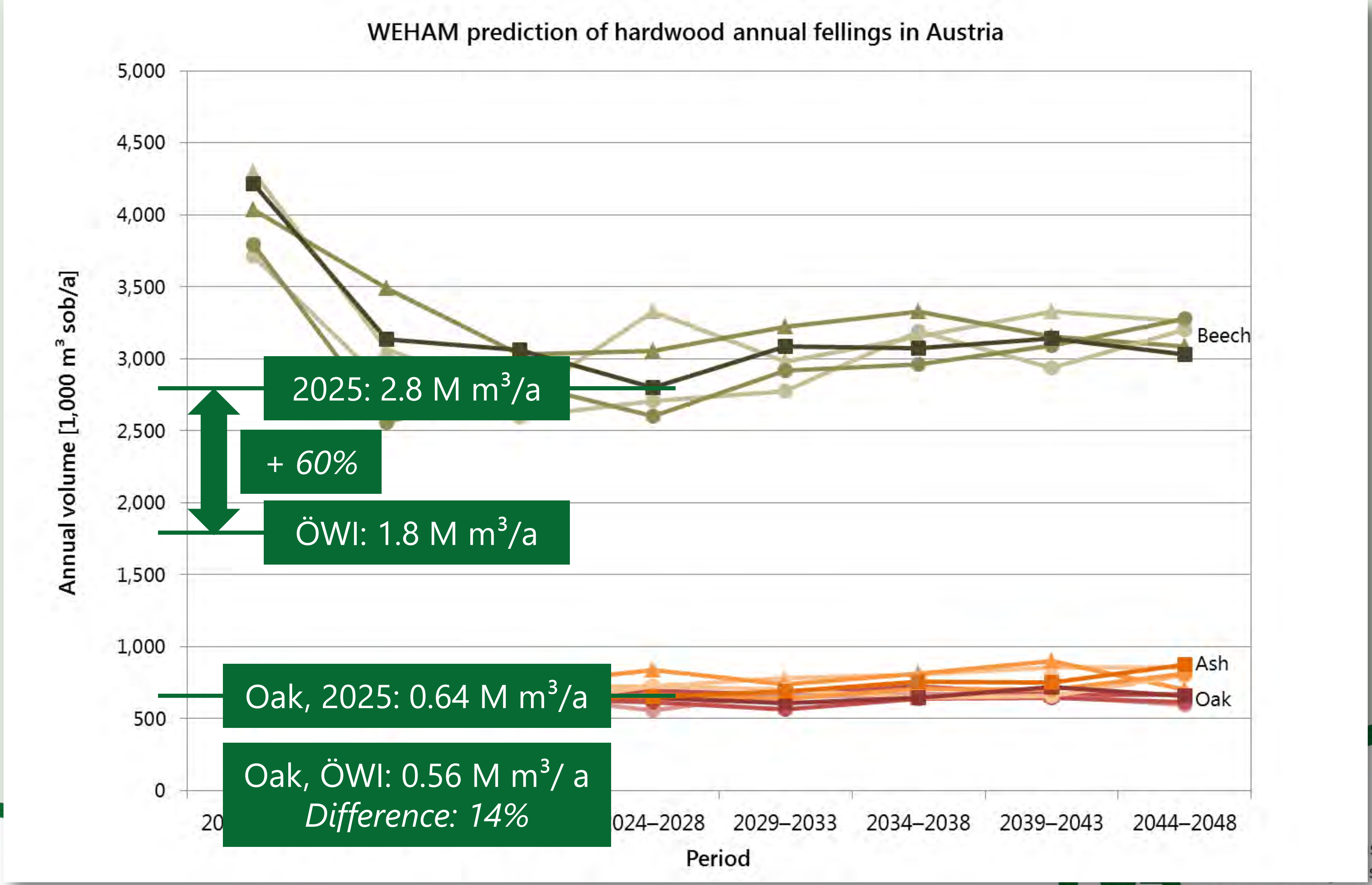


chs-
anstalt
berg

Resource forecasts for Austria: Overestimation of growth and fellings



Resource forecasts for Austria: Overestimation of growth and fellings

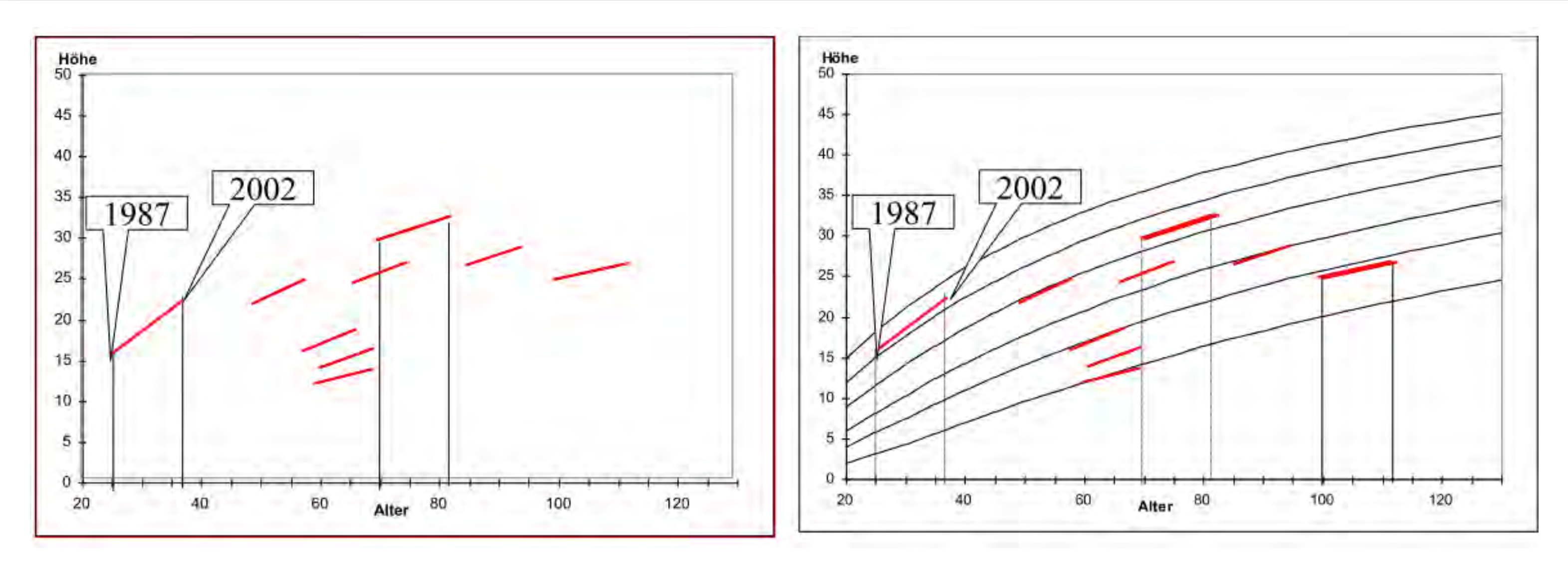


Baden-Württemberg

Resource forecasts for Austria: Overestimation of growth and fellings

Approach:

- Re-parameterization of growth models in WEHAM with repeated inventory data for beech and oak
(Data from ÖWI 2007–09 and preceeding inventory provided by BFW)
- Repetition of simulations



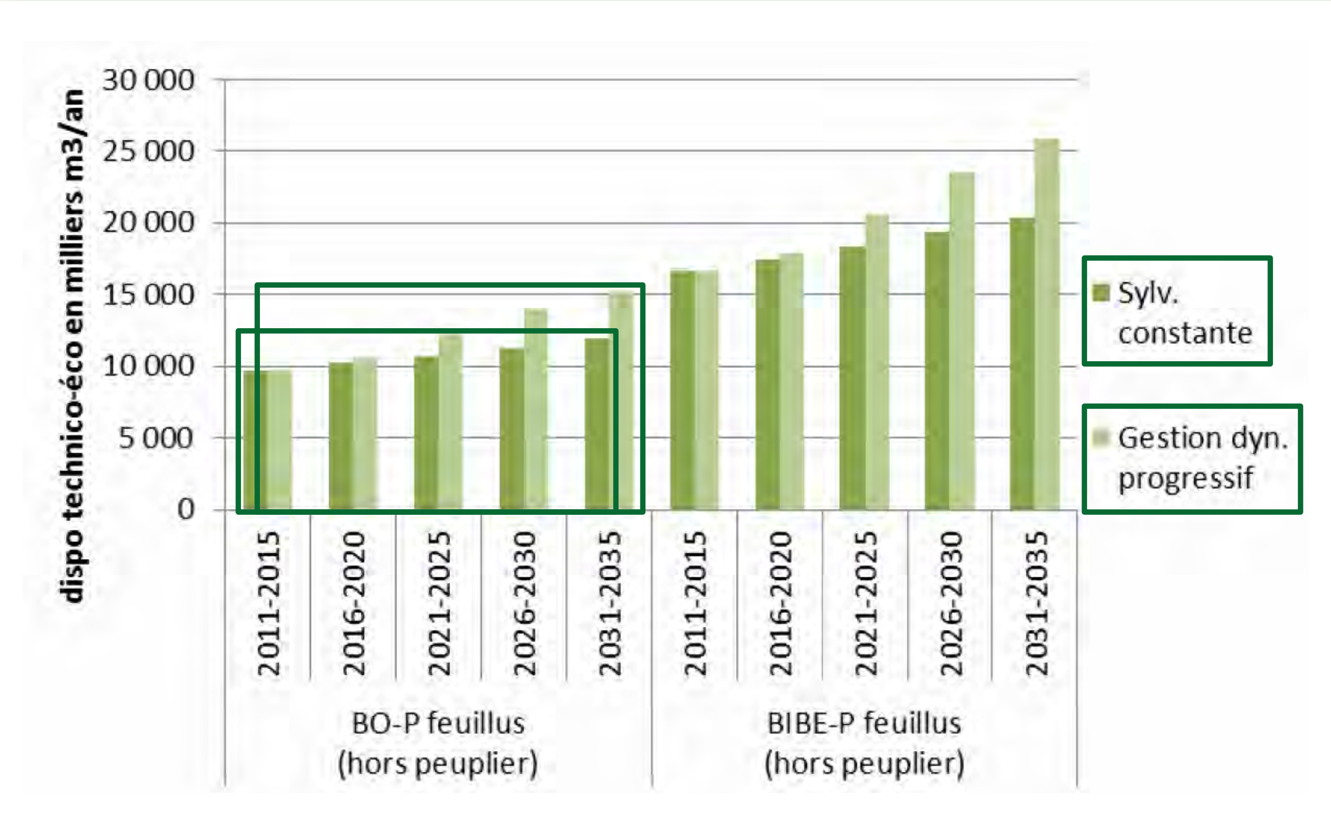
Resource forecasts for France: Study by IGN/FCBA

- First study on potential roundwood availability covering the entire forest area in France: *Disponibilités forestières pour l'energie et les matériaux à l'horizon 2035*; on request by the French environment agency
- Data basis: Inventory 2009–2013
- Models of growth/mortality and silviculture yield gross annual availability (comparable to the annual fellings in WEHAM)
- Applying volume reductions due to technical/economical restrictions leads to "usable annual availability"
- Two scenarios:
    - constant management: maintaining mean felling rates observed between the last two inventories for the distinguished forest type units (strata)
    - "dynamic management": progressively applying the highest observed felling rate to the entire stratum

Resource forecasts for France: Study by IGN/FCBA

Usable annual availability of hardwood timber (all species combined):

- increase from 9.7 to 11.9 M m³/a in the constant management scenario
- increase from 9.7 to 15.2 M m³/a in the "dynamic management" scenario



Forecast of Hardwood resources in Europe – Summary

Standing stocks

- All species show an increasing or at least constant development of the standing stock for the involved countries
- An exception is ash which may show instable growth and stock volume because of the dieback disease

Harvests

- Despite some methodical uncertainties related to the WEHAM forcast software approach, which was developed for German growth conditions constant or even increasing annual cuts for main hardwood species beech and oak throughout the next decades can be expected

Thank you for your attention!

Forstliche Versuchs-
und Forschungsanstalt
Baden-Württemberg

European Hardwoods for the Building Sector

grading of hardwoods

Peter Linsenmann

Additional focus areas of HFA

BioUp

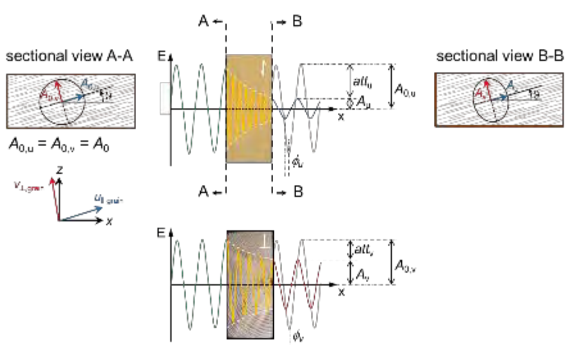
Akustik Center Austria

Test sample „grading“

	mm x mm	N
beech	30 x 150	83
ash	30 x 150	49
	30 x 200	60
oak	25 x 120	8
	30 x 150	75
Sweet chestnut	30 x 150	94
total		369

- origin in south-western Germany
- collaboration between FVA and HFA

Test sample „grading“



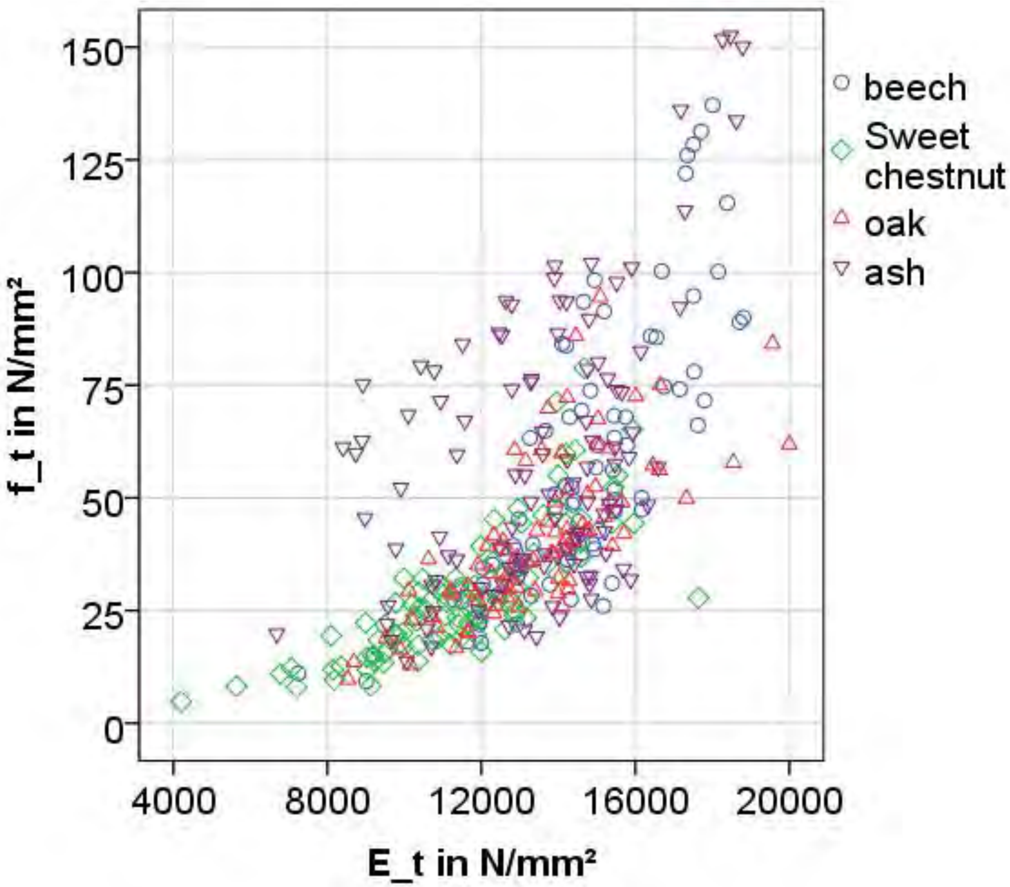
tensile strength test acc. to

ÖNORM
EN 408
Ausgabe: 2012-09-01

visual grading acc. to

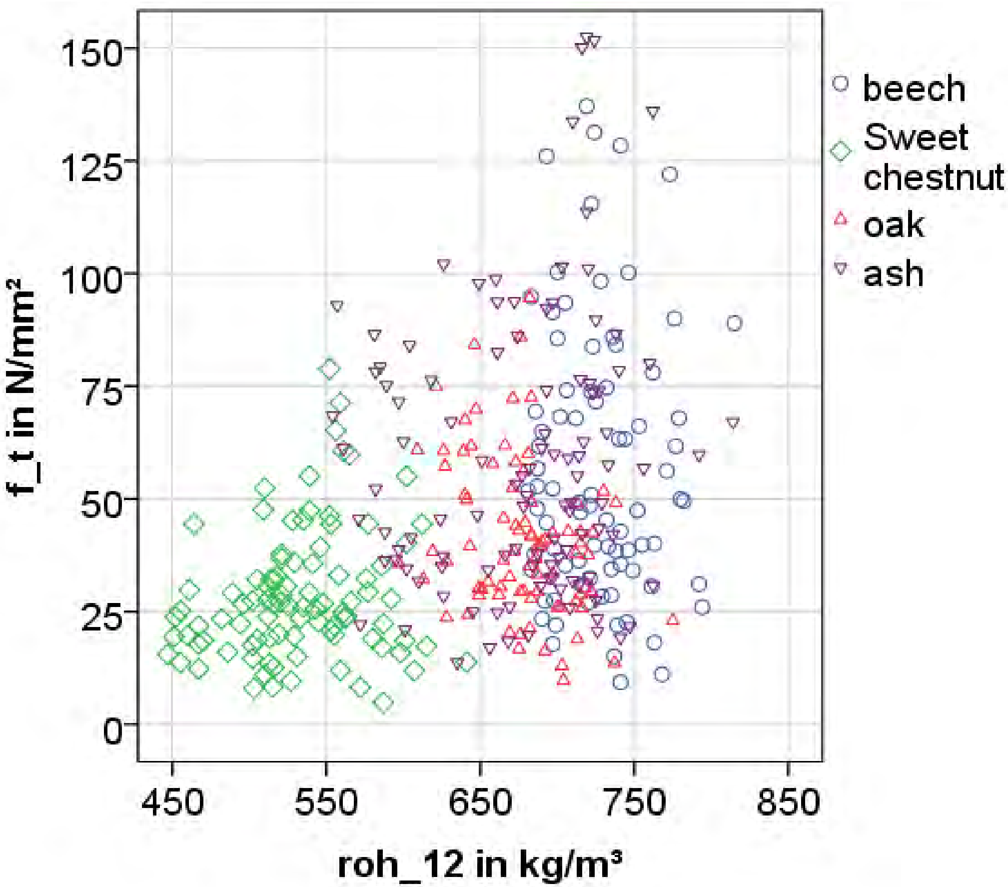
ÖNORM
DIN 4074-5
Ausgabe: 2009-06-15

Test sample „grading“



	beech	Sweet chestnut	oak	ash
N	83	94	83	109
$f_{t,mean}$ N/mm²	56,4	28,4	41,1	58,1
s (f_t) N/mm²	30,3	14,6	17,5	30,6
$E_{t,mean}$ kN/mm²	14,5	11,5	13,5	13,4
s (E_t) kN/mm²	2,3	2,4	2,2	2,4

Test sample „grading“



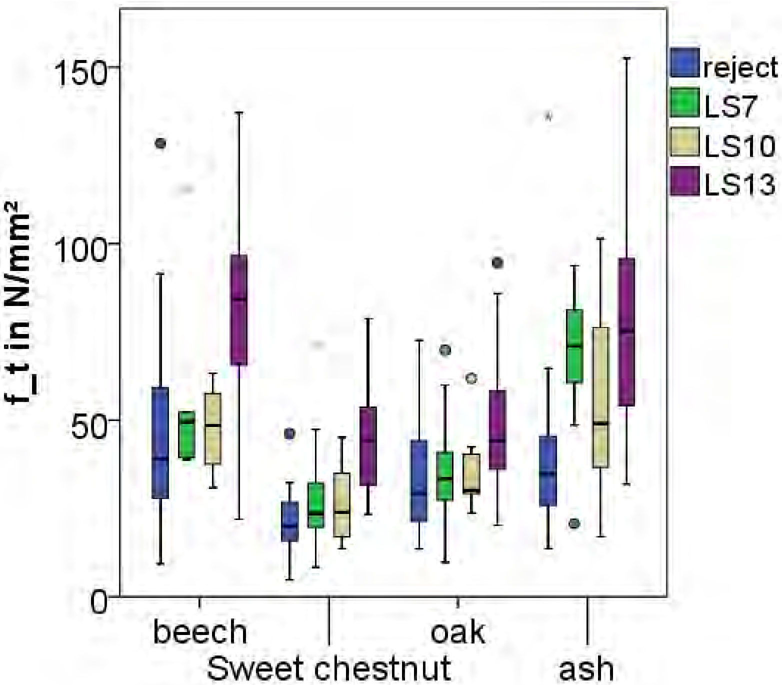
	beech	Sweet chestnut	oak	ash
N	83	94	83	109
$E_{t,mean}$ kN/mm²	14,5	11,5	13,5	13,4
s (E_t) kN/mm²	2,3	2,4	2,2	2,4
$roh_{12,mean}$ kg/m³	728	532	677	676
s (roh_{12}) kg/m³	31	43	33	56

Visual strength grading

	DIN 4074-5:2009 (DE / AT / SI)	NF B52-001-1:2011 (FR)
species	all hardwoods	tropical hardwoods, oak
criteria	knots, fibre deviation, bow / twist, cracks, wane, discolouration, insect damage	
		sapwood
	pith, annual ring width	

Visual strength grading

visual strength grades –
all criteria acc. to DIN4074-5

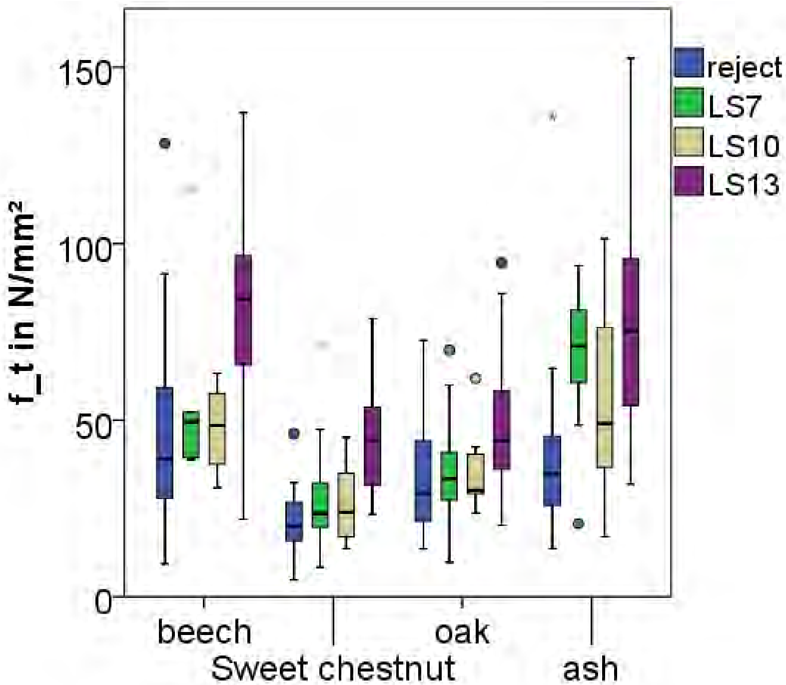


Visual strength grading

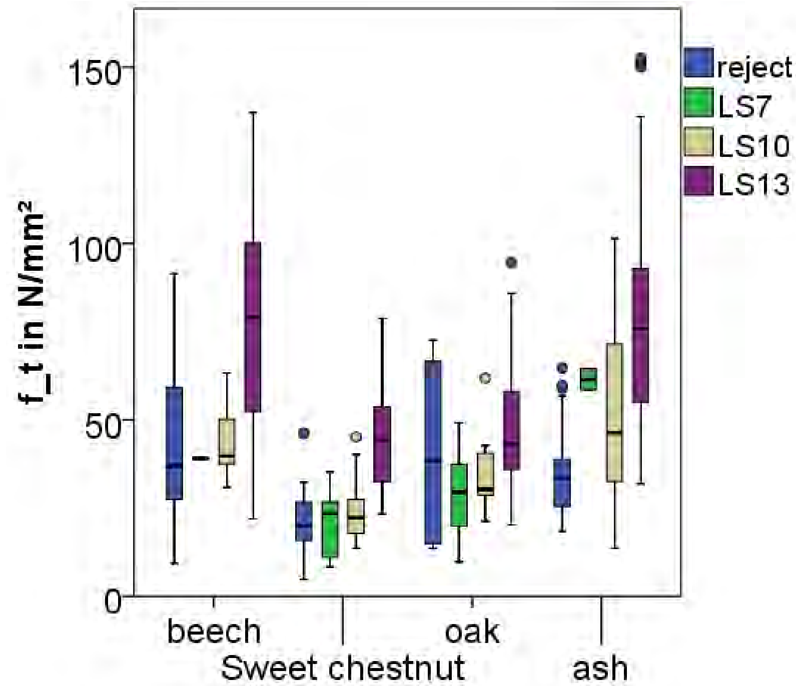
	DIN 4074-5:2009 (DE / AT / SI)	NF B52-001-1:2011 (FR)
species	all hardwoods	tropical hardwoods, oak
criteria	**knots**, **fibre deviation**, bow / twist, **cracks**, wane, discolouration, insect damage	
		sapwood
	pith, **annual ring width**	

Visual strength grading

visual strength grades –
all criteria acc. to DIN4074-5



visual strength grades –
all strength criteria acc. to EN14081-1



Visual strength grading

knot (single, 150 mm)
fibre deviation, pith
wane, cracks
twist, bow

stepwise linear regression on tensile strength

Visual strength grading

	single knot	knot cluster	fibre deviation	annual ring width	pith	bow	R^2
beech	1				2		0,49
ash	1		3		2		0,46
oak	1		2	3		4	0,47
Sweet chestnut	1	3			2		0,54

Visual strength grading

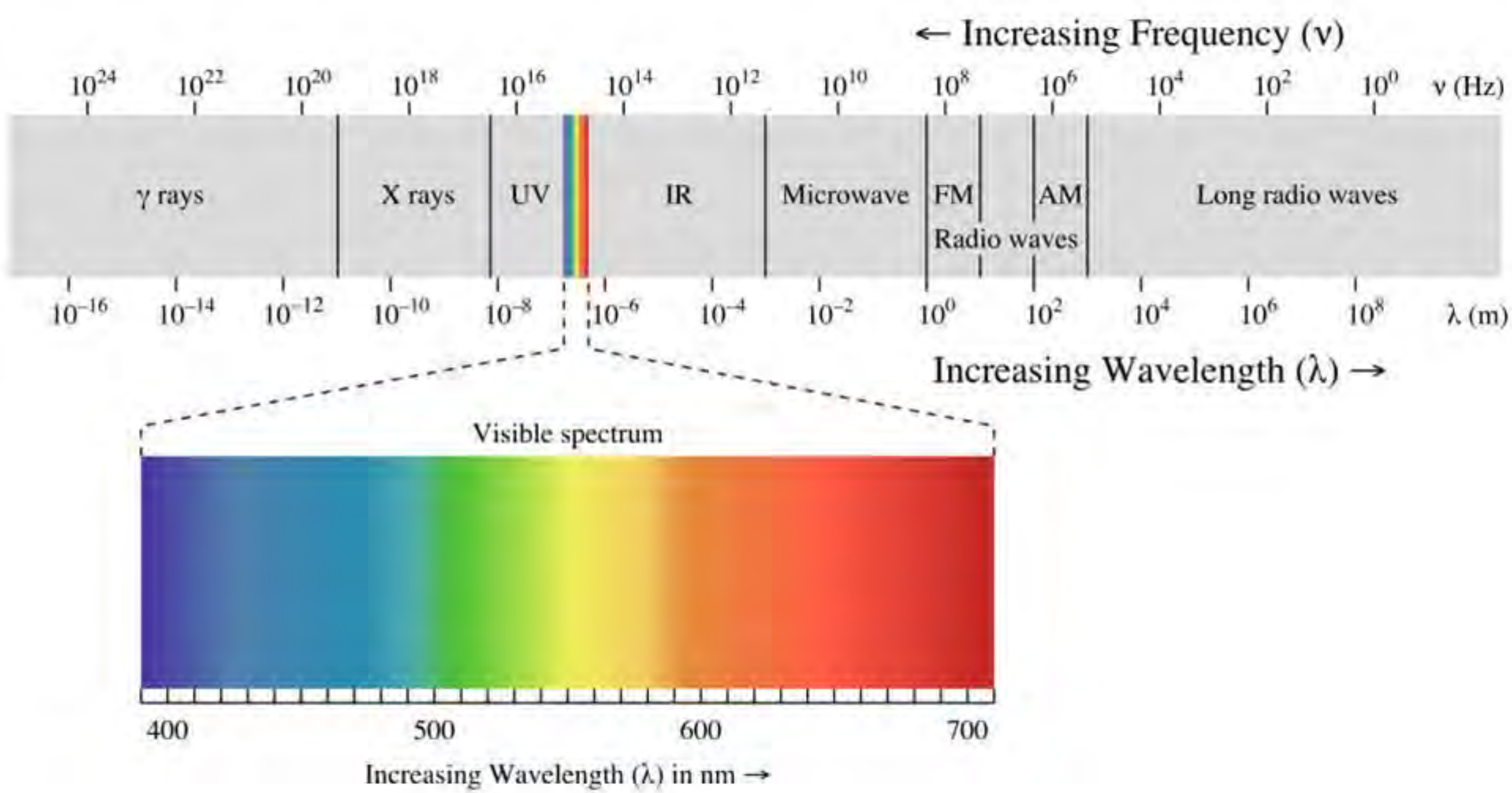
	single knot	knot cluster	fibre deviation	annual ring width	pith	bow	R^2
beech	1				2		0,49
ash	1		3		2		0,46
oak	1		2	3		4	0,47
Sweet chestnut	1	3			2		0,54

Visual strength grading

- existing German visual grading rule partly suited for strength grading
- grading criteria with the most impact
  - single knot value
  - pith
  - fibre deviation

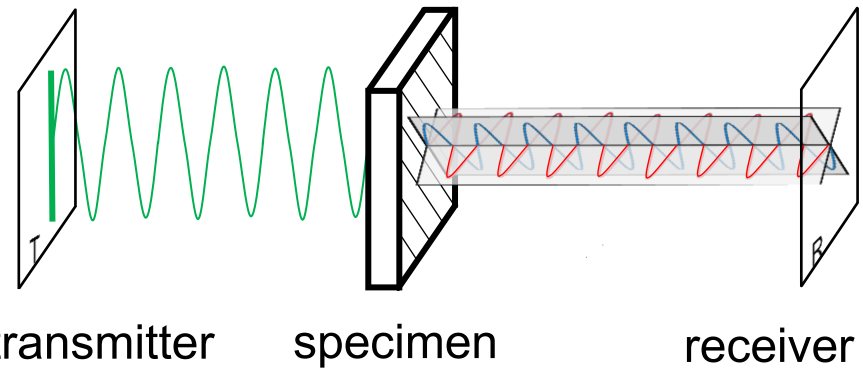
Microwave measurement

- microwave transmission as one possibility for machine strength grading

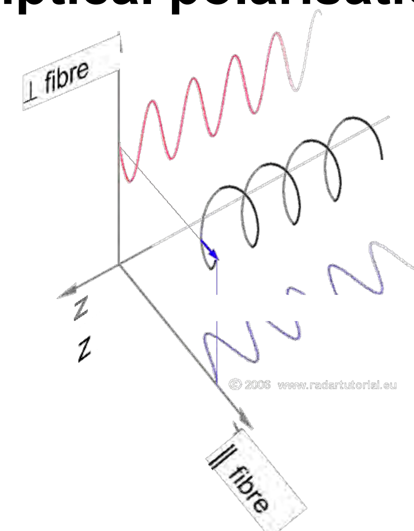


Microwave measurement

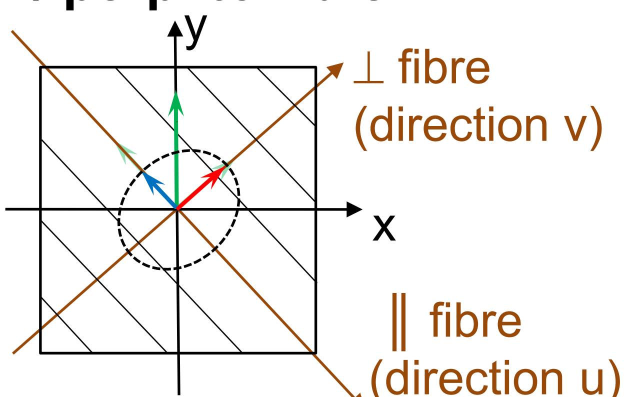
mw transition



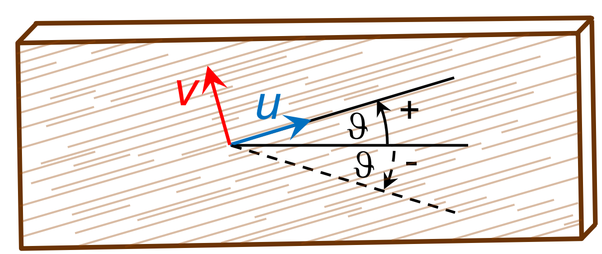
elliptical polarisation



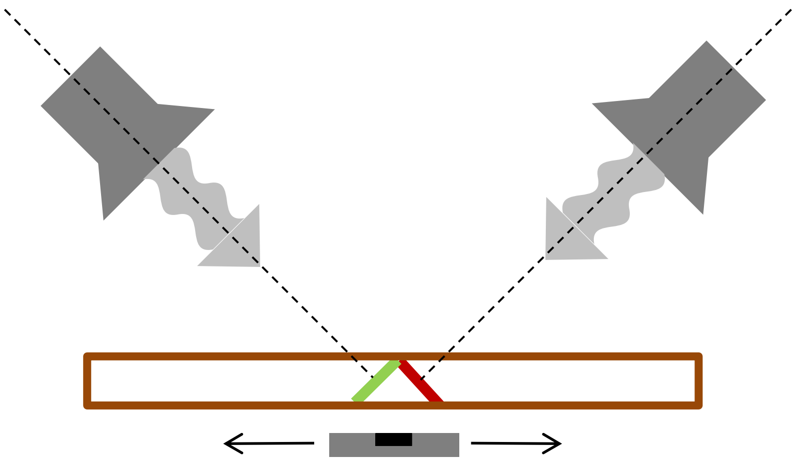
parallel / perp. to fibre

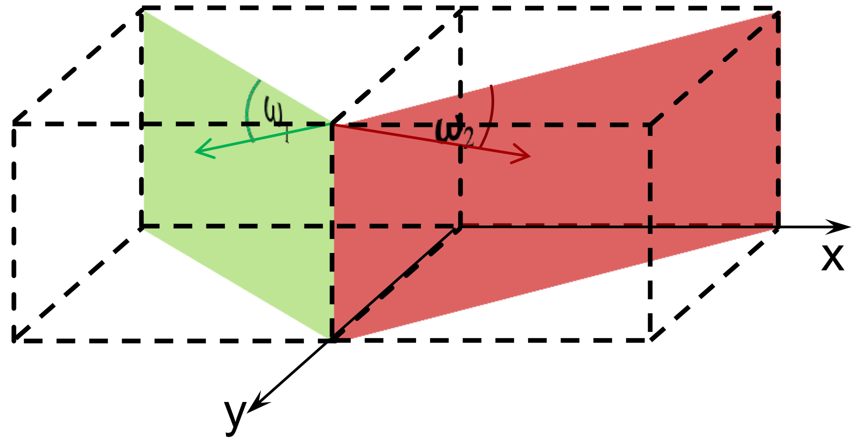


determination of 2d fibre orientation (horizontal)

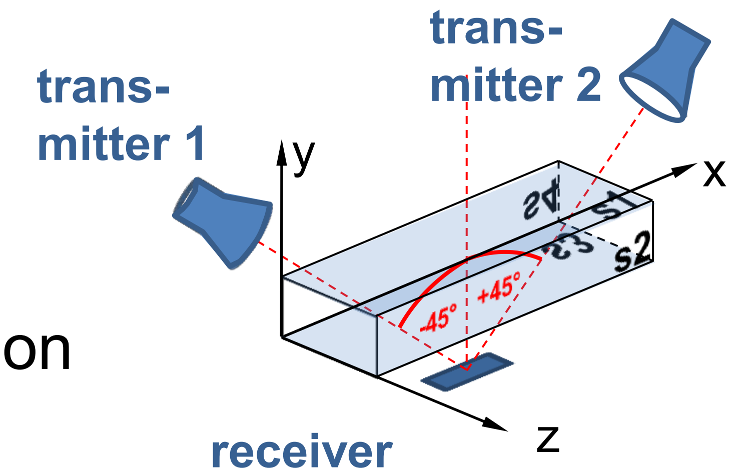


Microwave measurement





- two measurements -45° / +45°
- two angles ω_1, ω_2
- determination of vertical fibre orientation → spatial direction



Microwave measurement

Microwave measurement

Microwave measurment

- prerequisites:
  - 40 specimens – 20 with high and 20 with low fibre deviations
  - only 30 x 150 mm² due to screens (edge diffraction)
  - measurement within the test span
- definition of training and test sample
  - information on logs is available → basis for classification
  - all boards of one log assigned to training or test – no splits
  - distribution within training and test as representative as possible (density, tensile strength)

Microwave measurement

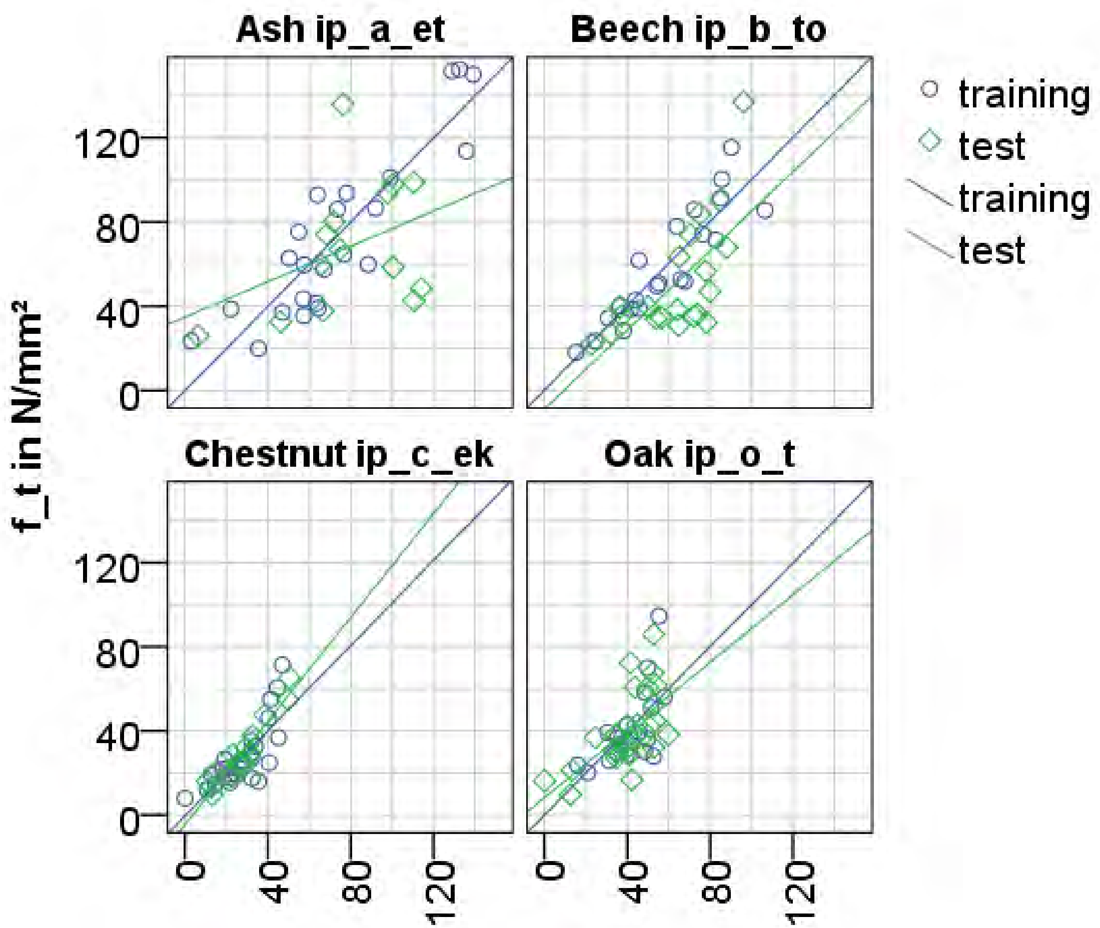
- development of regression model
  - derivation based on training
  - dependent variable is tensile strength
  - independent variables
- limitation: small sample size
  - IP models indicative
  - not necessarily applicable on boards from a different sample or species

Microwave measurement

	training	test	total
beech	21	20	41
ash	23	14	37
oak	18	27	45
Sweet chestnut	26	17	43
total	88	78	166

Microwave measurement

R^2	training	test
beech	0,81	0,45
ash	0,79	0,16
oak	0,39	0,39
Sweet chestnut	0,60	0,89



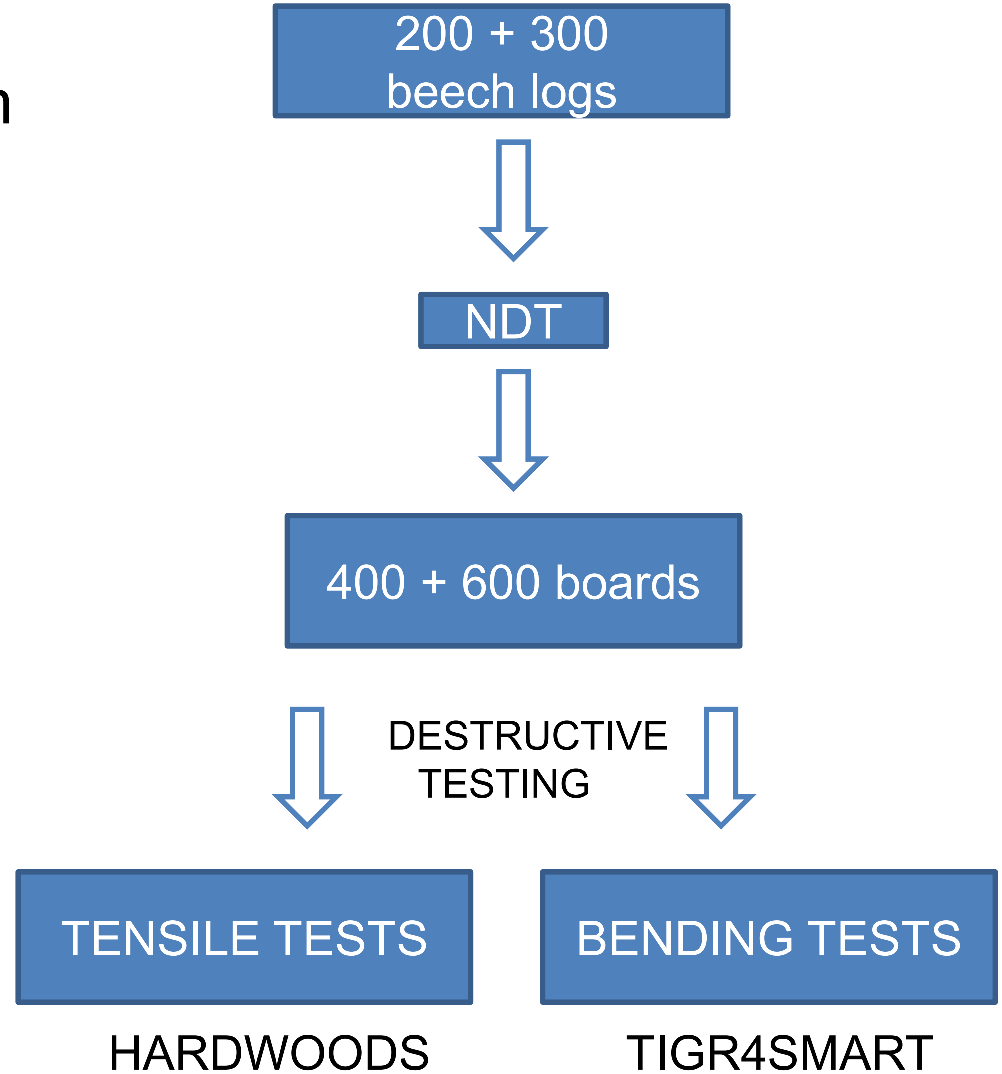
- abbreviations: e → E_dyn / k → tkar_150 / o → angle ω („diving“) / t → anlge ϑ („in plane“)

Test sample „allocation“

- allocation tests for Austrian beech in EN1912 in progress
  - first sampling in Austria completed – Vienna Woods / Lower Austria / Styria / Upper Austria – 400 specimens
  - selection and grading at sawmill in Styria
  - currently data analysis

Test sample „allocation“

- Slovenian tests on beech for allocation and modelling



Glulam made of hardwoods
State of the art – species, adhesives and national/European approvals

Simon Aicher

Materials Testing Institute University of Stuttgart
Department of Timber Constructions


Yesterday…

CE certification of structural glulam products

product	Harmonized European building product standard hEN	European Technical Assessment ETA
GLT from softwoods	EN 14080:2013	-
GLT from hardwoods	-	CUAP 03.04/29-1:2013 for GLT from oak, beech, chestnut EAD 130010-00-0304:2014 for GLT from beech LVL

Three EN 14080 routes to CE-marked glulam

1. Classified build-ups based on standardized lamination T-classes; the build-ups result from the EN 14080 calculation model

2. Calculated build-ups (EN 14080 calculation model) based on
   i) either standardized lamination T-classes acc. to EN 14080 or
   ii) test derived lamination strength / stiffness /density (EN 408; EN 384) and
   iii) declared finger joint strengths (within model boundaries)

3. Test based glulam strength class/profile
   i) tests with laminations
   ii) tests with finger joints
   iii) tests with beams

EN 14080 softwood glulam calculation model (1)

$$f_{m,g,k} = -2.2 + 2,5 \ (f_{t,0,l,k})^{0,75} + 1,5 \ (f_{m,j,k} / 1,4 - f_{t,0,l,k} + 6)^{0,65}$$

$f_{m,g,k}$ characteristic glulam bending strength
$f_{t,0,l,k}$ characteristic tension strength of lamination
$f_{m,j,k}$ characteristic bending strength of finger joint

- only valid if either

$$1,4 \ f_{t,0,l,k} \le f_{m,j,k} \le 1,4 \ f_{t,0,l,k} + 12$$

or (with $f_{m,j,k} = 1,4 \ f_{t,0,j,k}$)

$f_{t,0,j,k} \ge f_{t,0,l,k}$ or equally $f_{m,j,k} \ge f_{m,l,k}$

EN 14080 softwood glulam calculation model (2)

Tensile strength parallel to grain: $f_{t,0,g,k} = 0{,}8\ f_{m,g,k}$

Compression strength parallel to grain: $f_{c,0,g,k} = 1{,}0\ f_{m,g,k}$

Modulus of elasticity parallel to grain: $E_{0,g,mean} = 1{,}05\ E_{t,0,l,mean}$

Tensile strength perp. to grain: $f_{t,90,g,k} = 0{,}5$ MPa

Compression strength perp. to grain: $f_{c,90,g,k} = 2{,}5$ MPa

Shear strength: $f_{v,g,k} = 3{,}5$ MPa

Modulus of elasticity perp. to grain: $E_{90,g,mean} = 300$ MPa

Tensile strength classes for softwood laminations

EN 14080 Table 1 (extract)

T - class of boards[a]	$f_{t,0,l,k}$	$E_{t,0,l,mean}$	$\rho_{l,k}$
T14 (C24)	14	11 000	350
T14,5	14,5	11 000	350
T15	15	11 500	360
T16 (C27)	16	11 500	370
T18 (C30)	18	12 000	380
T21 (C35)	21	13 000	390
T22	22	13 000	390
T24 (C40)	24	13 500	400
T26	26	14 000	410
T27 (C45)	27	15 000	410
T28	28	15 000	420
T30 (C50)	30	15 500	430

[a] The C-Classes according to EN 338:2009 meet at least the required values of the respective T-classes.

Beam build-ups (GLc) and finger joint reqirements

EN 14080 Table 2 (extract)

Glued laminated timber	Outer zones of laminations			Intermediate zones of laminations			Inner zone of laminations		
Strength class	Strength class	Propor-tion [%]	$f_{m,j,k}$ [N/mm²]	Strength class	Propor-tion [%]	$f_{m,j,k}$ [N/mm²]	Strength class[a]	Propor-tion [%]	$f_{m,j,k}$ [N/mm²]
GL 20c	T13	2x33	21	-	-	-	T8	34	18
GL 22c	T13	2x33	26	-	-	-	T8	34	18
GL 24c	T14	2x33	31	-	-	-	T9	34	19
GL 30c	T22	2x17	40	-	-	-	T15	66	27
GL 30c	T22	2x17	41	-	-	-	T14	66	28
GL 30c	T22	2x20	40	T14	2x20	30	T11	20	22
GL 30c	T22	2x17	42	T14	2x23	31	T11	20	22
GL 32c	T24	2x17	44	-	-	-	T18	66	31
GL 32c	T26	2x17	45	-	-	-	T14	66	26
GL 32c	T26	2x10	48	T18	2x20	32	T11	40	22

Strengths and stiffnesses for classified GLc

EN 14080 Table 4 (extract)

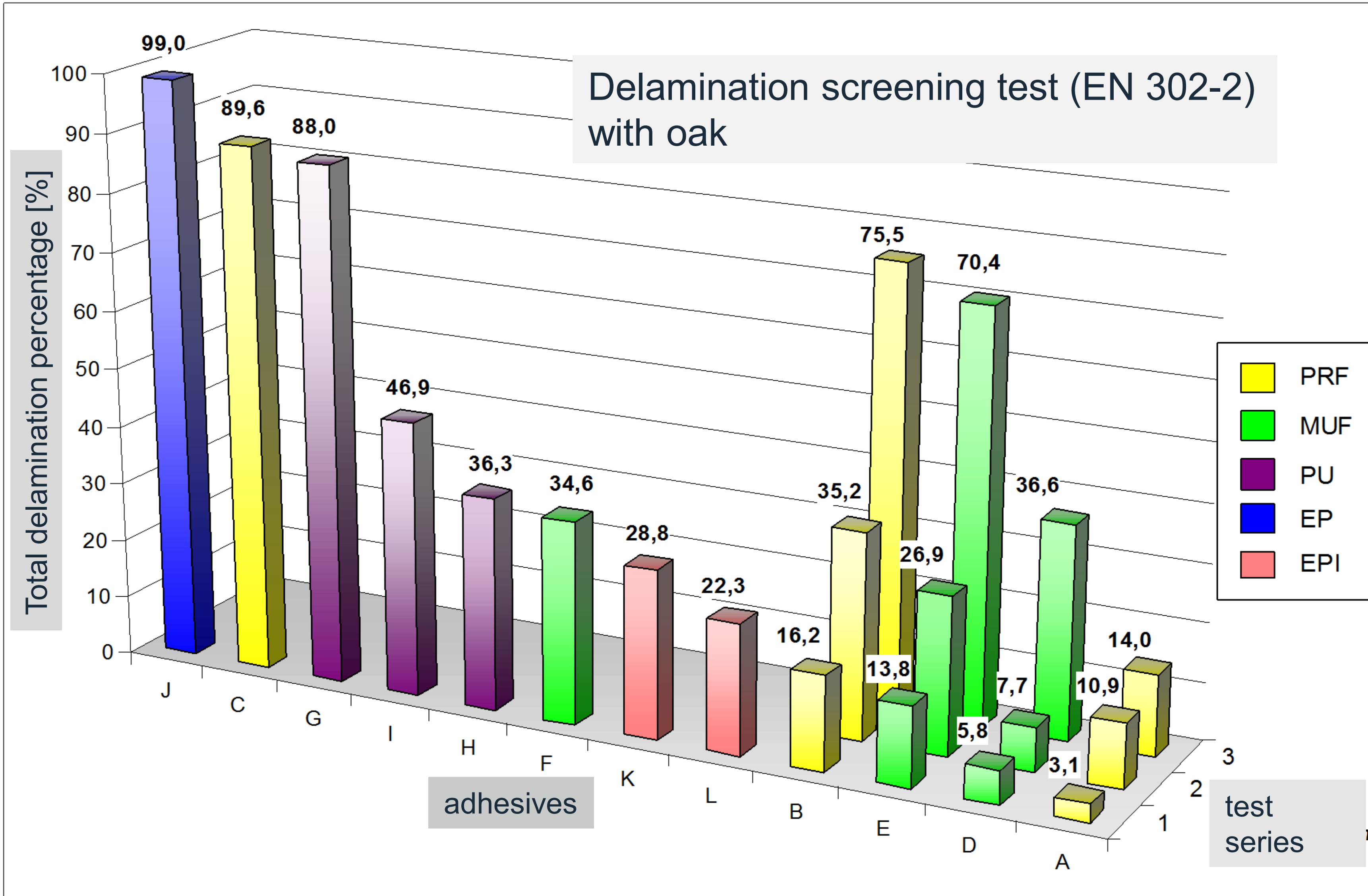
Property[a]	Symbol	GL 20c	GL 22c	GL 24c	GL 26c	GL 28c	GL 30c	GL 32c
		Glulam strength class						
Bending strength	$f_{m,g,k}$	20	22	24	26	28	30	32
Tensile strength	$f_{t,0,g,k}$	15	16	17	19	19,5	19,5	19,5
	$f_{t,90,g,k}$	0,5						
Compression strength	$f_{c,0,g,k}$	18,5	20	21,5	23,5	24	24,5	24,5
	$f_{c,90,g,k}$	2,5						
Shear strength (shear and torsion)	$f_{v,g,k}$	3,5						
Rolling shear strength	$f_{r,g,k}$	1,2						
Modulus of elasticity	$E_{0,g,mean}$	10 400	10 400	11 000	12 000	12 500	13 000	13 500
	$E_{0,g,05}$	8 600	8 600	9 100	10 000	10 400	10 800	11 200
	$E_{90,g,mean}$	300						
	$E_{90,g,05}$	250						

EU hardwoods: most relevant glulam species

1. Oak (France [23%], Germany [10%], Czech Rep.,..)
2. Beech (Germany [15%], France [11%],..)
3. Chestnut (France [5%], Spain, Italy,..)

4. Birch (Finland, Russia)
5. Poplar (Italy, France, Romania)
6. Eucalyptus grandis (Spain)
7. Robinia (Hungary)
8. Ash (Germany, Switzerland)

Adhesives for structural hardwood bonding



Approved adhesives for structural hardwood bonds

Wood species	PRF	MUF	Application	PU with primer
Oak (*Quercus petraea, Quercus robur*)	• Aerodux 185/ HRP 150/155 (Dynea AS)	• GripPro™Design (Akzo Nobel Adhesives AB)	• S/M	
Beech (*Fagus sylvatica*)	• Aerodux 185/ HRP 150/155 (Dynea AS) • Prefere 4040/5839 (Dynea AS) • Bakelite PF 1993 HL/ PF 2003 H (Hexion)	• GripPro™Design (Akzo Nobel Adhesives AB) • Prefere 4535/5046 (Dynea AS) • Kauramin 683/688 (BASF SE)	• S/M • M • M	• LOCTITE HB S309 Purbond + Primer LOCTITE PR 3105 Purbond (Henkel & Cie. AG)
Chestnut (*Castanea sativa*)		• GripPro™Design (Akzo Nobel Adhesives AB) • Prefere 4535/5035 (Dynea AS)	• S/M • M	
Birch (*Betula spec.*)		• GripPro™Design (Akzo Nobel Adhesives AB)	• S/M	

S = separate application of resin and hardener   M = mix-in application

Approved hardwood glulams (ETAs and national)

First year of approval	Approval: German Technical Approval Z-9.1- …	Approval: European Technical Approval ETA	Species of laminations (origin)	Service Class for glulam use	Holder of Approval
2004	577	-	Dark Red Meranti (Indonesia)	1, 2	Enno Roggemann, Bremen, Germany
2008 – 2012	Approvals in single cases (Germany)		Oak (Germany, Czech Rep.)	1	Different holders, Germany
2009	679	-	Beech (Germany)	1	Studiengemeinschaft Holzleimbau, Wuppertal, Germany
2012 2013	704 -	- 13/0642	Oak (France)	1, 2	Elaborados y Fabricados Gamiz, S.A., Spain
2013	821	-	Oak (Germany, Czech Rep.)	1, 2	Holz Schiller GmbH, Regen; Germany
2013	-	13/0644	Sweet Chestnut (Spain)	1, 2	SIEROLAM SA., Spain
2013 2015	837 -	- 14/0354	Beech LVL (Germany)	1, 2	Pollmeier Furnierwerkstoffe GmbH, Creuzburg; Germany

Hardwoods GLT CUAP 03.04/29-1

limitations

Wood species	oak	chestnut	beech
max. width of lamellae (mm)	160	200	160
max. thickness of lamellae (mm)	20	30	30
max. depth of GLT (mm)	400	900	900
min/max width of GLT (mm)	50 - 160	50 - 200	50 - 200
max. length of GLT (m)	12	18	18
service classes	1 and 2	1 and 2	1
moisture content (%)	8 - 12	8 - 12	8 - 12
min number of lamellae	4	4	4

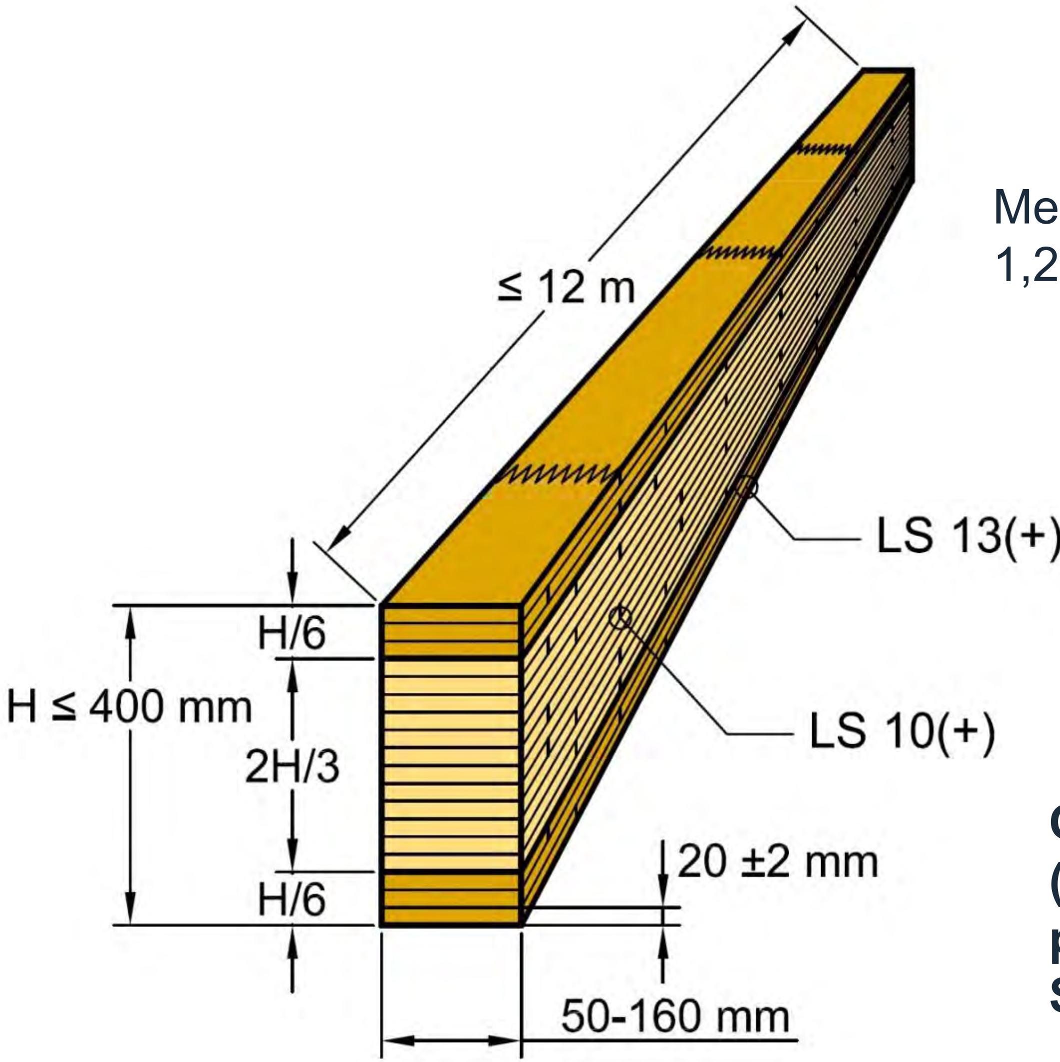
Hardwoods GLT CUAP - Assessment of lamellae

Product characteristics	method of verification	method of assessing and judgement	No of samples	Declaration in ETA
density	EN 408	x_{05}, x_{95} acc. to EN 14358	100 per grade/dimension	-
Tensile strength and modulus of elasticity parallel to grain	EN 408 (cl. 12 + 13)	x_{05} ($f_{t,0}$) x_{50} (E_0) EN 408 + EN 14358	100 per grade/dimension	$f_{t,0,l,k}$ $E_{0,mean}$
Bending strength	-	-	100	-
Tensile strength of finger joints	EN 408 (free length 200 mm)	x_{05} ($f_{t,j}$) EN 408 + EN 14358	100 per grade/dimension	$f_{t,j,05}$
Bending strength of finger joints	EN 385	x_{05} ($f_{m,j}$) EN 385 + EN14358	100 per grade/ dimension	$f_{m,j,05}$

Hardwoods GLT CUAP - Assessment of glulam

Product characteristics	method of verification	method of assessing and judgement	No of samples	Declaration in ETA
Bending strength (+ modulus of elasticity and modulus of rigidity)	EN 408 (cl. 9,10,19,11.2)	EN 408 x_{05} (f_m) x_{50} (E_m) x_{50} (G) EN 14358	30 per dimension	$f_{m,05}$ $E_{m,mean}$ G_{mean}
Compression strength	EN 408 (cl. 15)	EN 408 x_{05} ($f_{c,0}$) EN 14358	15 per dimension	$f_{c,05}$
Tensile strength	EN 408 (cl. 13), alternatively estimated from min($f_{t,0,l,k}$; $f_{t,0,j,k}$)	EN 408 x_{05} ($f_{t,0}$) EN 14358	15 per dimension	$f_{t,05}$
Shear strength	Principle of EN 408, but l/h = 8	x_{05} (f_v) CUAP 03.04/29+ EN 14358	15 per dimension	$f_{v,05}$

Oak glulam (ETA – 13/0642), company Gamiz, Spain

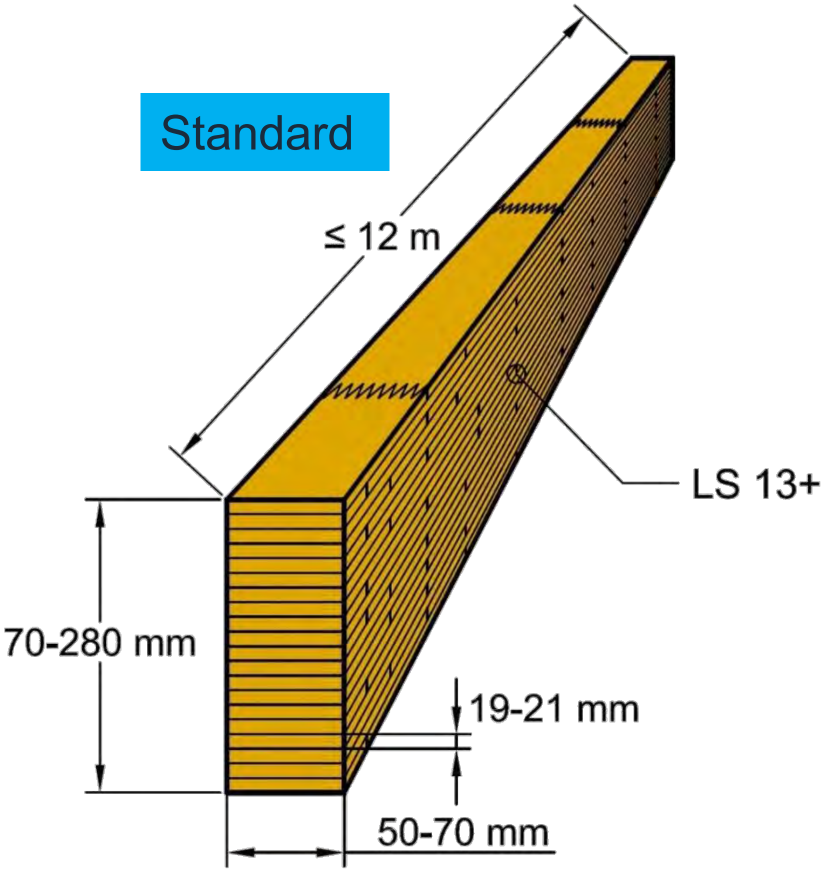


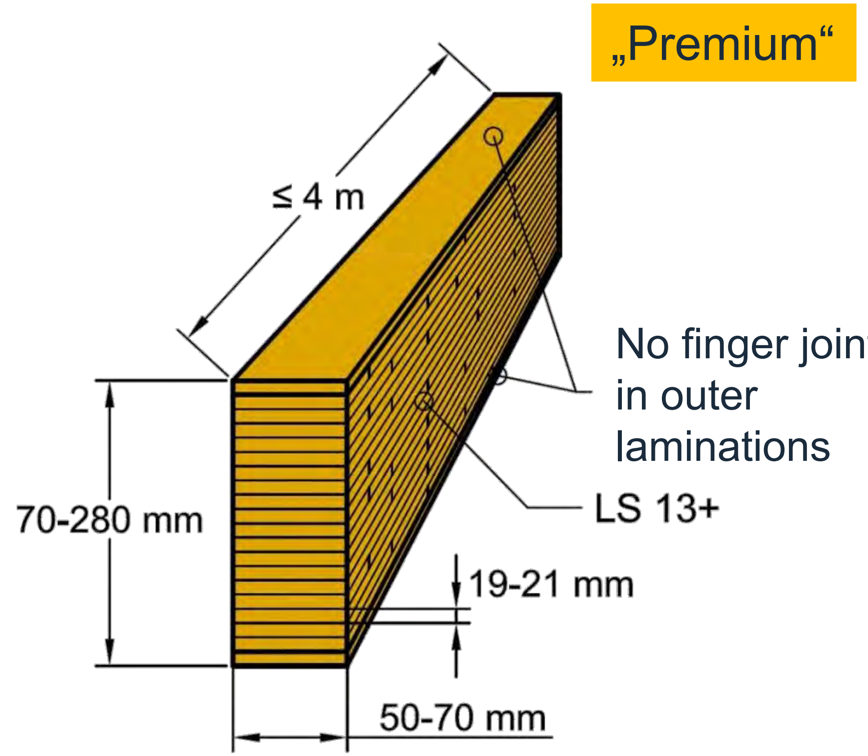
Mean length of boards:
1,2m

Oak
(Quercus robur, Quercus petraea)
Source: France

Oak glulam (Z - 9.1- 821), company Schiller, Germany

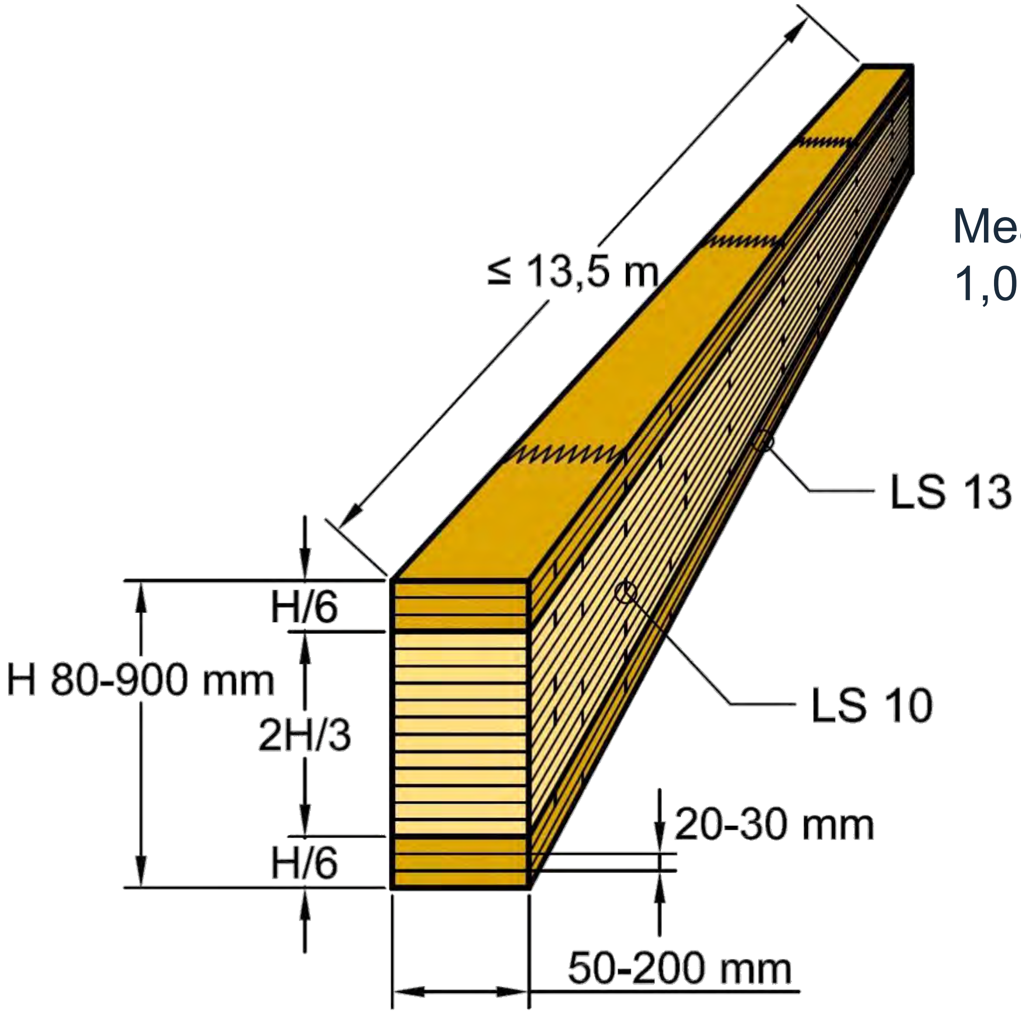
Mean length of lamellas:
0,6m





Oak
(Quercus robur, Quercus petraea)
Source: Germany, Czech Rep.

Oak glulam (ETA – 13/0646), company Sierolam, Spain



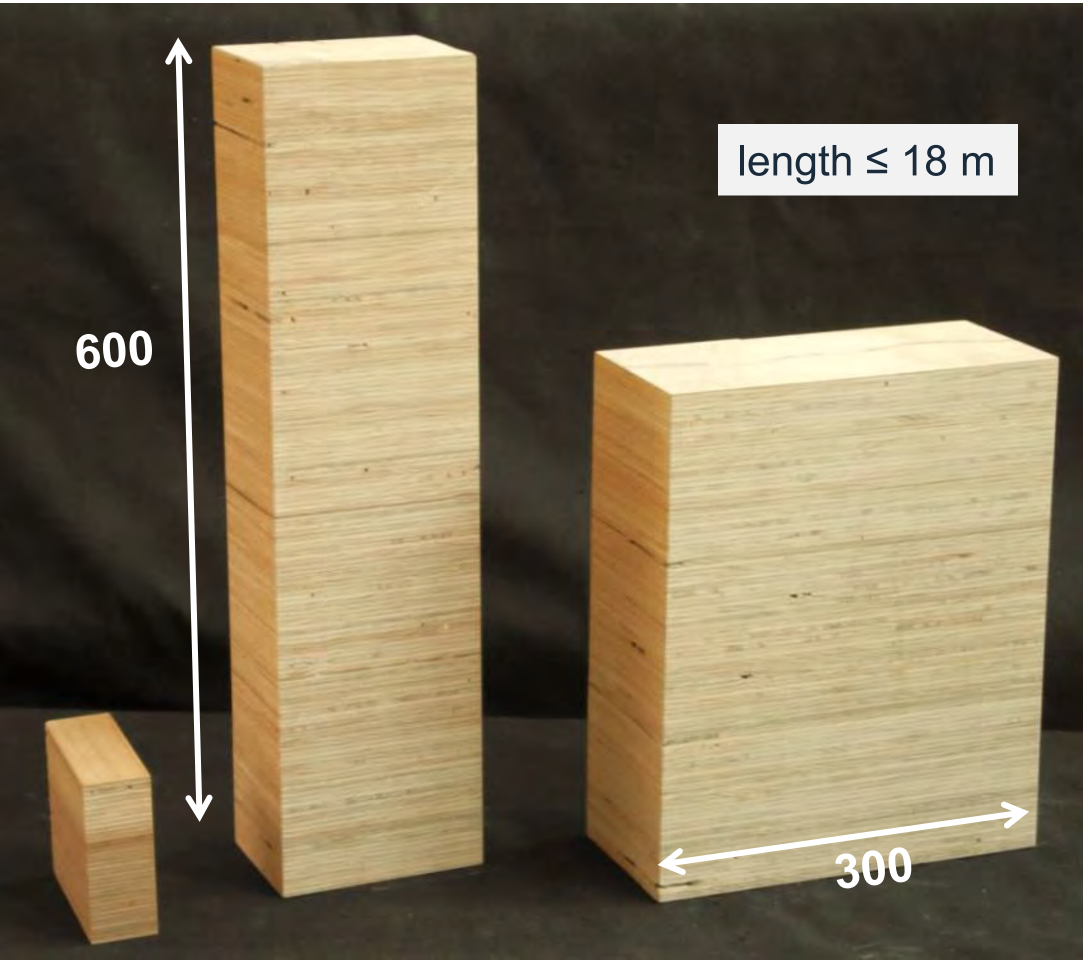
Mean length of lamellas:
1,0m

Sweet chestnut (castanea sativa)
Source: North of Spain

Beech glulam, company Hess Timber, Germany

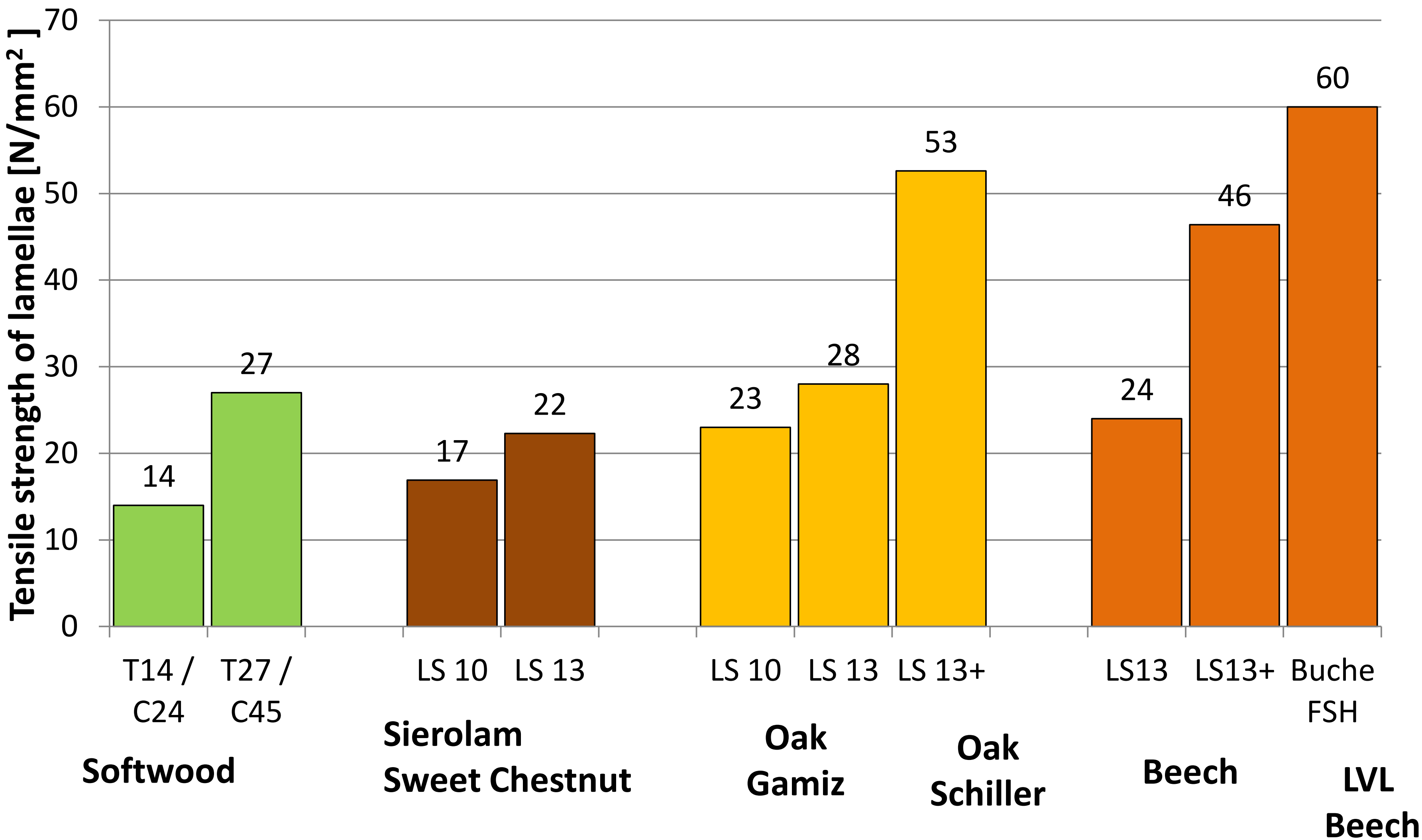
yet not acc. to Z-9.1-679

Beech-LVL glulam (ETA–14/0354), comp. Pollmeier, Germany

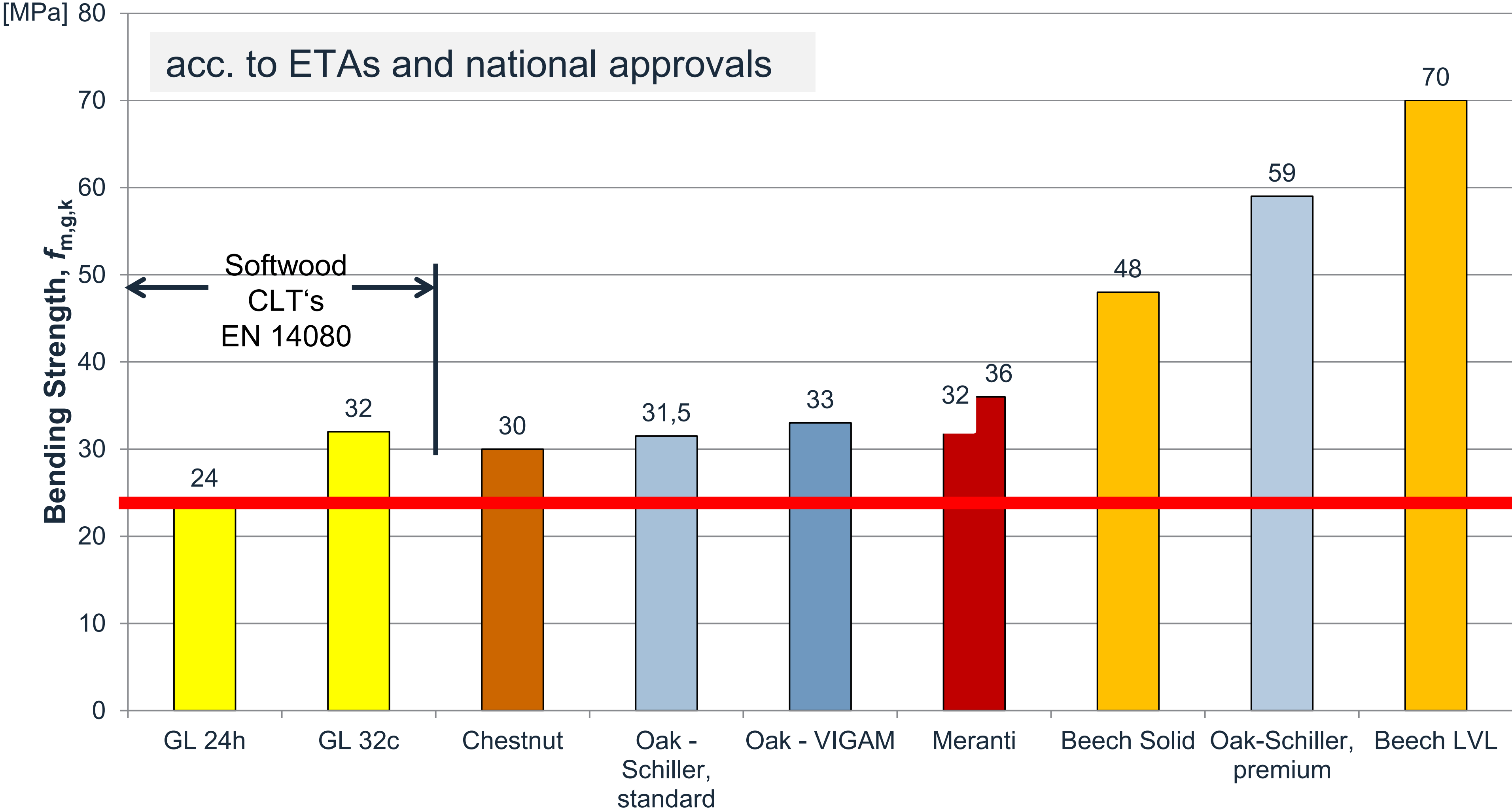


A new EAD and a respective new ETA is preparation, allowing for considerably increased dimensions (depth 2 m, length 30 m) and block glued cross-sections

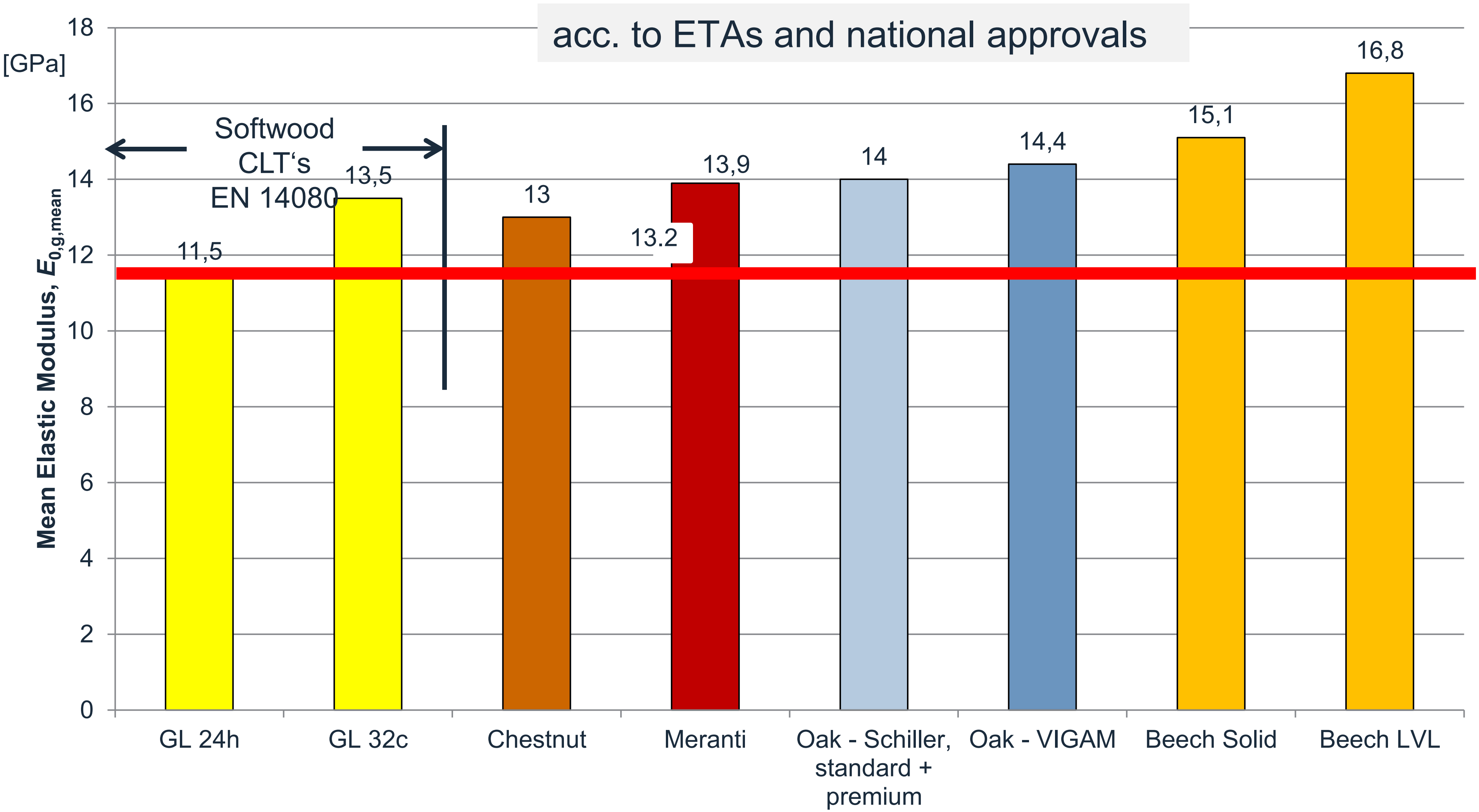
Tensile strength of European hardwood lamellas



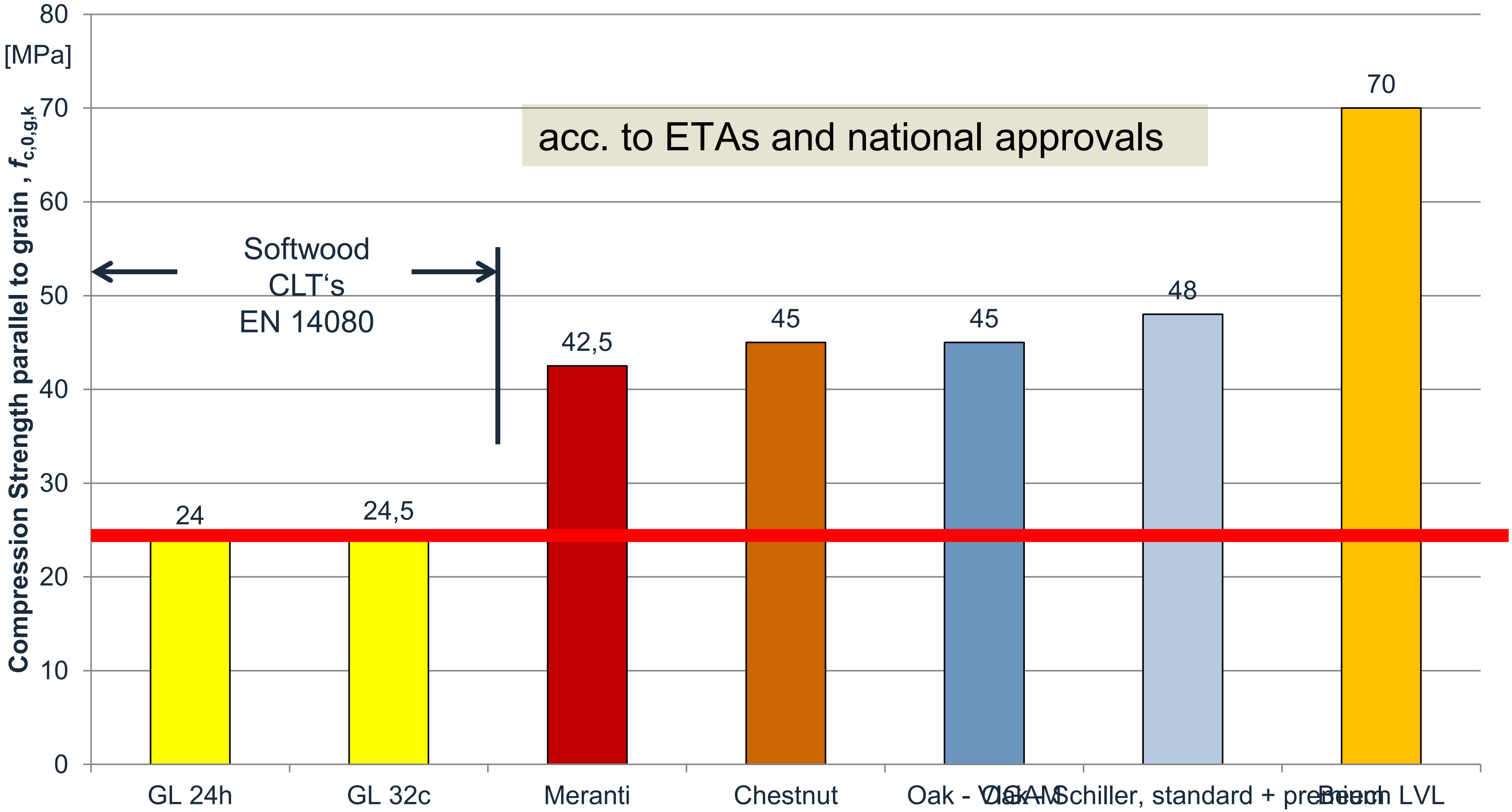
Hardwood glulam bending strengths



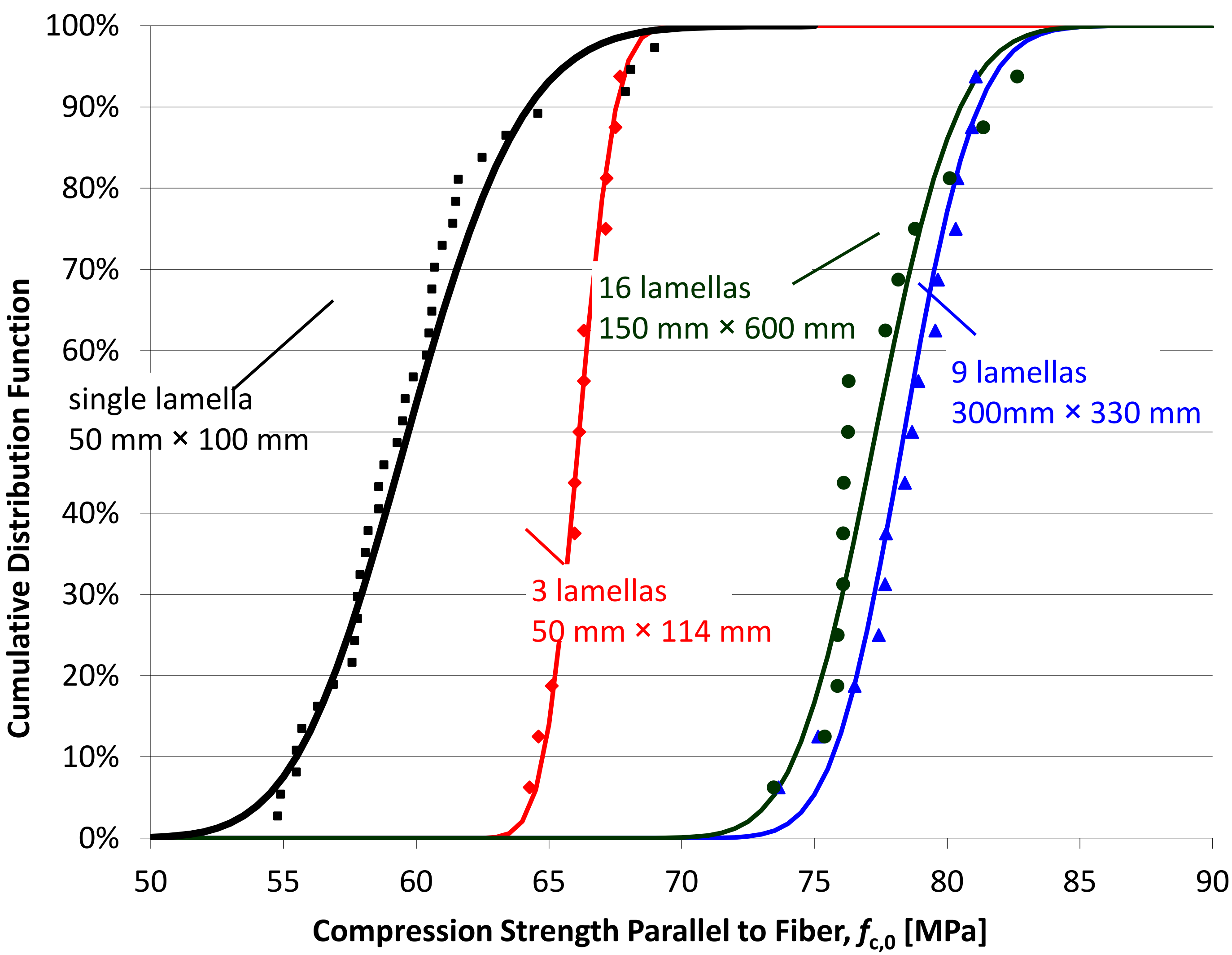
Hardwood glulam E-modules



Hardwood glulam compression strengths



Beech LVL glulam – compression strength parallel



Ratios of wood and joint bending strengths

approved hardwood GLT	lamination grade	bending strength of lamination $f_{m,l,k}$ (MPa)	bending strength of finger Joint (MPa) $f_{m,j,k}$	$\frac{f_{m,j,k}}{f_{m,l,k}}$
Chestnut Sierolam	S13	34	45	1,32
Oak Vigam	(S10)	38	49	1,29
	(S13)	47	51	1,09
Oak Schiller	(S13+)	≥ 80	≥ 60	0,75
Producer xy	-	50	31	0,62

Condition of EN 14080 $f_{m,j,k} \geq f_{m,l,k}$ often not fulfilled,

hence present EN 14080calculation procedure not applicable

Glulam made of hardwoods

State of the art in Europe

Any further questions?

No! ➡ Thank you very much for your audience!

Requirements from GL producer's and sawmiller's point of view, prototype production and testing of homogenous and combined oak glulam in France

Guillaume Legrand, Morgan Vuillermoz
Technology Institute FCBA

EU Hardwood side-event at Garmish

Motivation for EU Hardwoods research in France

Strong willingness to put hardwoods to good and larger use in buildings and constructions.

↳ Undertaken investigations:

- Possible degrees of change - at primary processing including round wood supply, and secondary processing - in comparison to current value chain
- Testing of the new glulam products accessible through those alternative pathways
- Related consequences in terms of production performances, economical balance and organization (intra and inter company)

⇒ Recommendations for changes in production - chain and adapted lamella specifications (compromise)

1st scenario for test production (2015)

New business relationships to be built but minimal internal change required from sawmiller and GL producer

- How good for glulam are lamellae picked up from existing stocks of **usual square-edged timber** produced at oak sawmill?
- And what would be required along the chain to improve performances?

1st scenario for test production (2015)
Sampling of QF2 / QF3 oak lamellae

Chosen specifications for oak lamellae: traditional square edged timber

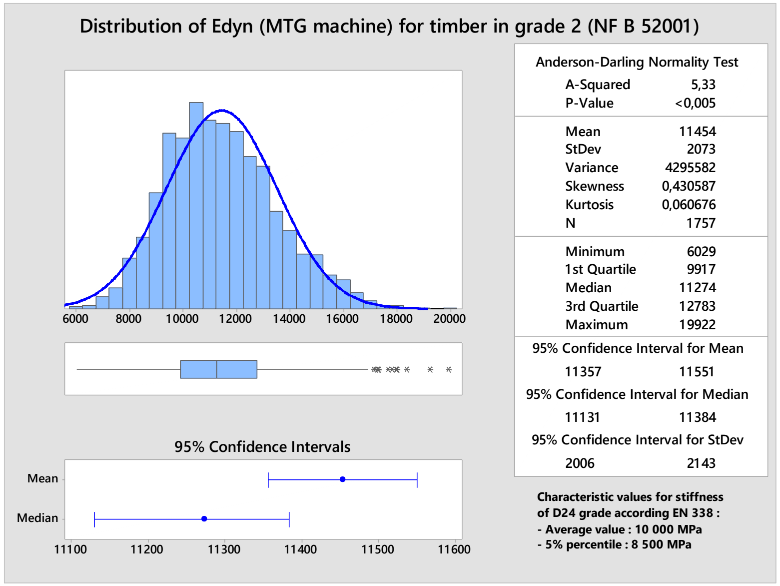
- Dimension : 27 $\pm$ 1 x 160 mm
- Length : 1.1 to 2,8 m ; mean = 1,8 m
- Moisture content: 10-12%
- Aesthetics: QF2 and QF3 classes acc. to EN 975-1
- Time before delivery: 3 weeks !
- Volume: 20 m^3

$\rightarrow$ Several origins : heterogeneity of the sampling

$\rightarrow$ QF1 class sawings to complete the volume …

1st scenario for test production (2015)

Sorting of D18, D24 and D30 strength classes oak lamellae



- Sawings : 27 x 160 mm² → laminations : 24 x 160 mm²
- Strength grading through equivalence D24 (from QF2 / QF3)
  and *extra* D18 (from QF2 / QF3) and D30 (from QF1) by FCBA acc. to NF B 52001-1
- E_{dyn} (MTG)
- Density

→ Selection of lamellae with comparable characteristics to compose each beam

⇒ beams

1st scenario for test production (2015)

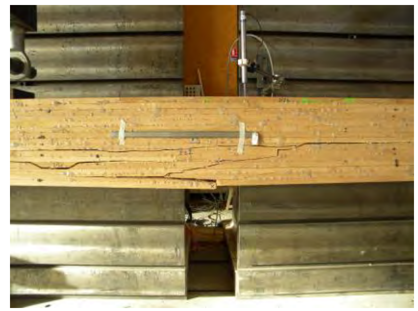
Production of homogenous and combined oak glulam out of D18, D24 and D30 lamellae

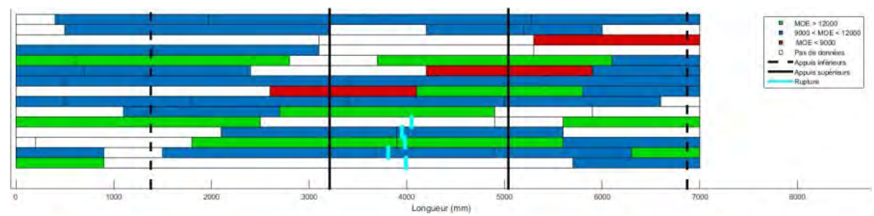
Production at SIMONIN (Montlebon, FR) with a MUF adhesive from AKZO NOBEL

	Composition	Lamellae		Beams	
		Strength grade	n / beam	Cross-section (mm²)	n
	Homogenous	D24	8	160 x 160	20
	Homogenous	D24	15	300 x 160	20
Extra	Homogenous	D30	9	180 x 160	20
Extra	Combined	D30 / D18 / D30	3 - 3 - 3	180 x 160	10

1st scenario for test production (2015)

Testing of homogenous and combined oak glulam out of D18, D24 and D30 lamellae





Testing at FCBA according to EN 14080 - 2013 :

- Massive laminations : flat wise bending test
- Finger jointed laminations : flat wise bending test
- Beams :
  - Bending and compression tests
  - Bonding quality : delamination and shear tests
  - Map of the failure

1st scenario for test production (2015)

Testing of homogenous oak glulam out of D24 lamellae

Properties		Beams composition: D24 — Visual strength grading acc. to NF B 52001-1 — Results (Correction to h = 300 mm, n = 40)		GL24h — Acc. to EN 14080:2013 for softwoods, C24 → GL24h, Correction to h = 300 mm
Beams	Modulus of elasticity in bending $E_{0,g,mean}$ (N/mm^2)	11 700	#	11 500
	Bending strength $f_{m,g,mean}$ (N/mm^2)	42,8		/
	Bending strength $f_{m,g,k}$ (N/mm^2)	32,4	>	27,0
	Density $\rho_{g,mean}$ (kg/m^3)	653		/
	Density $\rho_{g,k}$ (kg/m^3)	627	>	385
Finger joints n = 30	Bending strength $f_{m,g,k}$ (N/mm^2)	30,1		30,0

1st scenario for test production (2015)

Testing of homogenous and combined oak glulam out of D18 and D30 lamellae

Properties		Beams composition					
		D30 Visual strength grading acc. to NF B 52001-1			D30 / D18 / D30 Visual strength grading acc. to NF B 52001-1		
		Results h = 180 mm n = 20		GL28h Acc. to EN 14080:2013 for softwoods C30 → GL28h Correction to h = 180 mm	Results h = 180 mm n = 10		GL28c Acc. to EN 14080:2013 for softwoods C30 / C18 → GL28c Correction to h = 180 mm
Beams	Modulus of elasticity in bending $E_{0,g,mean}$ (N/mm²)	11 400	$<$	12 600	11 200	$<$	12 500
	Bending strength $f_{m,g,mean}$ (N/mm²)	46,3		/	52,6		/
	Bending strength $f_{m,g,k}$ (N/mm²)	35,7	$>$	33,2	34,2	$>$	33,0
	Density $\rho_{g,mean}$ (kg/m³)	655		/	662		/
	Density $\rho_{g,k}$ (kg/m³)	622	$>$	425	638	$>$	387
Finger joints n = 30	Bending strength fm,g,k (N/mm²)	29,6		36	29,6 36,0		38,6 26,0

1st prototype production (2015)
Lessons learnt from sawmill and GL producer point of view

- Homogenous Oak glulam comparable to softwoods glulam GL24h could be produced from D24 visually graded French oak which can already be sourced as traditional square-edged product at sawmill

- Glulam modulus of elasticity and finger jointed lamella strength are main factors limiting the performances of Oak glulam produced from lamellae from higher class D30

- Supplier – client relationship can be woven between sawmiller and GL producer but expectations will be fulfilled only under adapted conditions:
  - Longer time for delivery and visibility on annual demand for the sawmill
  - Strength grading (visual method) performed at the sawmill
  - Acceptation of mixes of lengths and qualities by GL producers

2^{nd} scenario for test production (2016)

What if we could make the best of the mixed forest resource and dared combined-GL products?

- How performant would homogenous and combined oak glulam be when produced from **purposely-specified round wood**?
- What are the consequences of such change along the chain, from sourcing to sawmilling and glulam production?

2^{nd} scenario for test production (2016)
Design and monitoring

Changes introduced at every step of the production chain:

1. Purpose-driven round wood specifications used to identify a suitable batch
   → D2b - D3 diameter class and < 100 years old stand, as documented by the national study on French oak resource (Lanvin & Reuling 2009)
   - *Lack of opportunities on the market*
   - *High mechanical performances*

   → Found on round wood auction catalog (ONF FD – Sarrebourg FR)

2. Purpose-driven sawing and processing at sawmill used to deal with such diameter / quality class (Trendel – Haguenau FR)
   + Strength grading and check *Vs* GL producer requirements for immediate processing (FCBA for Trendel FR)

3. Combined glulam production (SIMONIN – Montlebon FR)
   → Acceptation of all qualities using the right quality at the right place

And ***feedback*** collected by FCBA along the chain on quantitative (yield, strength properties, …) and qualitative (organization, service and quality, …) aspects

2^{nd} scenario for test production (2016)
Sampling

Chosen specifications for oak lamellae: sawings from specific D2b - D3 diameter class and < 100 years old round woods

- Dimension : 24 x 160 mm
- Length : 1,1 to 2,9 m ; mean : 2,1 m
- Moisture content: 8-10%
- Time before delivery: 3 months
- Volume: 10 m^3

$\rightarrow$ Single origin

$\Rightarrow$ Homogeneity of the sampling

2^{nd} scenario for test production (2016)

Sorting of D18, D24, D30 and D40 oak lamellae

Strength grade	Distribution %
D18	5
D24	13
D30	44
D40	37

- Sawings : 23 x 160 mm²
- Strength grading through equivalence D18 to D40 acc. to # NF B52001-1
- E_{dyn} (MTG)
- Density

⇒ Design of beams

2^{nd} scenario for test production (2016)

Production of homogenous and combined oak glulam out of D18 to D40 lamellae

Production at SIMONIN (Montlebon, FR) with a MUF adhesive from AKZO NOBEL

Composition	Lamellae		Beams	
	Strength grade	n / beam	Cross-section (mm^2)	n
Homogenous	D30	9	180 x 160	25
Combined	D30 / D18 / D30	3 - 3 - 3	180 x 160	5
Homogenous	D40	9	180 x 160	15
Combined	D40 / D24 / D40	3 - 3 - 3	180 x 160	15

2nd scenario for test production (2016)

Production of homogenous and combined oak glulam out of D18 to D40 lamellae

Testing at FCBA according to EN 14080 - 2013 :

- Massive laminations : flat wise bending and tensile test
- Finger jointed laminations : flat wise bending test
- Beams :
  - Bending tests
  - Bonding quality : delamination and shear tests
  - Map of the failure

2nd scenario for test production (2016)

Testing of homogenous and combined oak glulam out of D18 and D30 lamellae

Properties		Beams composition			
		D30 Visual strength grading acc. to # NF B 52001-1		D30 / D18 / D30 Visual strength grading acc. to # NF B 52001-1	
		Results h = 180 mm n = 25	GL28h Acc. to EN 14080:2013 for softwoods C30 → GL28h Correction to h = 180 mm	Results h = 180 mm n = 5	GL28c Acc. to EN 14080:2013 for sofwoods C30 / C18 / C30 → GL28c Correction to h = 180 mm
Beams	Modulus of elasticity in bending $E_{0,g,mean}$ (N/mm²)	15 800	> 12 600	15 000	> 12 500
	Bending strength $f_{m,g,mean}$ (N/mm²)	63,8	/	56,3	/
	Bending strength $f_{m,g,k}$ (N/mm²)	46,5	> 33,2	X	33,0
	Density $\rho_{g,mean}$ (kg/m³)	725	/	729	/
	Density $\rho_{g,k}$ (kg/m³)	703	> 425	X	387
Finger joints n = 30	Bending strength $f_{m,g,k}$ (N/mm²)	54,5	36	54,5 57,7	38,6 26,0

2nd scenario for test production (2016)

Testing of homogenous and combined oak glulam out of D24 and D40 lamellae

Properties		Beams composition			
		D40 Visual strength grading acc. to # NF B 52001-1		D40 / D24 Visual strength grading acc. to # NF B 52001-1	
		Results h = 180 mm n = 15	GL32h Acc. to EN 14080:2013 for sofwoods C40 → GL32h Correction to h = 180 mm	Results h = 180 mm n = 15	GL32c Acc. to EN 14080:2013 for sofwoods C40 / C24 → GL32c Correction to h = 180 mm
Beams	Modulus of elasticity in bending $E_{0,g,mean}$ (N/mm²)	16 300	> 14 200	17 100	> 14 600
	Bending strength $f_{m,g,mean}$ (N/mm²)	81,2	/	71	/
	Bending strength $f_{m,g,k}$ (N/mm²)	61,7	> 37,9	55,1	> 39,1
	Density $\rho_{g,mean}$ (kg/m³)	726	/	732	/
	Density $\rho_{g,k}$ (kg/m³)	709	> 440	712	> 424
Finger joints n = 30	Bending strength $f_{m,j,k}$ (N/mm²)	59,8	41	59,8 52,5	48,4 32,3

2nd scenario for test production (2016)

Lessons learnt from sawmill and GL producer point of view

- Well performing homogenous and combined oak glulam can be produced from lamellae sawn out of chosen round wood resource allowing to overcome the limiting effect of modulus of elasticity of traditional square edged oak timber
- Prototype processing at the sawmill was hindered by too tight time constraints and, to a lesser extend, diameter class but those limits can be overcome in case of less-experimental conditions
- As in 1st prototype production, supplier – client relationship can be woven between sawmiller and GL producer but expectations will be fulfilled only under adapted conditions
  - Longer time for delivery for the sawmill
  - Strength grading (visual method) performed at the sawmill for the GL producer

Comparative performances of prototype productions

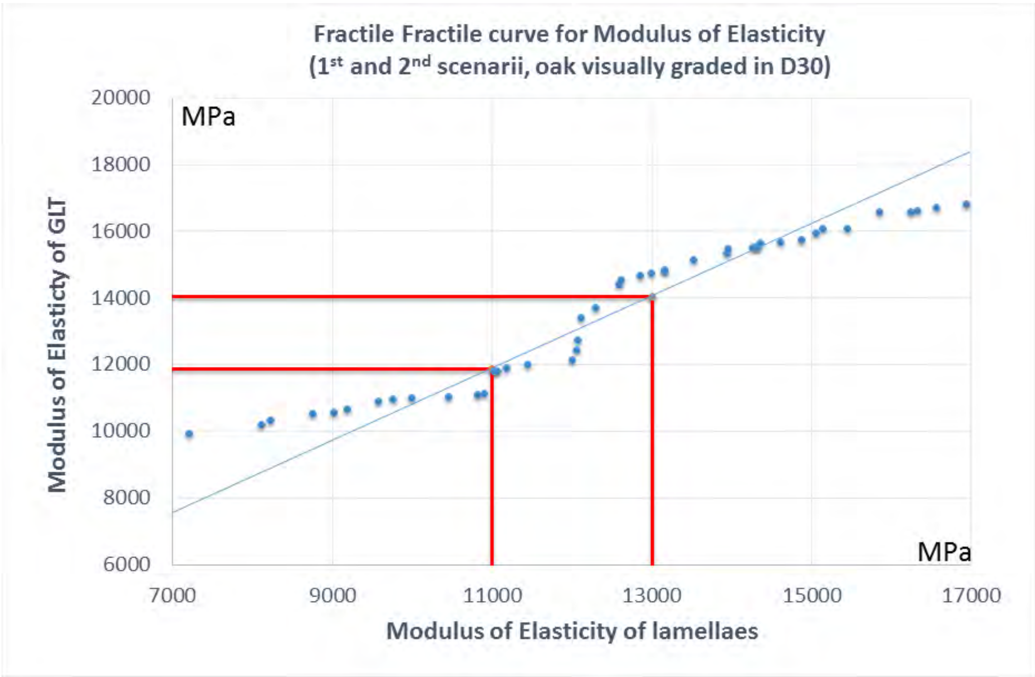
	Reference production	**1st prototype production**	**2nd prototype production**
Round wood	Northern EU	2nd log of large diameter high quality (B) oak	Butt log of mid diameter oak thinnings (CD)
Sawmilling	Imports	Usual square edged timber sorted as D24, with *extra* D18 and D30	Purpose-driven sawn lamellae sorted as a mix of D40, D30, D24 and D18
GL production	100	277	283
GL type	Spruce	Oak	Oak
Degree of change	Business as usual	Small change	Change at every step of the chain

Lessons learnt from sawmill and glulam producer point of view

- Glulam produced out of French oak can reach high in terms of strength performances and combined glulam are worth being considered
- Even if production efficiency can be reached through less experimental organization, oak glulam should not compete with softwoods glulam but instead find its own market using its mechanical, aesthetical and social assets
- Supplier – client relationship can be woven between sawmillers and GL producers but expectations will be fulfilled only under adapted conditions:
  - Longer time for delivery and visibility on annual demand for the sawmill
  - Strength grading (visual method) performed at the sawmill for the GL producer
  - Acceptation of mixes of lengths and qualities by the GL producers

Additionnal lessons learnt from prototype productions

- Results from test productions 1 + 2 can contribute to the development of a new model for the prediction of the behavior of glulam made of hardwoods and support the introduction of new standard classes in a future harmonized standard



Example of model for MOE based on test productions 1 + 2

Looking forward to see oak GL bloom on the French and EU market!

Morgan Vuillermoz (morgan.vuillermoz@fcba.fr)
Guillaume Legrand (guillaume.legrand@fcba.fr)

French oak GL, SIMONIN

Modelling and design equations for hardwood glulam

Cristóbal Tapia Camú

Material Testing Institute, University of Stuttgart
Division of Timber Constructions

<1>

Introduction

Current situation

- There is no general model to design *hardwood* glulam beams as compared with softwood glulam

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$$f_{m,g,k} = -2.2 + 2.5 \cdot f_{t,0,\ell,k}^{0.75} + 1.5 \cdot \left(\frac{f_{m,j,k}}{1.4} - f_{t,0,\ell,k} + 6 \right)^{0.65}$$

valid only for

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Introduction

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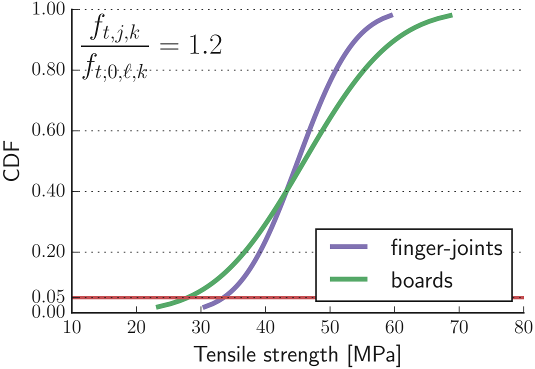

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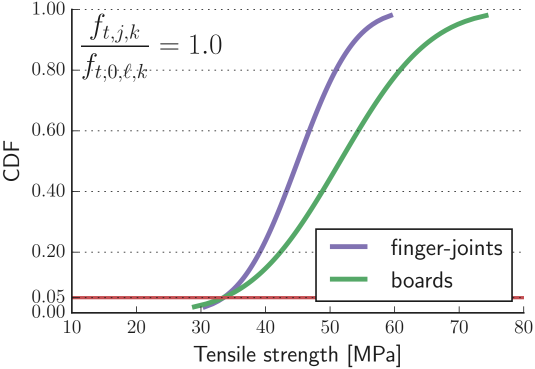

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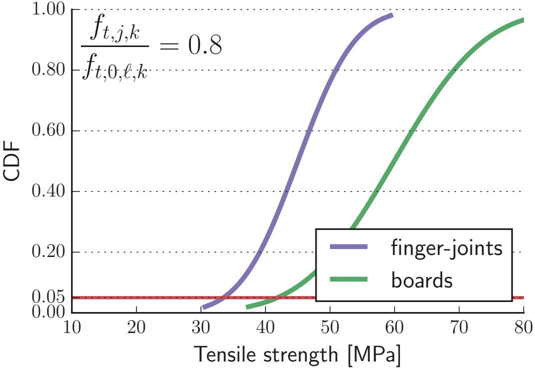

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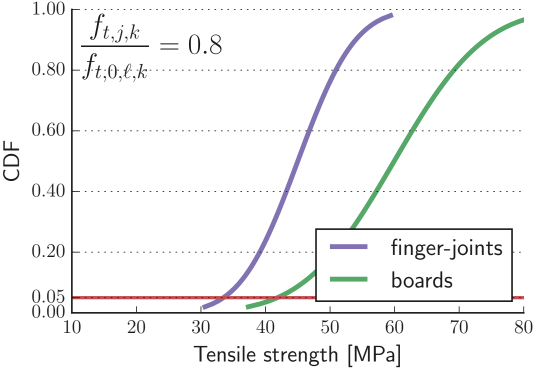

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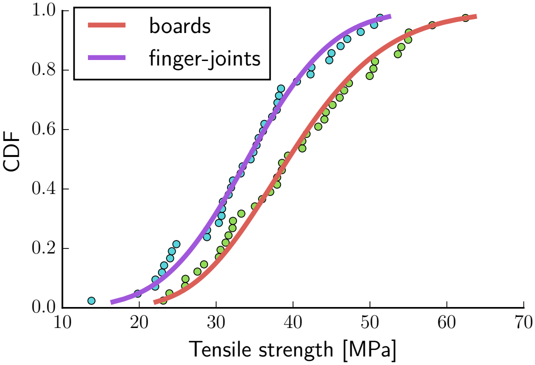

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Modelling hardwood glulam

Main concept

- Create a model to predict bending strength of glulam, based on the results obtained from tests of single boards and finger-joints.

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- Failure mechanism taken into account using *XFEM* and *fracture energies*
- . . . different fracture energies for finger-joints and boards

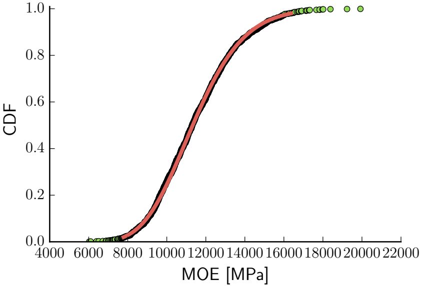
Individual boards

Needed distributions:

Individual boards

Needed distributions:

- Modulus of Elasticity (MOE)

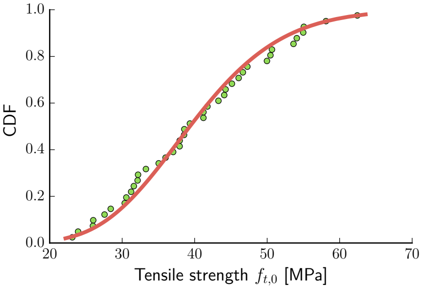


Characterization of the material properties

Individual boards

Needed distributions:

- Modulus of Elasticity (MOE)
- Tensile strengths



Characterization of the material properties

Individual boards

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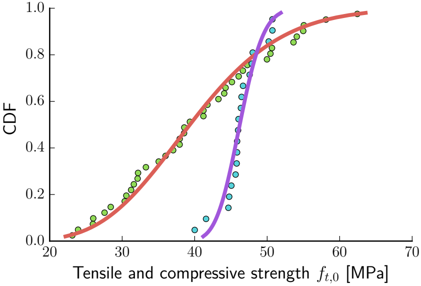

Individual boards

Needed distributions:

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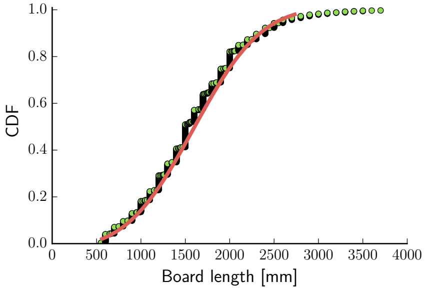
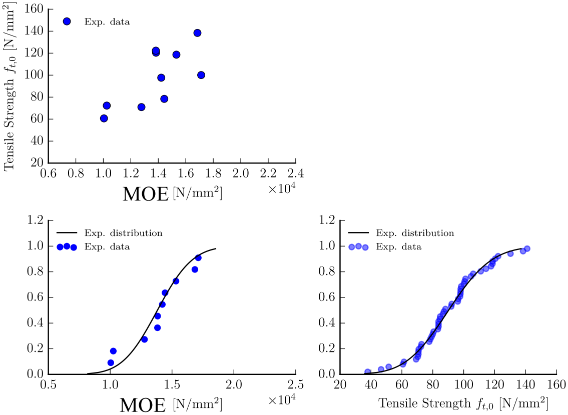
- Lengths



Individual boards

Also, it is important to get some correlations between these values



Characterization of the material

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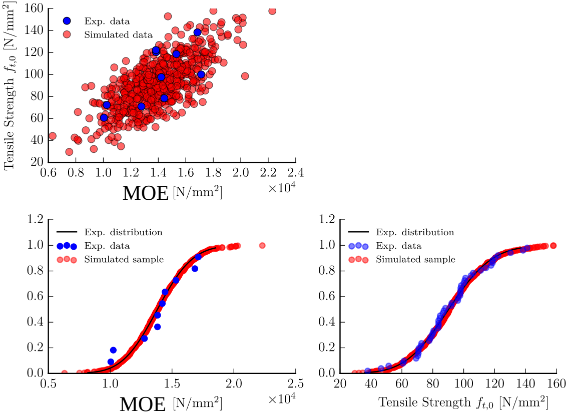
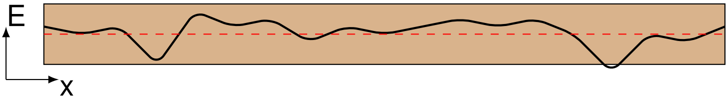


Characterization of the material

MOE variation along each board



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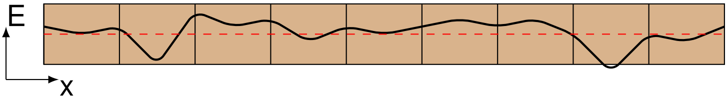

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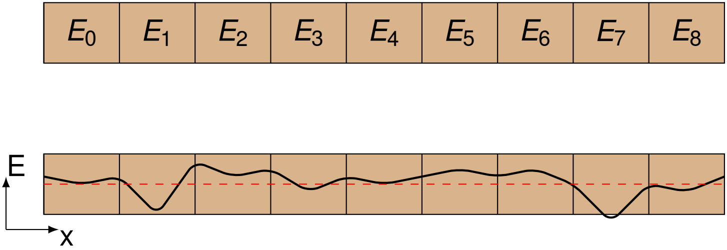

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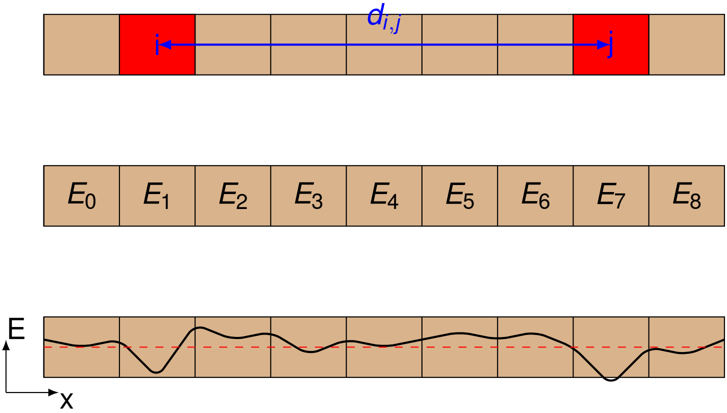

MOE variation along each board

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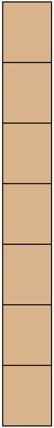
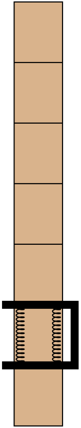


MOE variation along each board

- A simple experiment was performed
- Extensometer with length = 230 mm was used



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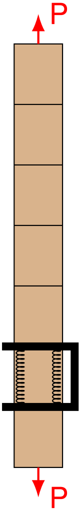

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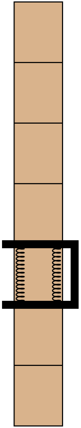

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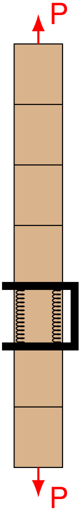

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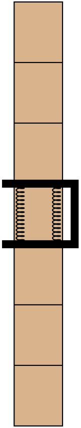

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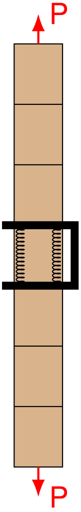

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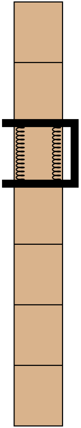

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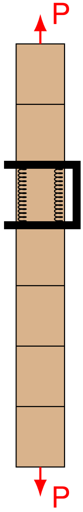

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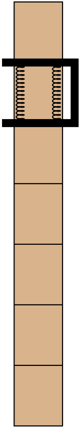

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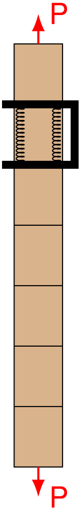
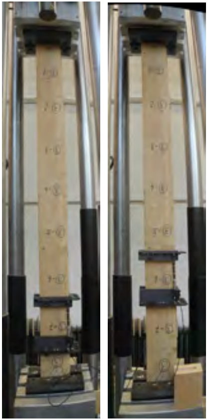


Testing MOE variation

Characterization of the material

Testing MOE variation



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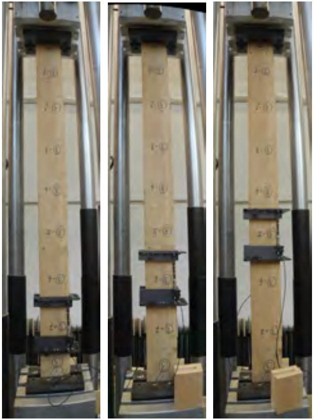

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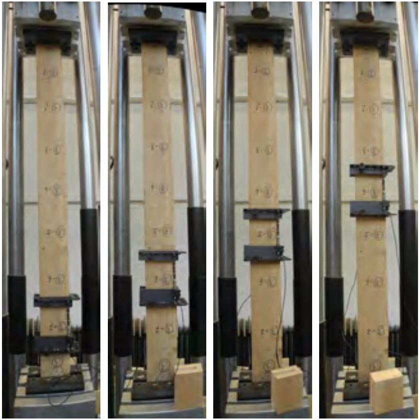
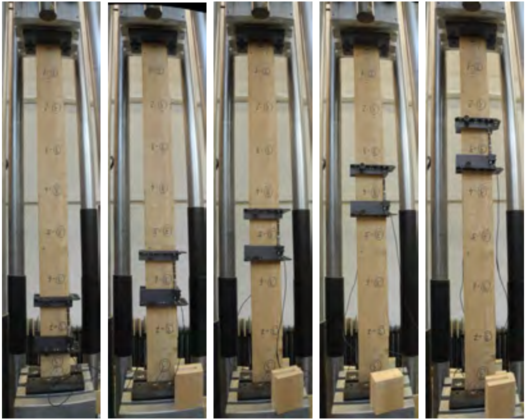


Characterization of the material

Testing MOE variation



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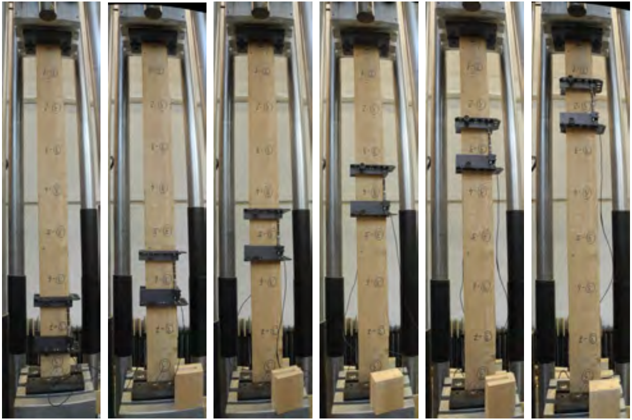

Testing MOE variation

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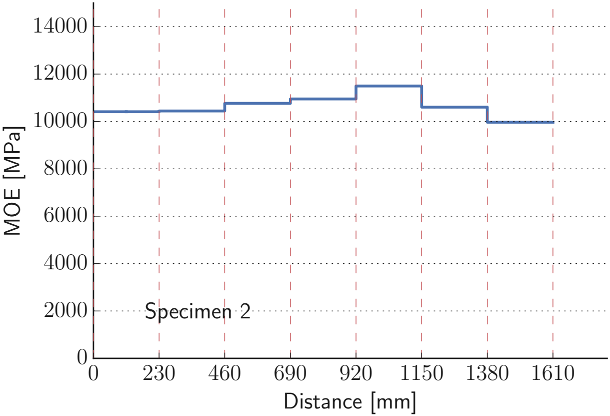
Some results of the MOE variation along the board



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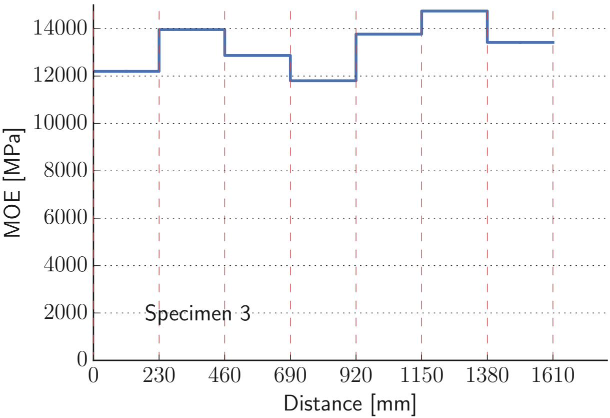

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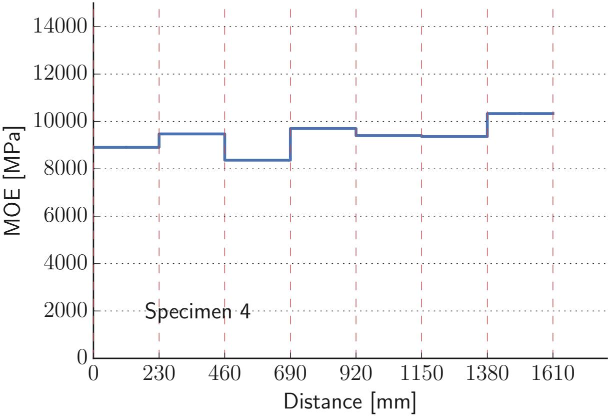

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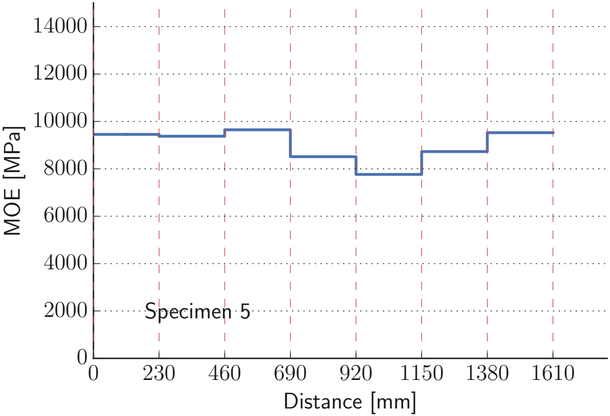

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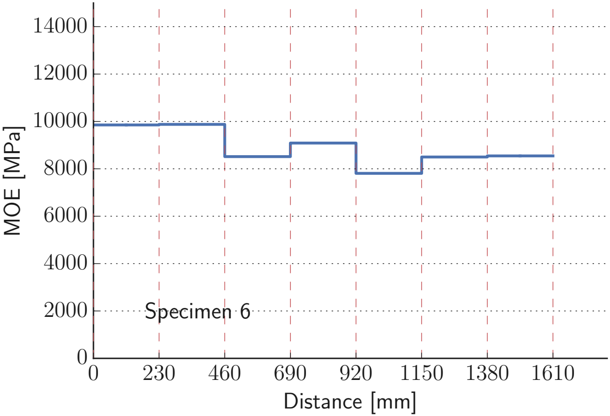

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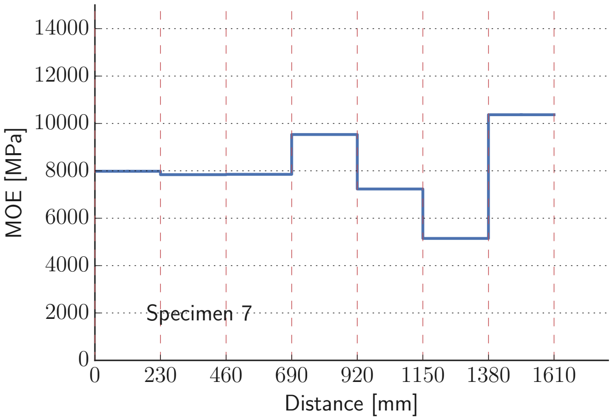
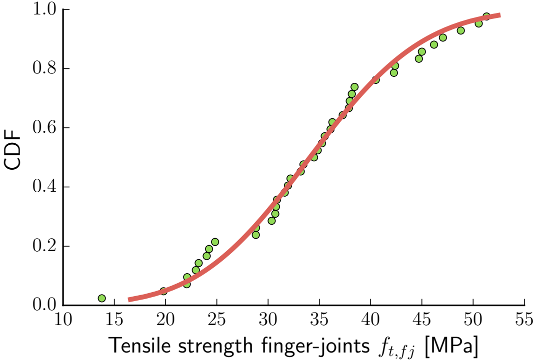
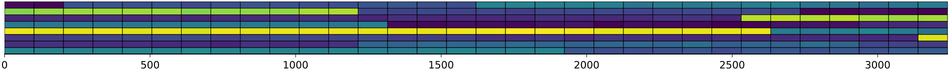


Characterization of the material properties

Finger-joints



FE-Model



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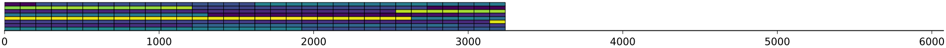

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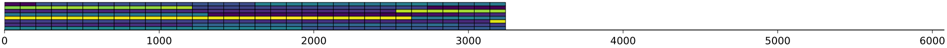
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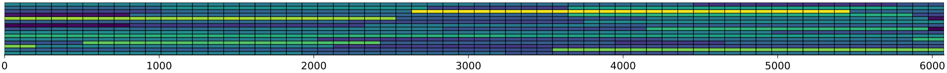
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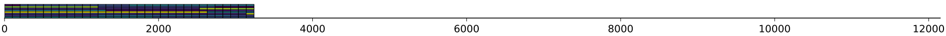

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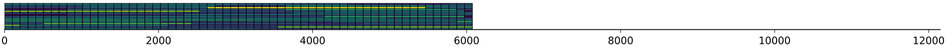

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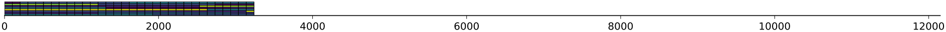
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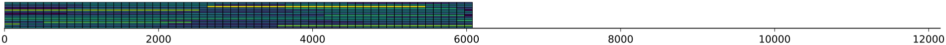
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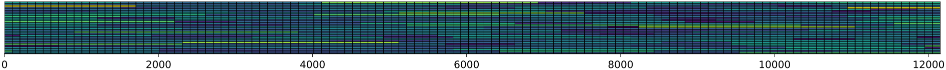
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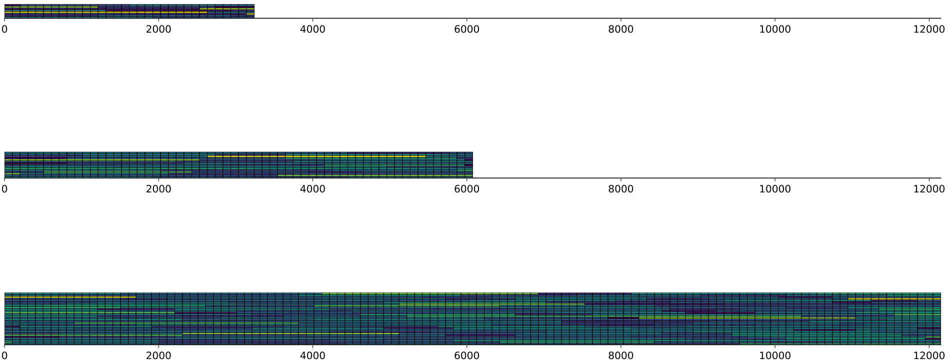
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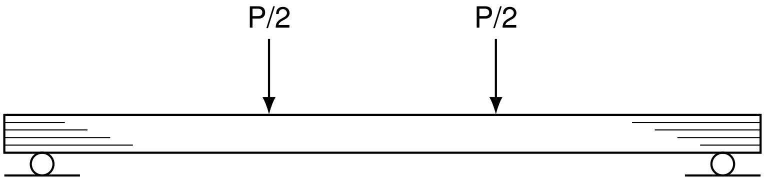

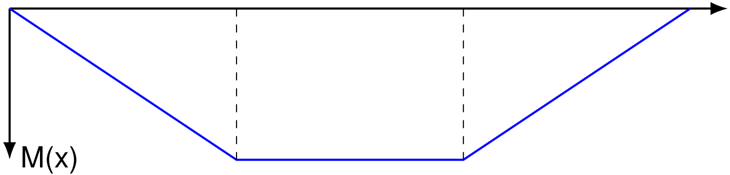

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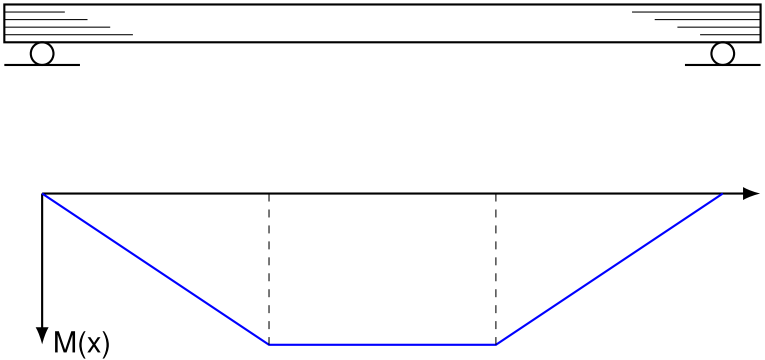

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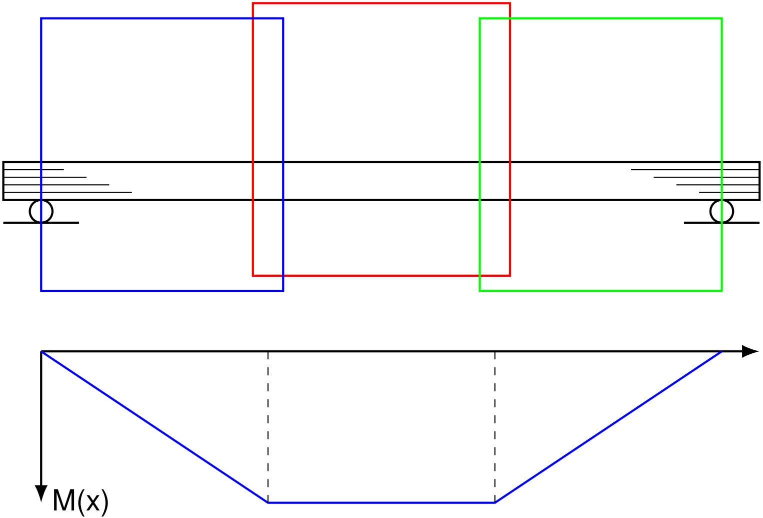

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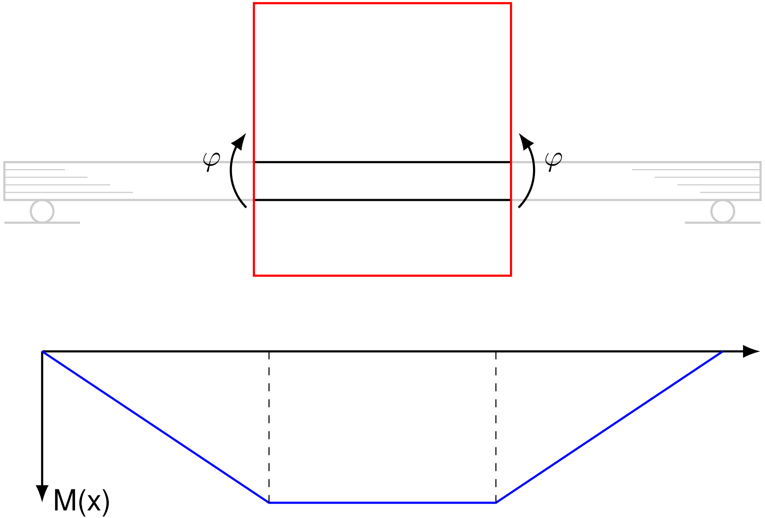

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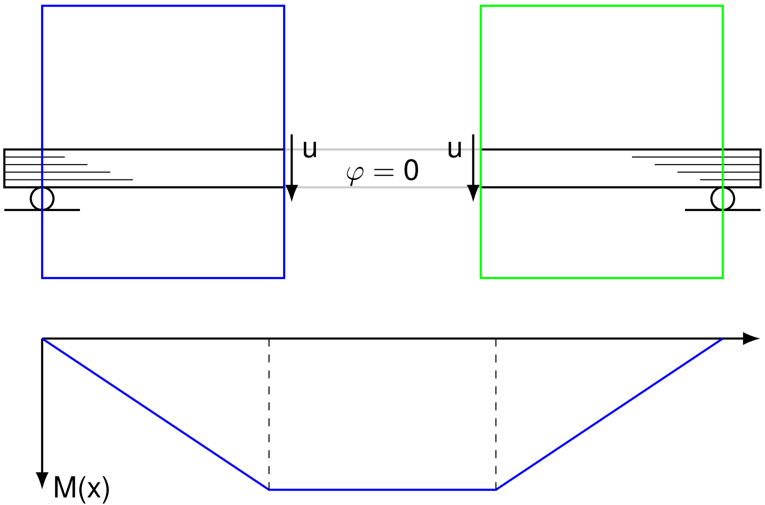
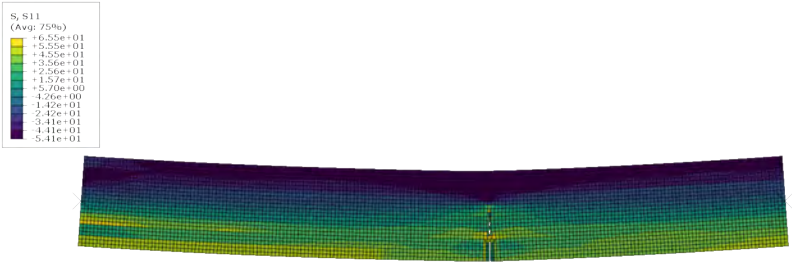


FE-Model

beam failure



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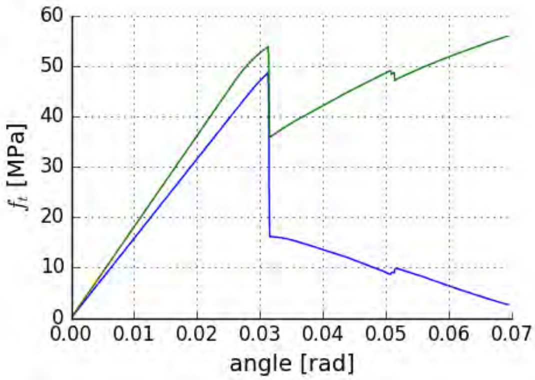

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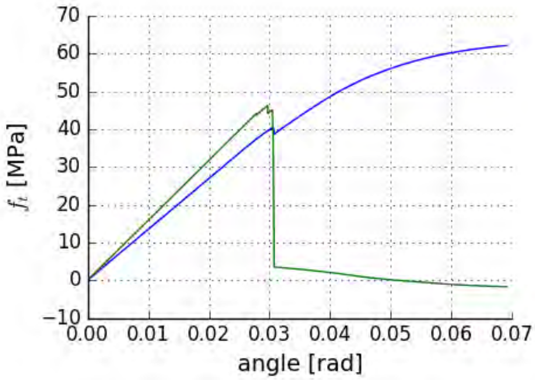

<3>

Results

Simulation

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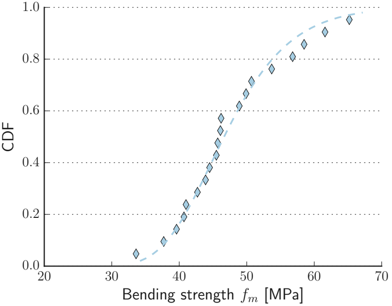
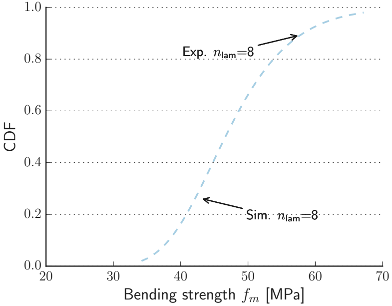
- Number of simulations:
  - 8 laminations: N = 300
  - 15 laminations: N = 182
  - 30 laminations: N = 49

Simulation results





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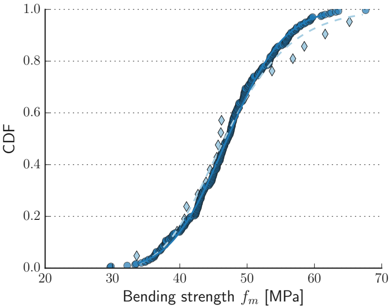

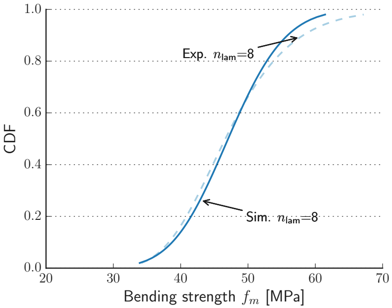

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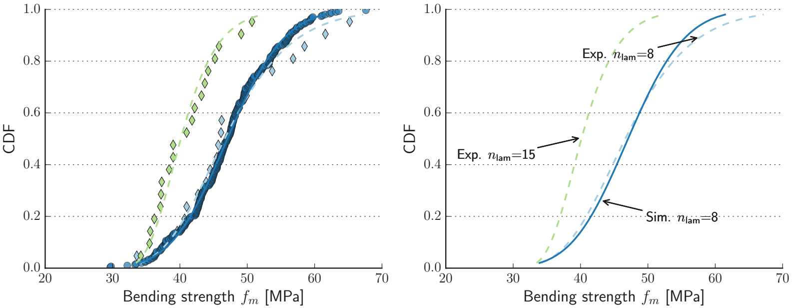

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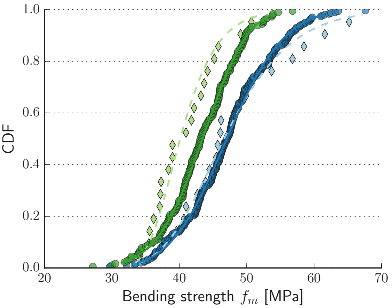

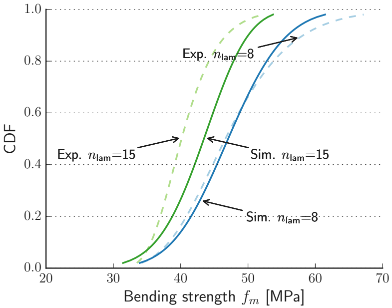

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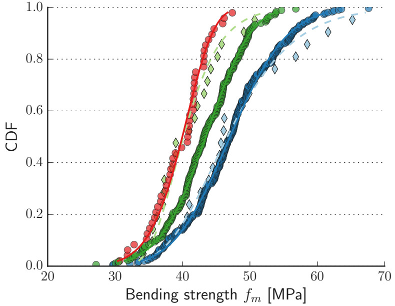
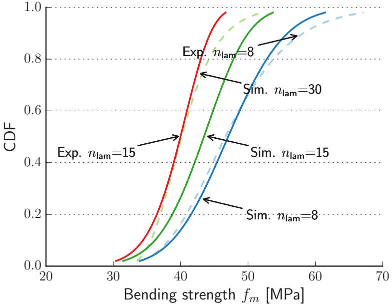
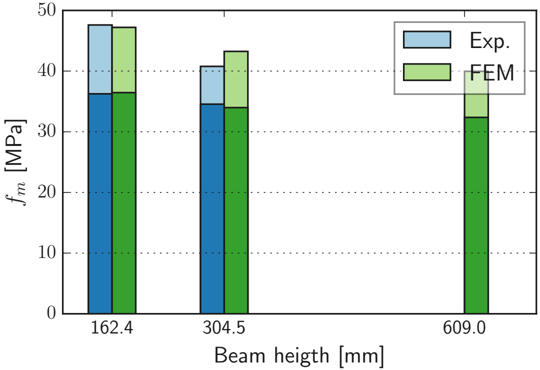




Design equation



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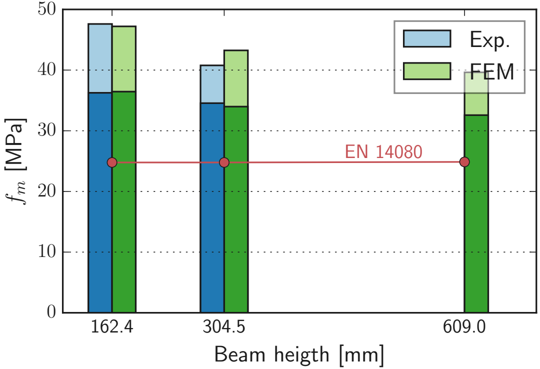
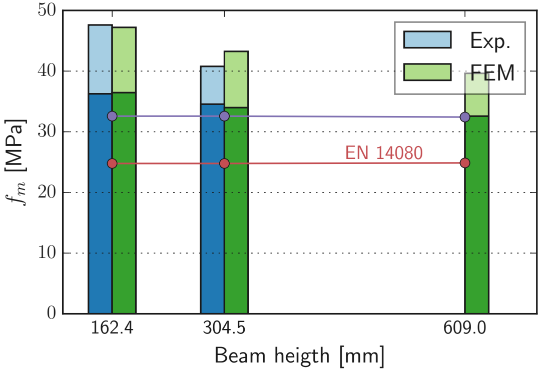


$$f_{m,g,k} = -2.2 + 2.5 \cdot f_{t,0,\ell,k}^{0.75} + 1.5 \cdot \left(\frac{f_{m,j,k}}{1.4} - f_{t,0,\ell,k} + 6 \right)^{0.65}$$

Design equation



$$f_{m,g,k} = -2.2 + 2.5 \cdot f_{t,0,\ell,k}^{0.80} + 1.5 \cdot \left(\frac{f_{m,j,k}}{1.6} - f_{t,0,\ell,k} + 6 \right)^{0.60}$$

<4>

Conclusions

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  - an increased number of elements over the thickness of each lamination (n=3), which allows for a better behavior under failure
- Although some results do still not correlate satisfactory with experimental data, there is still enough possibilities for improvements (e.g. improved variation of MOE within a lamination)

Outlook

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- To do this, this model will be compared against a wider range of datasets (partly already available)
- It can be expected that a set of parameters, for at least a specific interval of board densities, will be available within a foreseeable time frame of maximum two years.

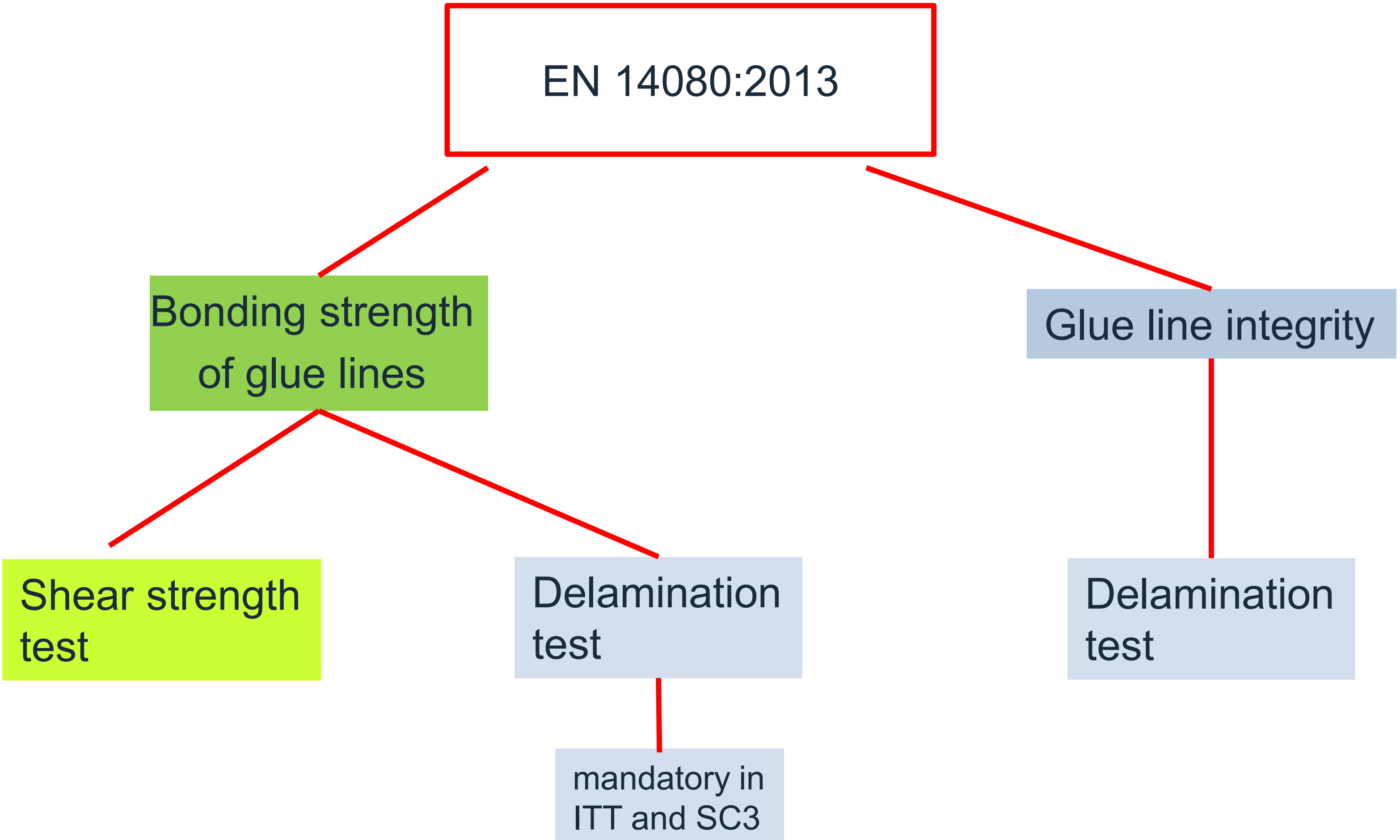
Thanks for your attention!

Glueline integrity verification for glulam made of various hardwood species

Maren Hirsch and Simon Aicher

Materials Testing Institute (MPA), University of Stuttgart
Department of Timber Constructions

Starting position



EN 14080 requirements on delamination tests

Type [a]	Number of cycles	1	2	3
Glued laminated timber, Glulam with large finger joints and block glued glulam	Method A	–	5	10
	Method B	4	8	–
	Method C	10	–	–
Glued solid timber with lamination thicknesses from 60 mm up to 85 mm (inclusive)	Method A	–	10	15
	Method B	8	12	–
	Method C	15	–	–
[a] For Glued solid timber having lamination thicknesses from 45 mm up to 60 mm linear interpolation applies.				

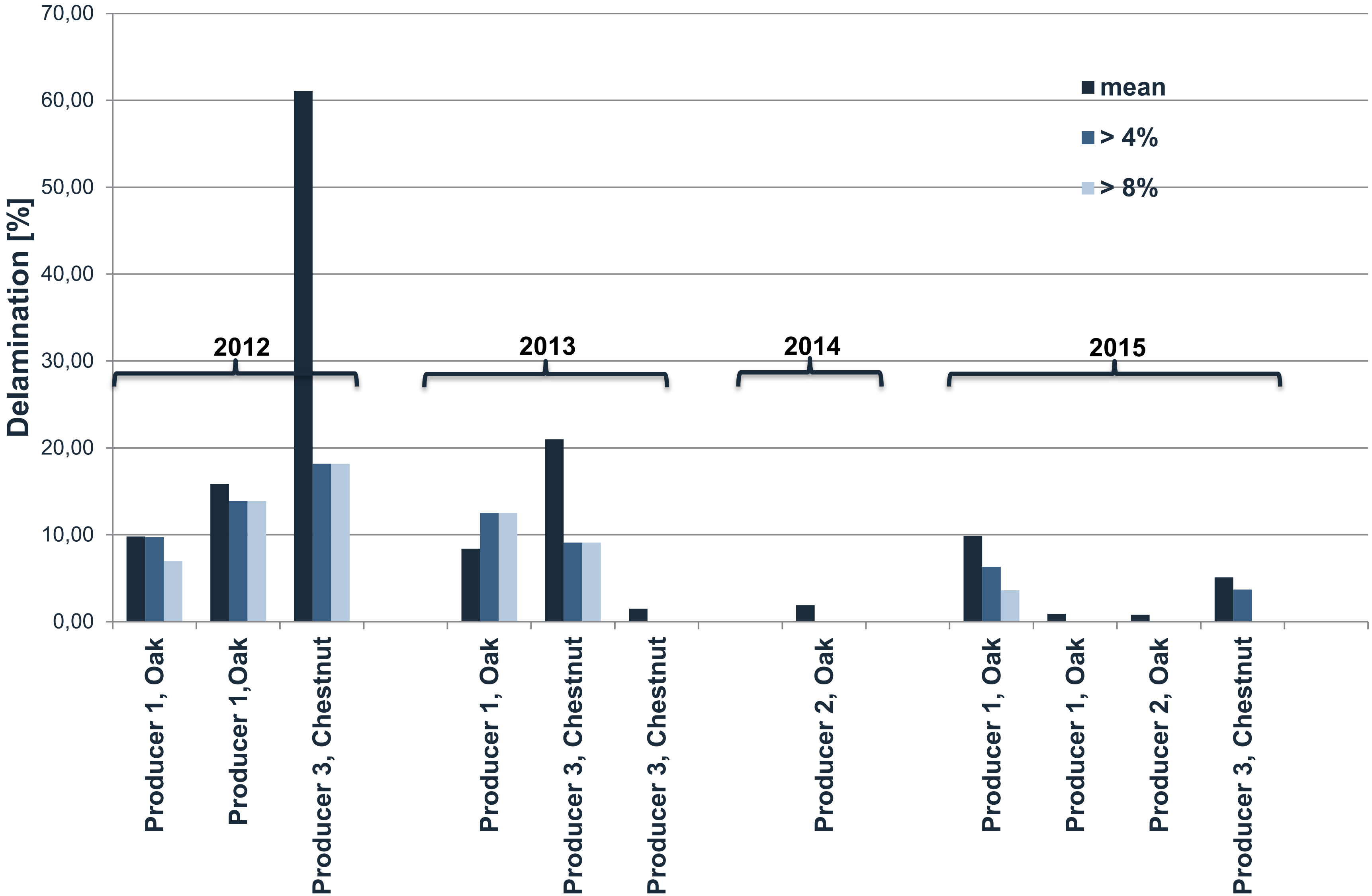
EN 14080 requirements on shear strength tests

	Average			Individual values		
Shear strength f_v, in N/mm^2	**6**	**8**	$f_v \geq 11$	$4 \leq f_v < 6$	**6**	$f_v \geq 10$
Minimum wood failure percentage, in %[b]	90	72	45	100	74	20

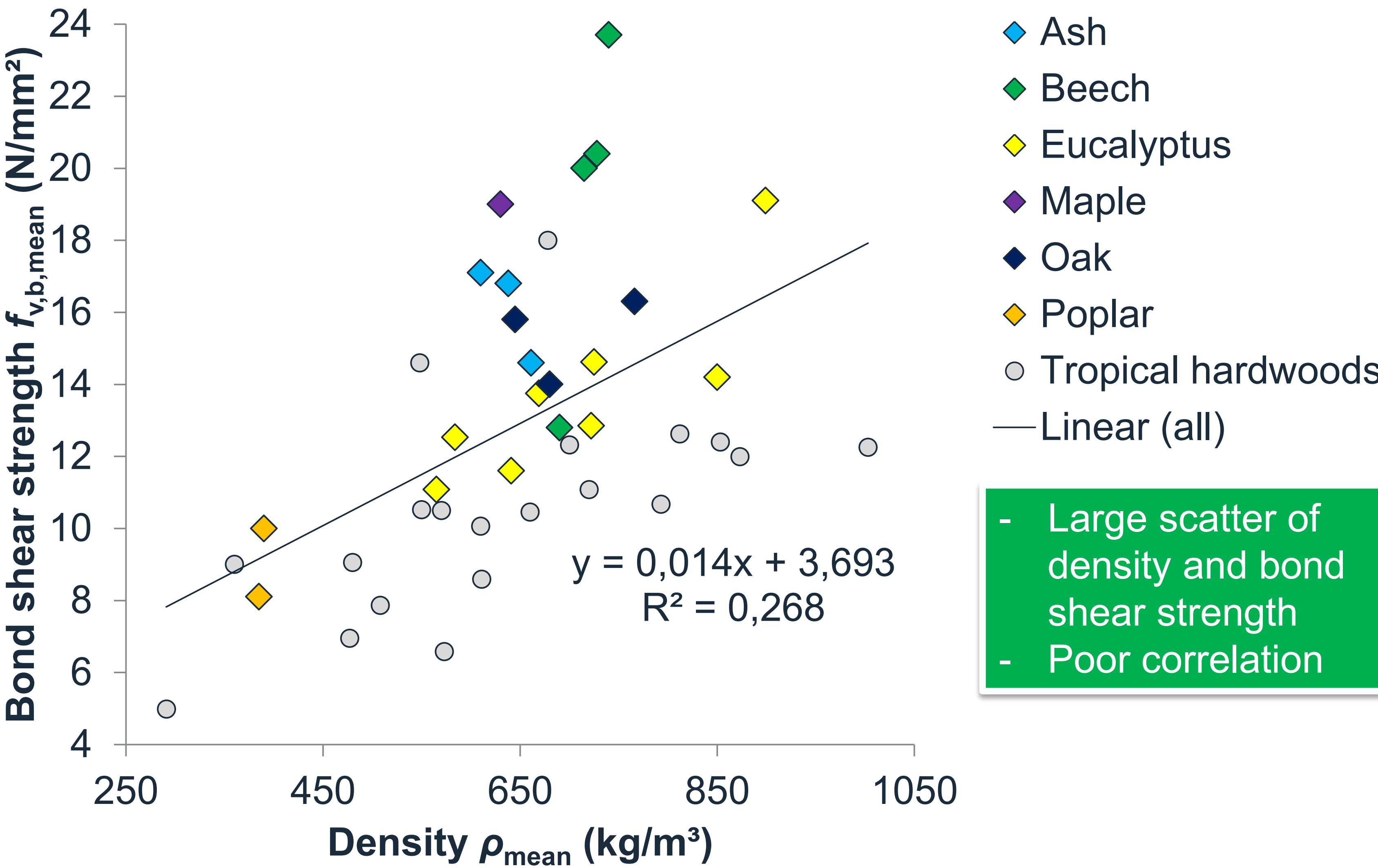
[a] For values in between linear interpolation shall be used.

[b] For average values the minimum wood failure percentage shall be: 144 – (9 f_v). For the individual values the minimum wood failure percentage for the shear strength $f_v \geq 6{,}0$ N/mm^2 shall be: 153,3 – (13,3 f_v).

Delamination test results with hardwood glulams

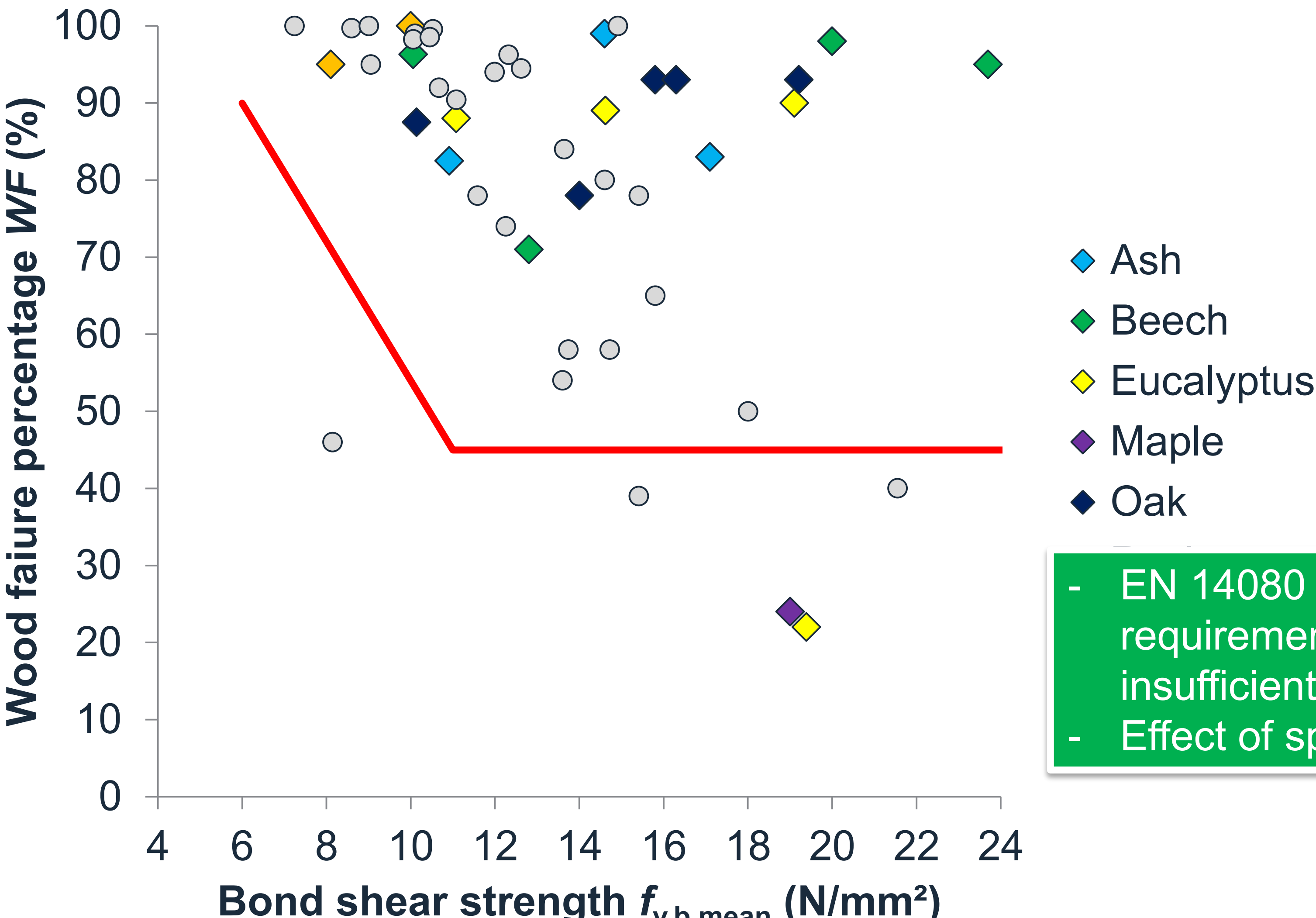


Literature review on bond shear strength (1)



- Large scatter of density and bond shear strength
- Poor correlation

Literature review on bond shear strength (2)



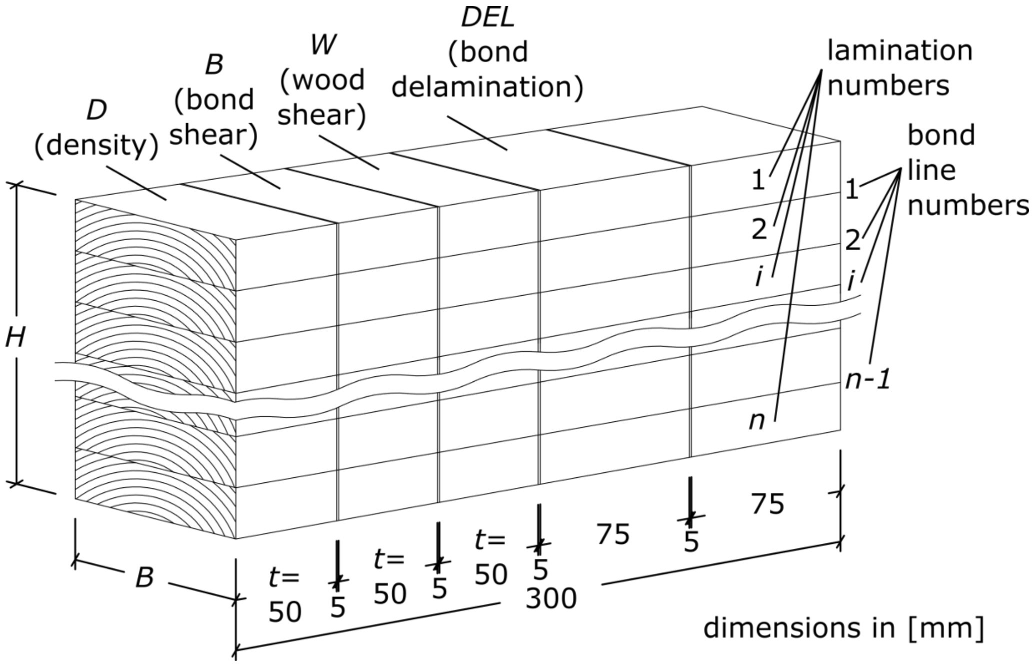
- EN 14080 requirement insufficient
- Effect of species

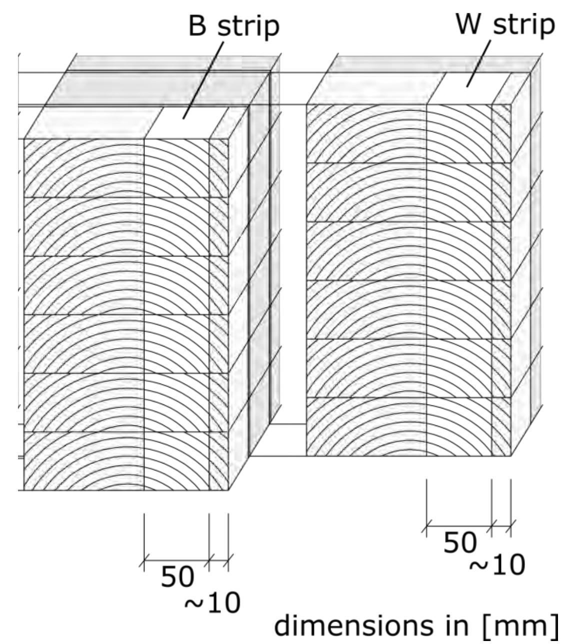
Experimental study on bond shear strength

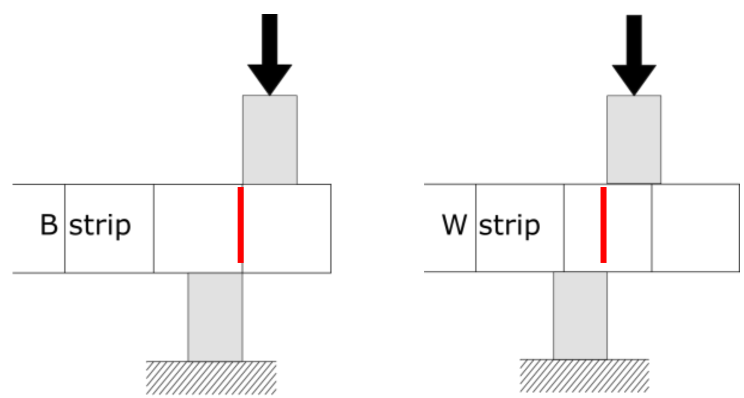
→ Bond shear tests with industrially produced GLTs made of 4 European hardwood species

Species	Approval	Adhesive	Density
Ash	Swiss comp. rule	PRF	695 ± 12
Beech	(Z-9.1-679)	MUF	742 ± 53
Chestnut	ETA-13/0646	MUF	596 ± 51
Oak	ETA-13/0642	MUF	752 ± 49

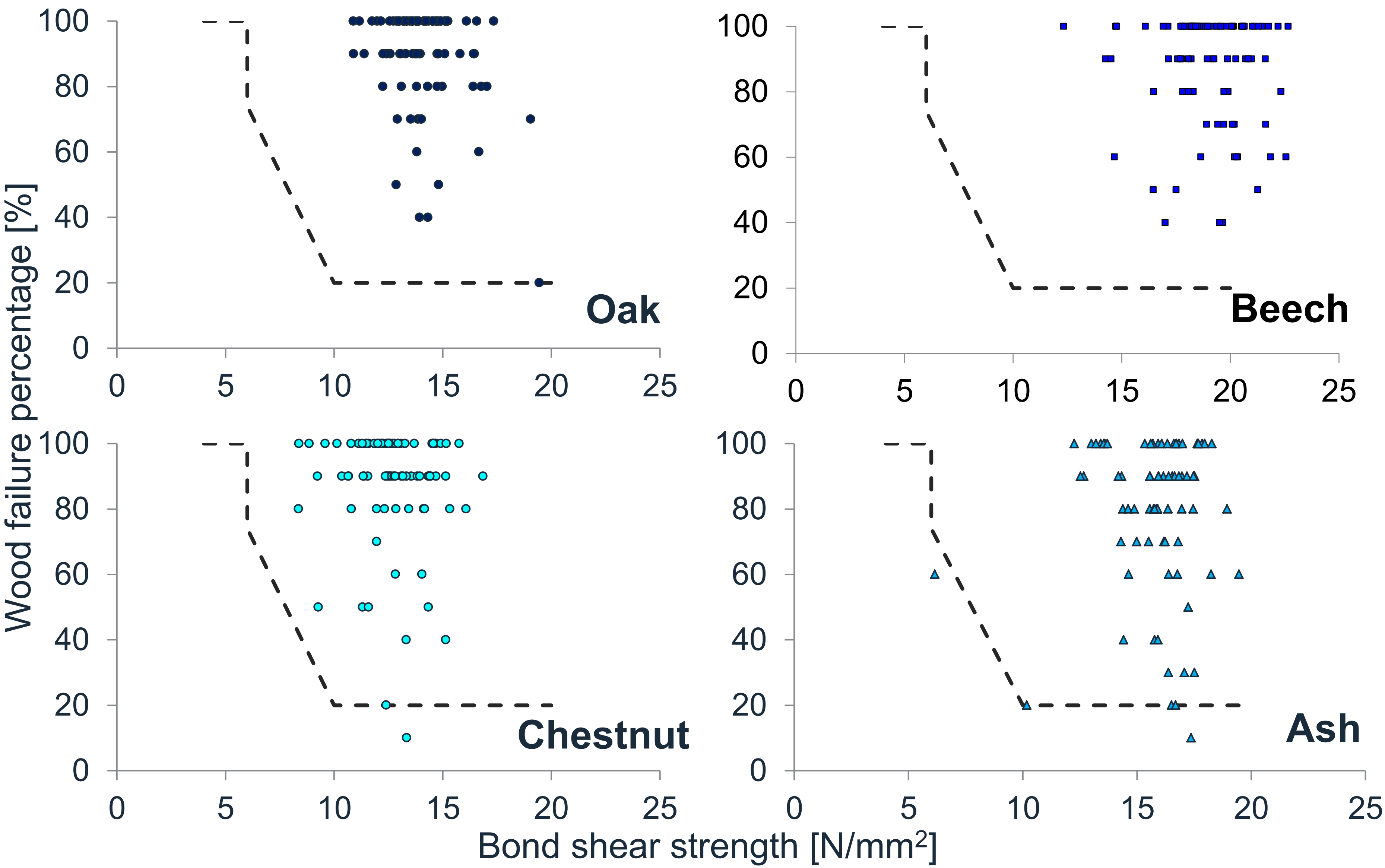
Experimental study – Test method



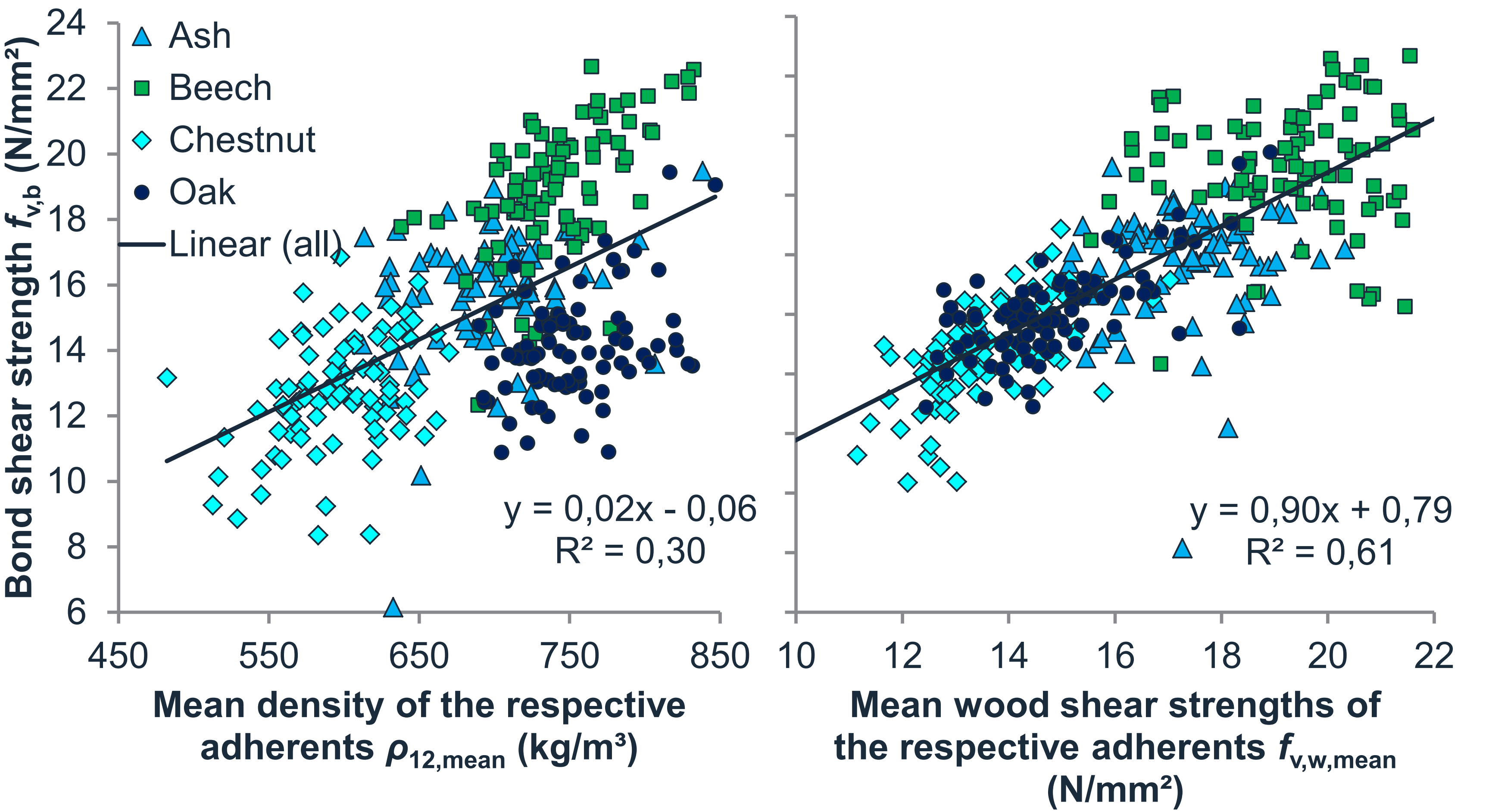




Test Results



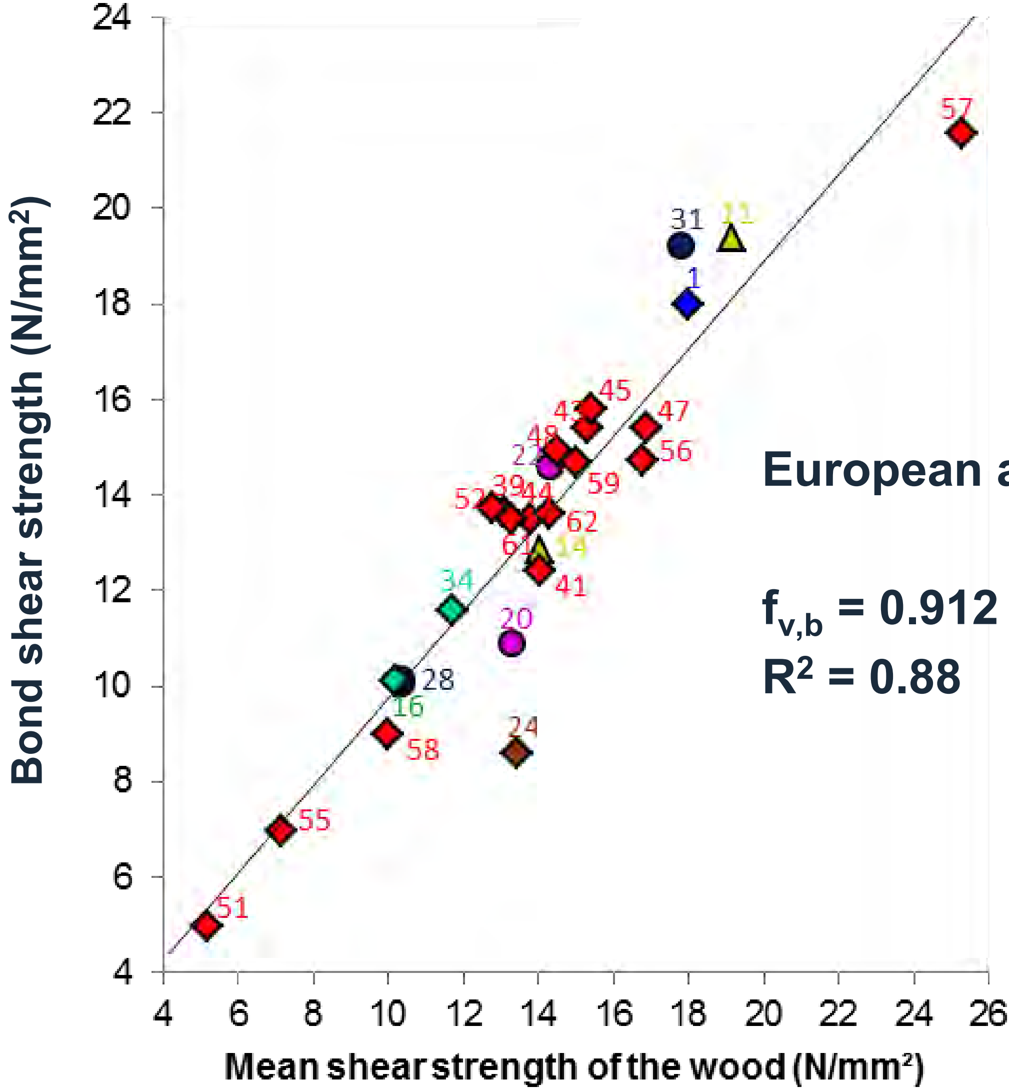
Bond shear strength correlations



Poor correlation

Good correlation

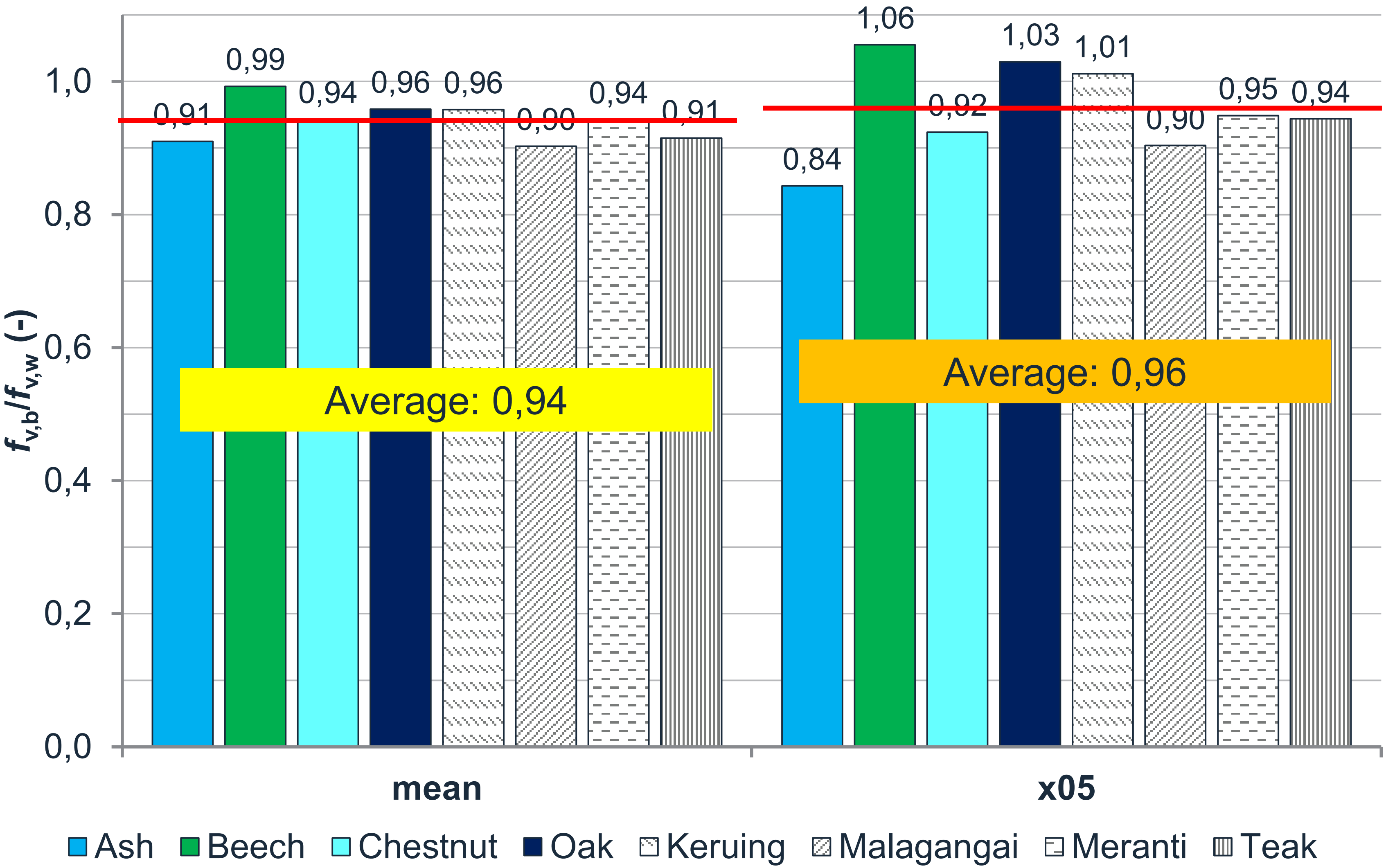
Bond vs. wood shear strength correlation



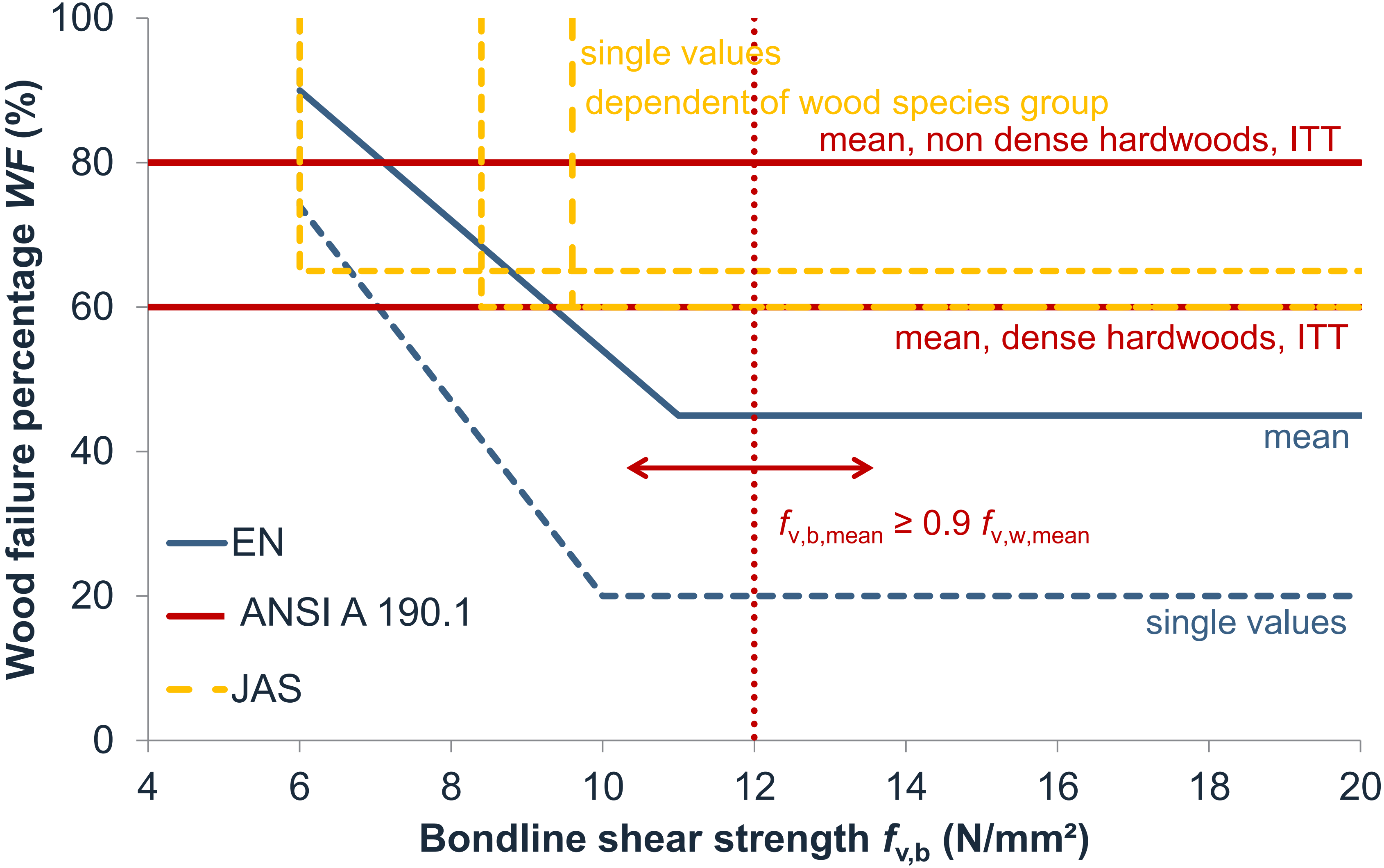
European and tropical hardwoods

$$f_{v,b} = 0.912 * f_{v,w} + 0.628$$
$$R^2 = 0.88$$

Ratio of bond vs. wood shear strength



WF – $f_{v,b}$ requirements acc. to int. standards



Hardwood shear strength requirements

Proposals for future hEN 14080-2

ITT

$$f_{v,b,05} \geq 0.9\ f_{v,w,05}$$

and

$$WF_{10} \geq 50\%$$

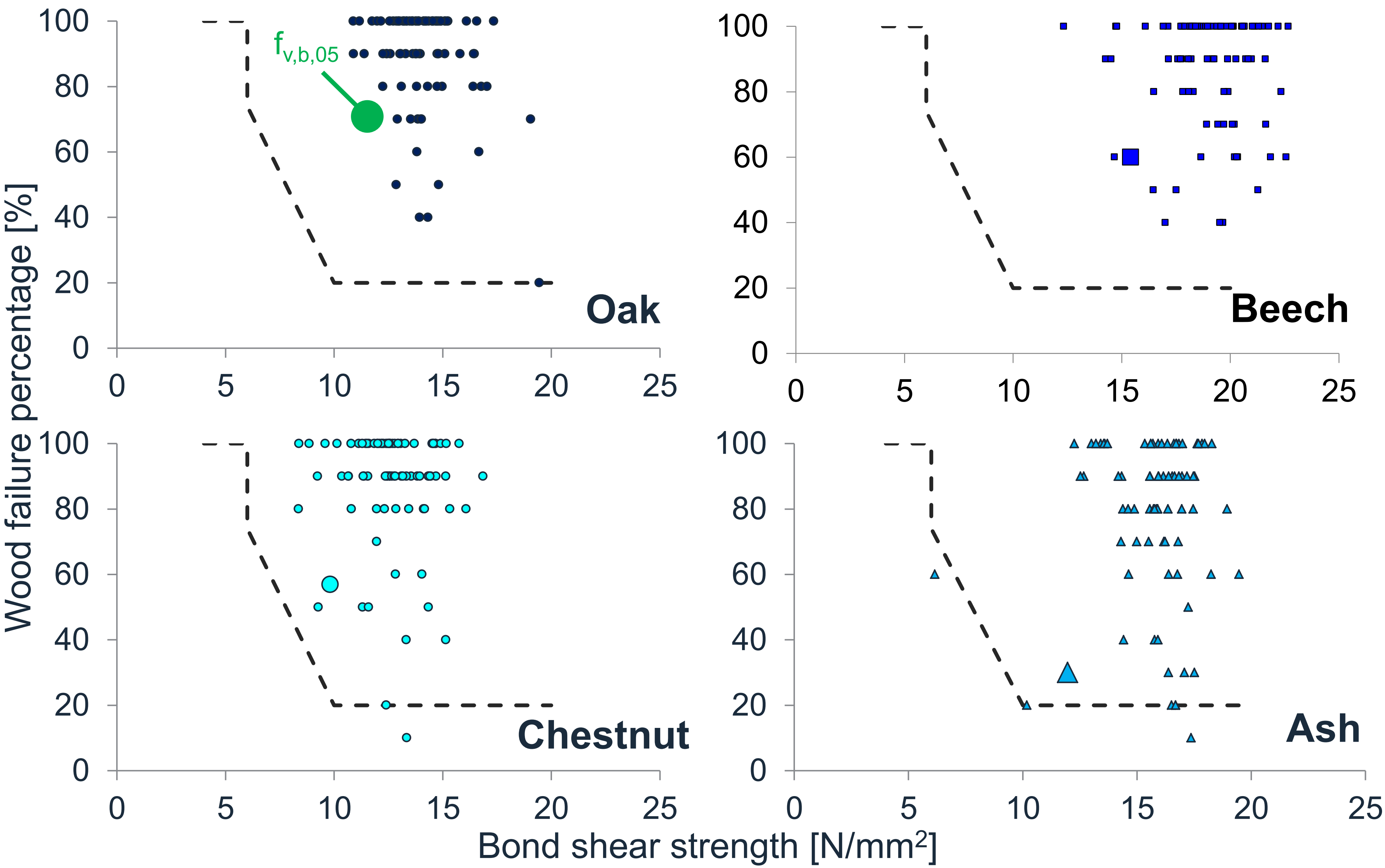
FPC

$$f_{v,b,mean} \geq 0.9\ f_{v,w,mean}$$

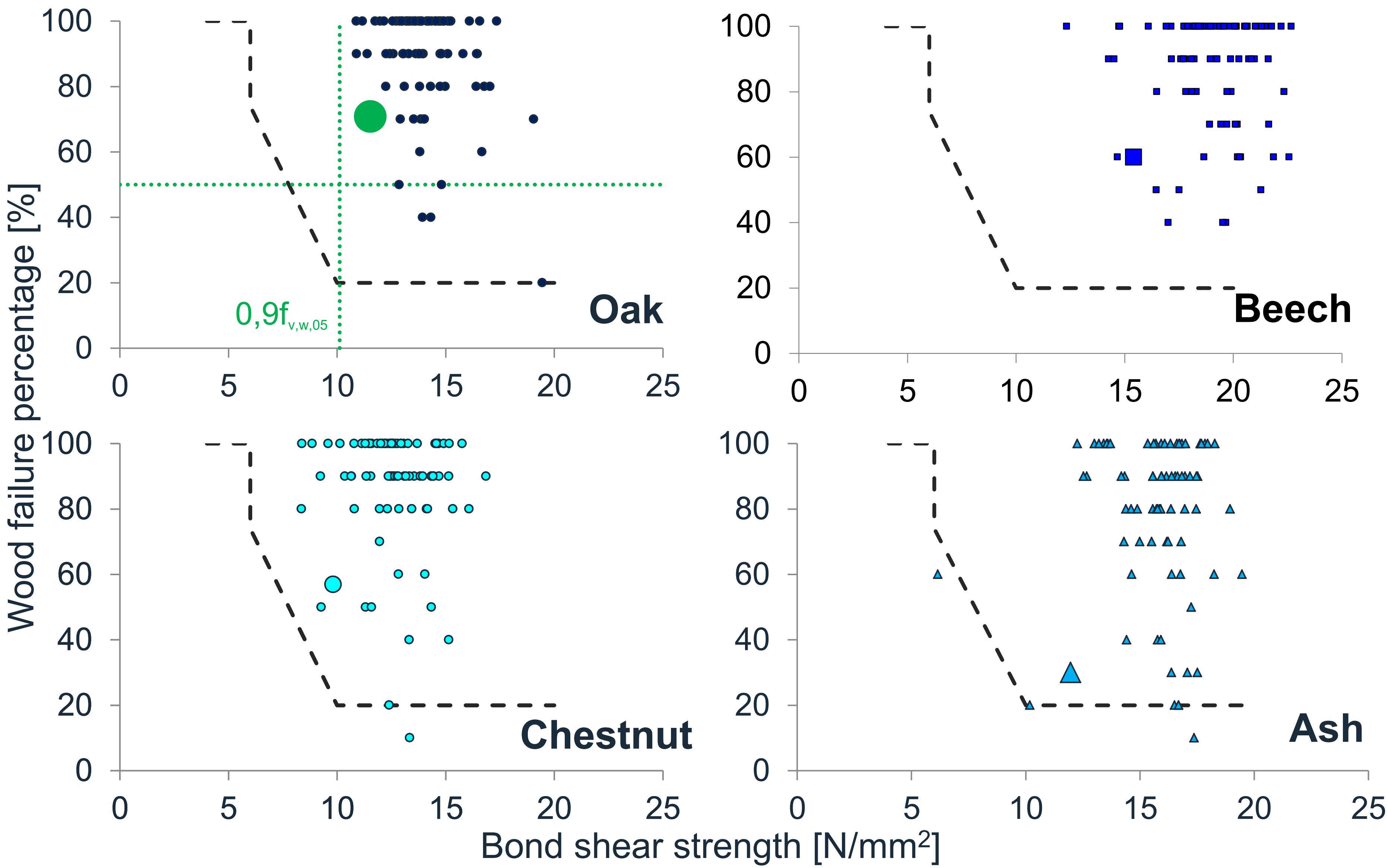
and

$$WF_{mean} \geq 80\%$$

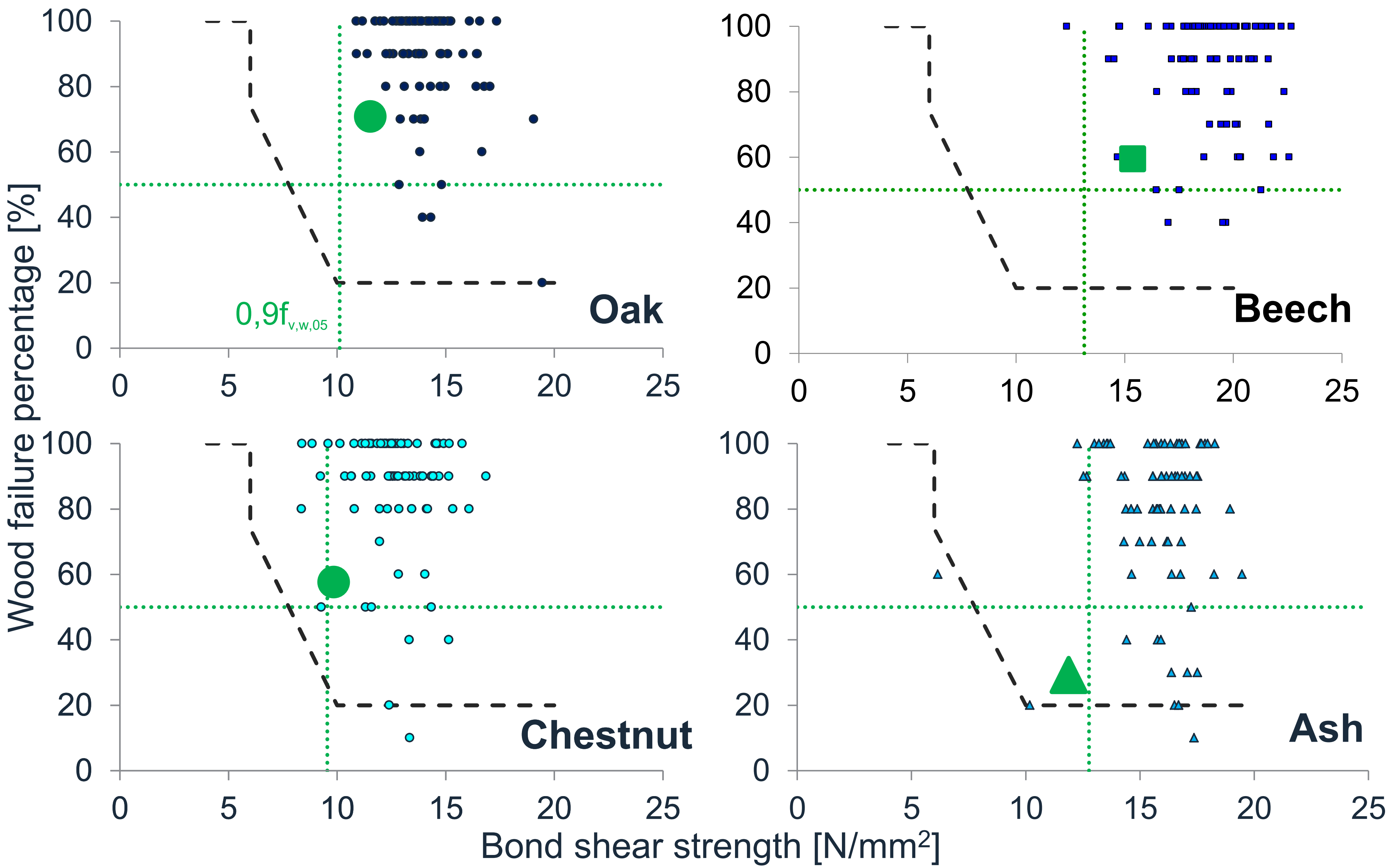
Test Results - ITT



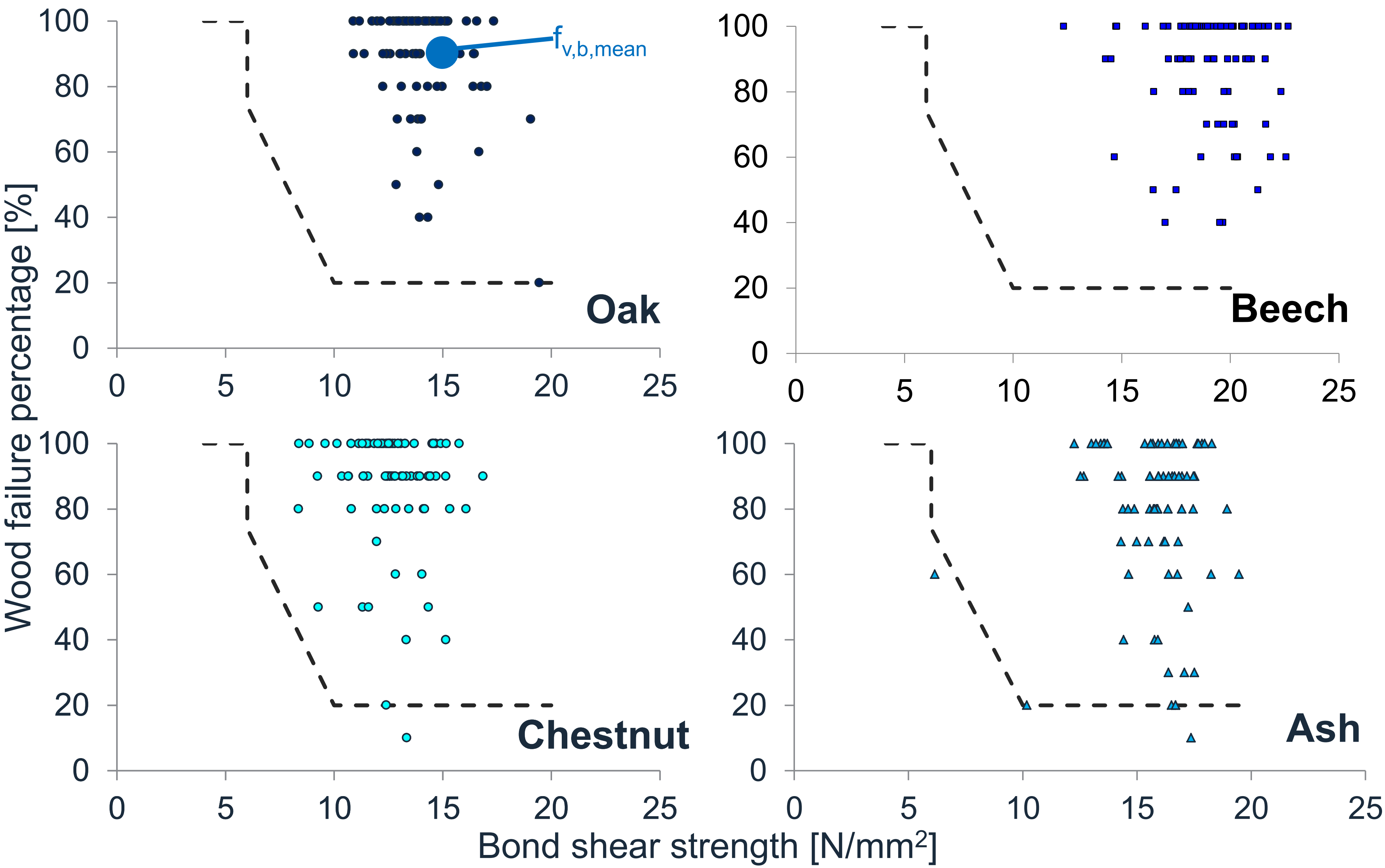
Test Results - ITT



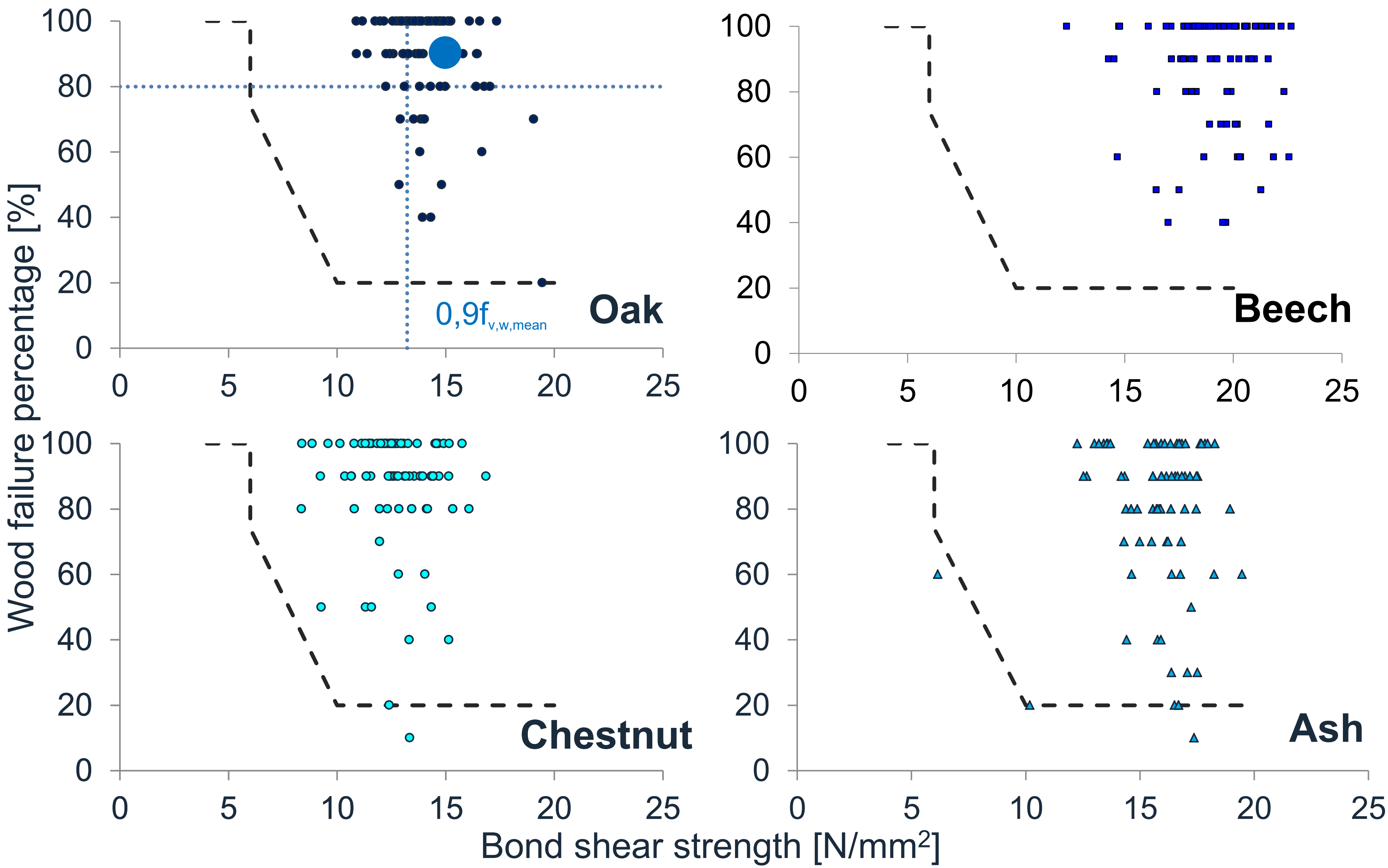
Test Results - ITT



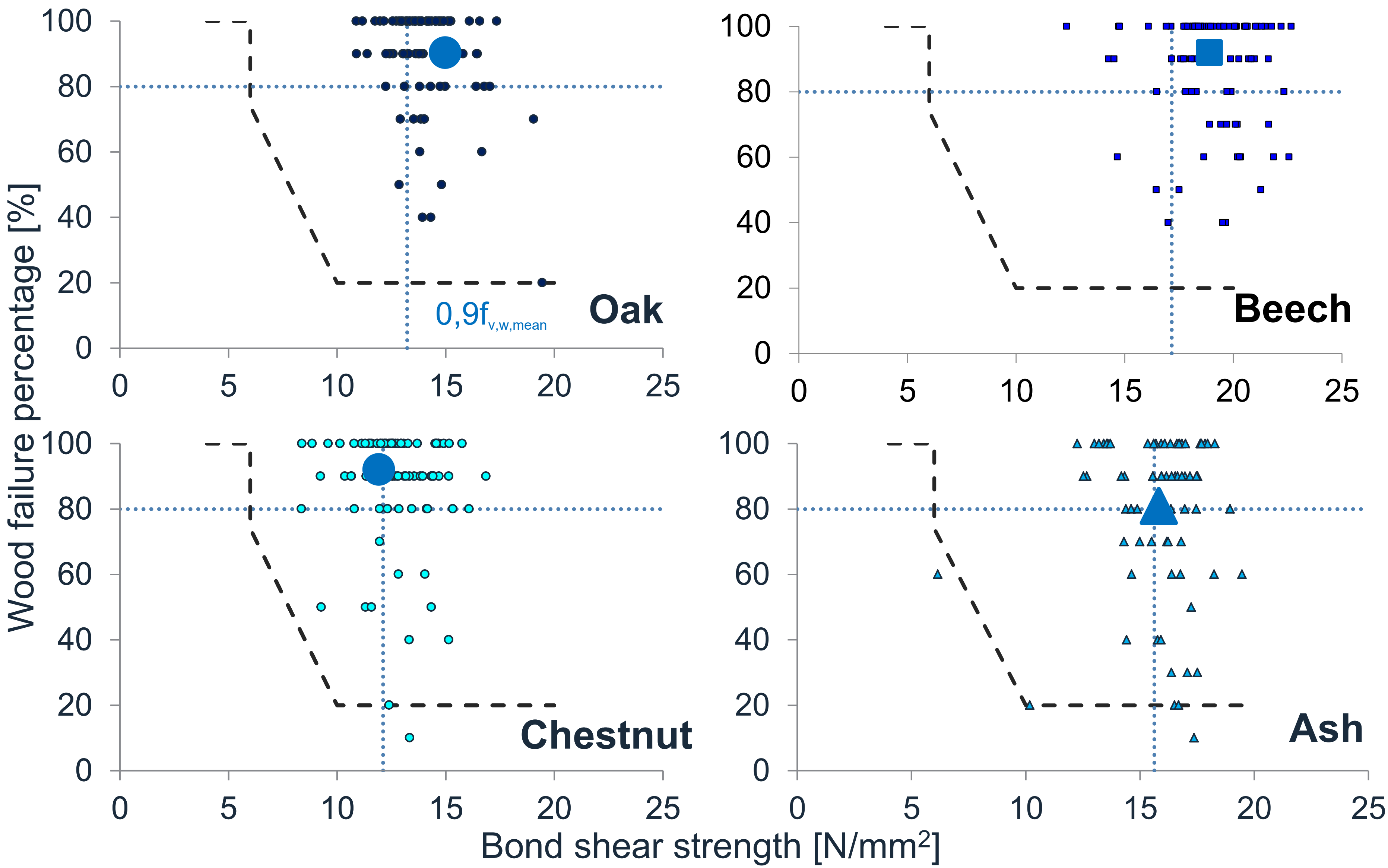
Test Results - FPC



Test Results - FPC



Test Results - FPC



Conclusions

A hardwood species overarching shear strength and wood fibre failure requirement is possible based on correlated bond and wood shear strength tests and requirements similar yet improved to ANSI A190.1

Thank you for your attention!

Hybrid beech and spruce cross-laminated timber

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Overview

1. Cross-laminated timber (CLT)
2. Why beech?
3. Rolling shear properties of beech boards
4. Production of beech-spruce hybrid CLTs
5. Testing of beech-spruce hybrid CLTs in the flatwise direction
6. Design implications for flatwise loaded slabs
7. Testing of beech-spruce hybrid CLTs in the edgewise direction
8. Further checks (glueing)
9. Initial findings from 5-layer tests / Outlook

1. Cross-laminated timber (CLT)

Currently produced homogeneously, primarily from **softwoods** (spruce/fir)

1a. Advantages:

- Dimensional possibilities
- Dimensional stability
- Decent mechanical properties
- Machinability
- Prefabrication
- Rapid erection
- Environmentally friendly
- ………

1b. Disadvantages:

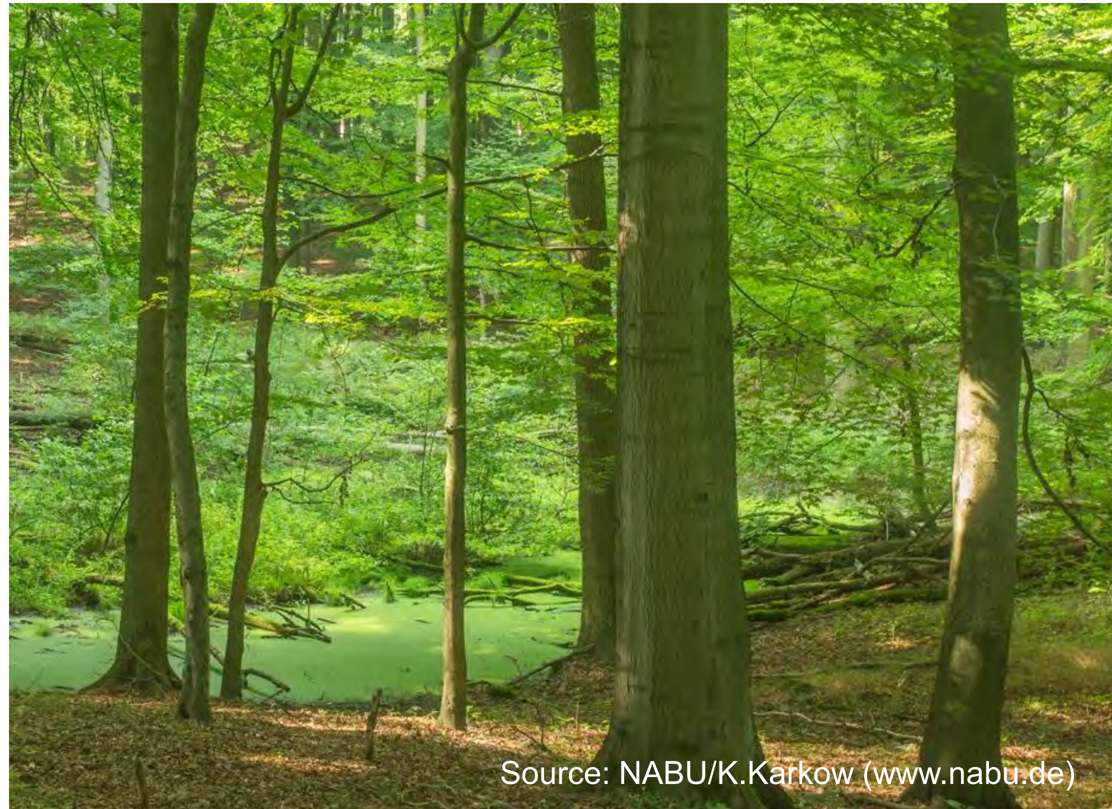
- **Low rolling shear properties in cross-layer**
- **Reduced stiffness in edgewise direction**

2. Why beech?

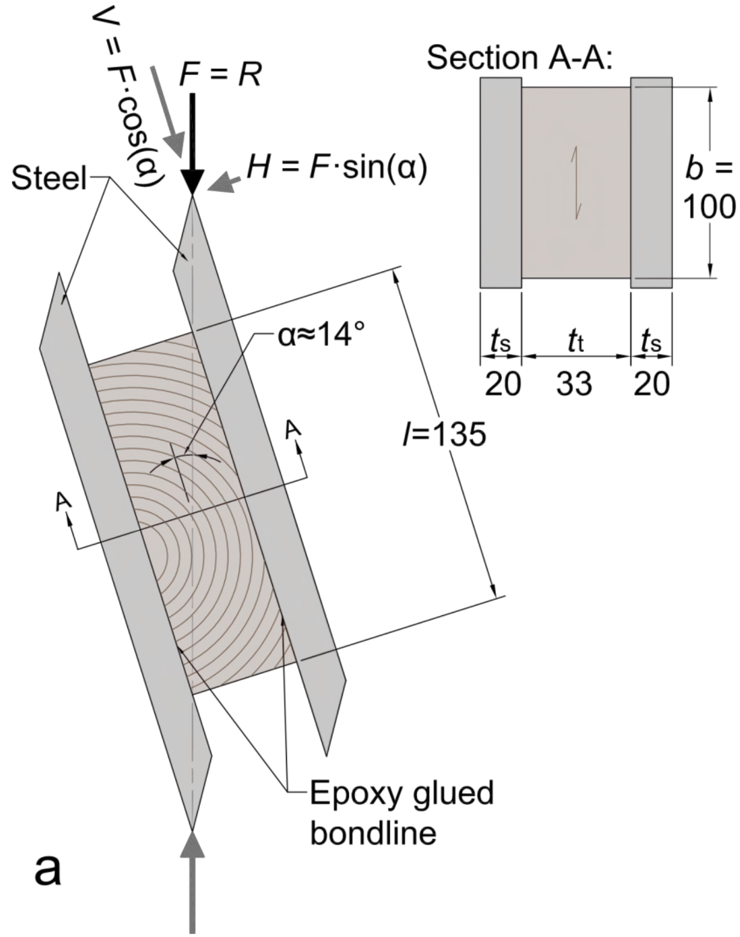
- Unused beech forest stands in Central Europe

- Increased plantation of beech in Europe

- Higher stiffness and strength properties vs. softwoods, and hence also assumingly for rolling shear (even for lower grades, typically only used for thermal purposes)

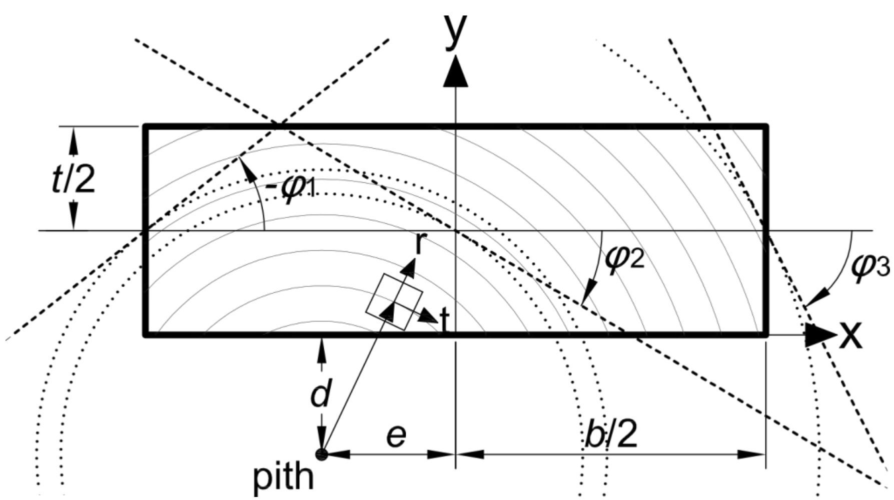


3a. Testing of individual boards

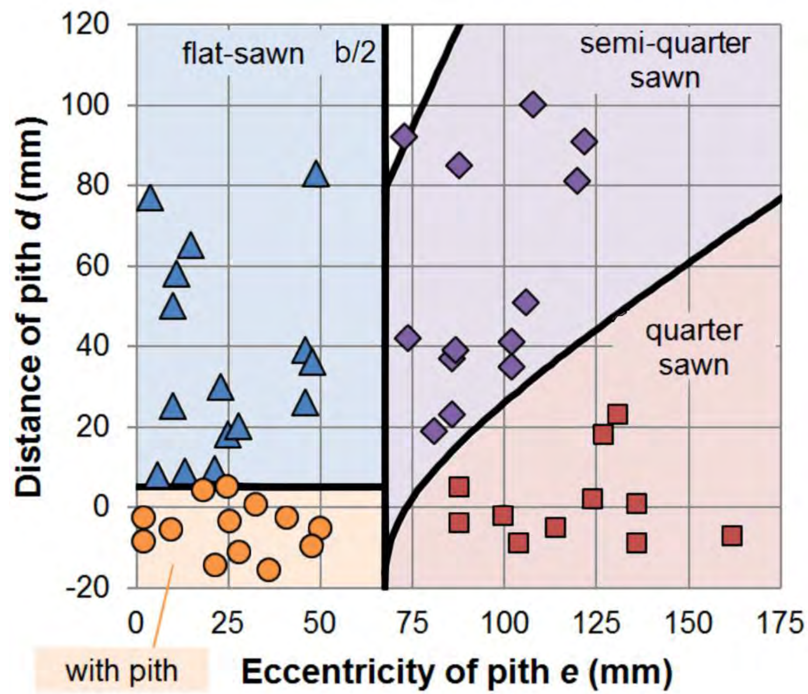


3. Rolling shear properties of beech boards

3b. Specimen classification



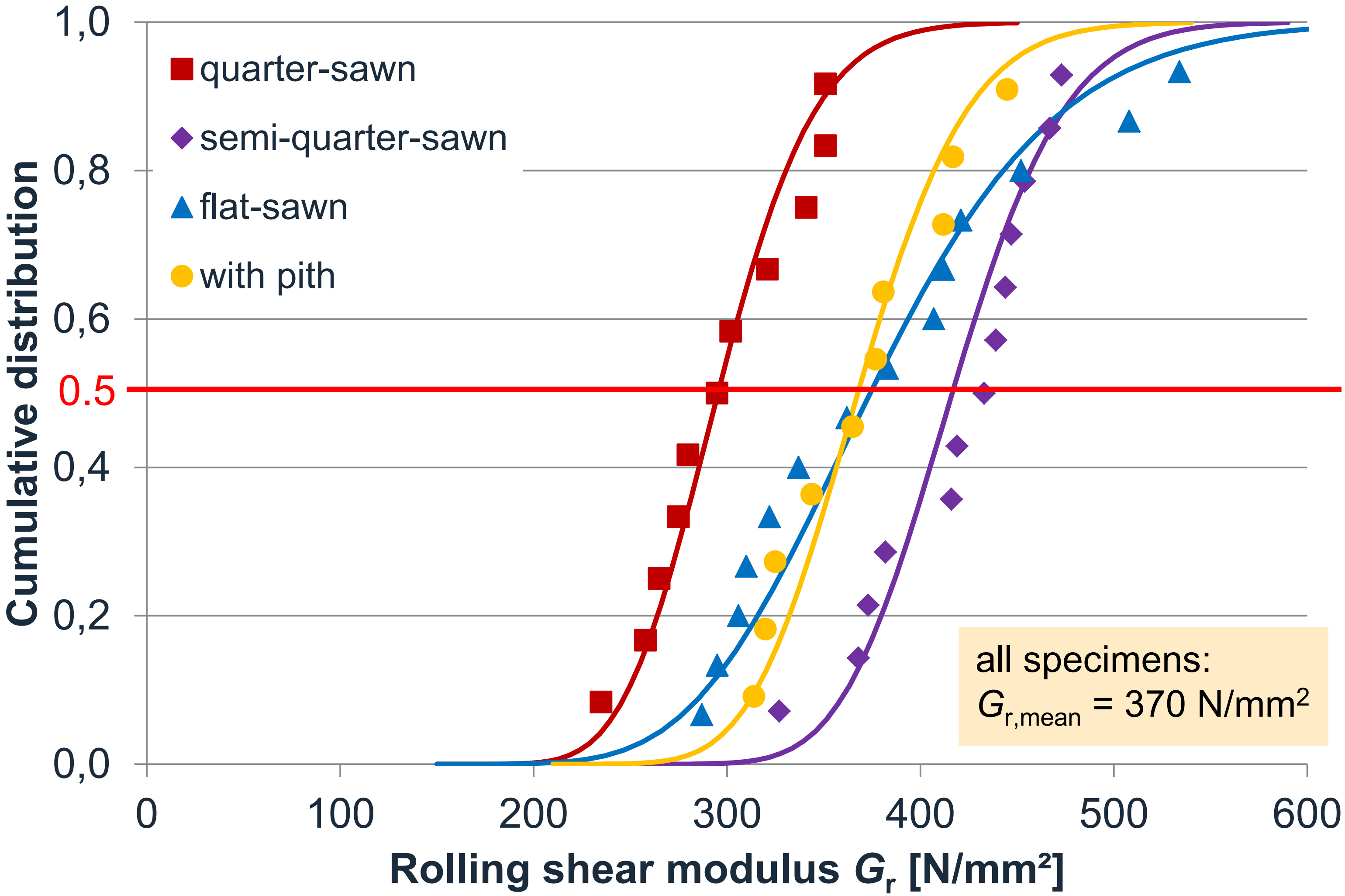
$\varphi_{mean} = (|\varphi_1|+|\varphi_2|+|\varphi_3|)/3$



- *Quarter-sawn*: $60° \leq \varphi_{mean} \leq 90°$,
- *Semi-quarter-sawn*: $30° \leq \varphi_{mean} < 60°$, $\varphi_1 > 0°$,
- *Flat-sawn*: $0° \leq \varphi_{mean} < 30°$, $\varphi_1 \leq 0°$, d > 5 mm,
- *Including pith*: $\varphi_1 \leq 0°$, d ≤ 5 mm

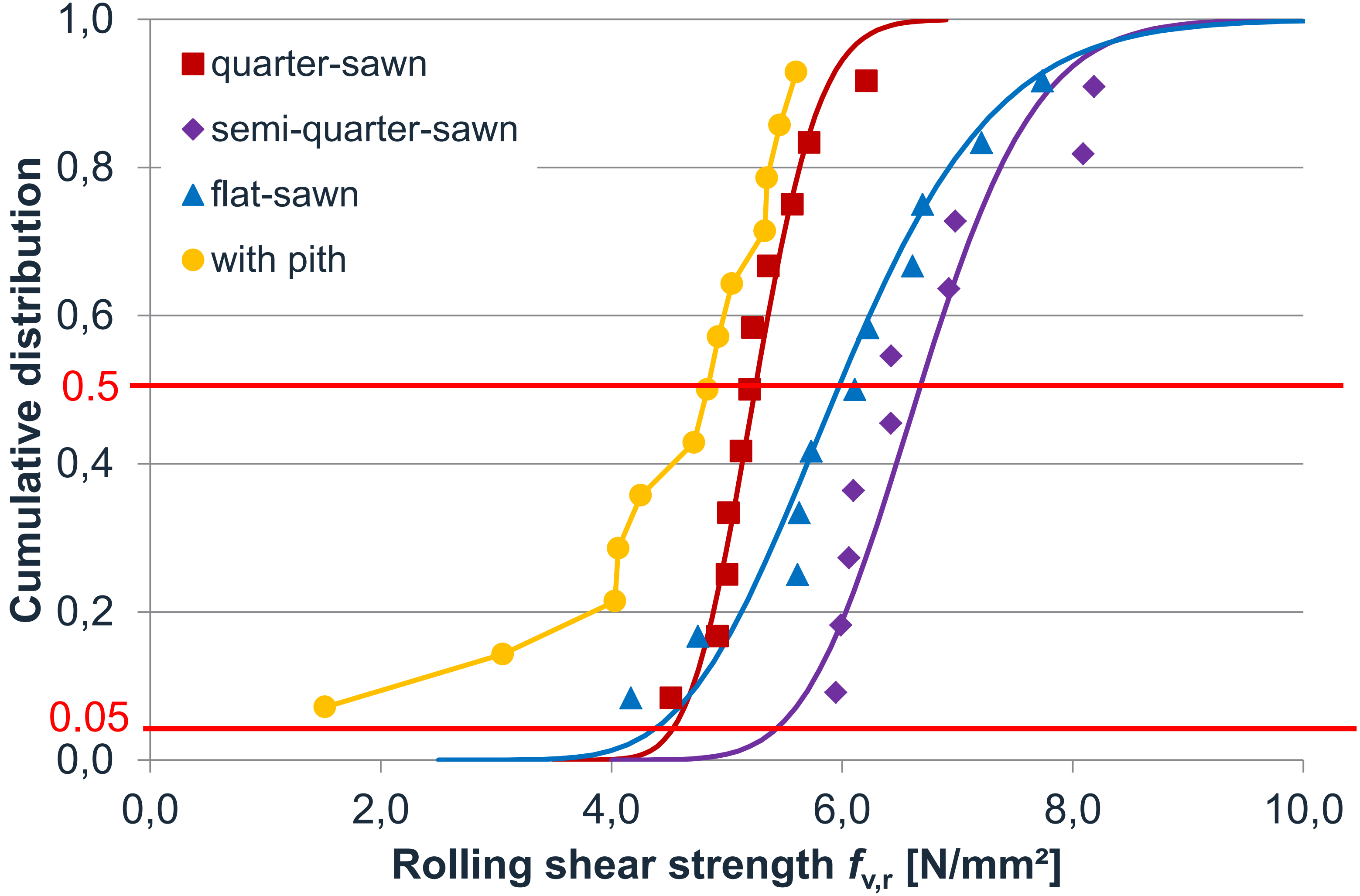
3. Rolling shear properties of beech boards

3c. Results – Rolling shear modulus

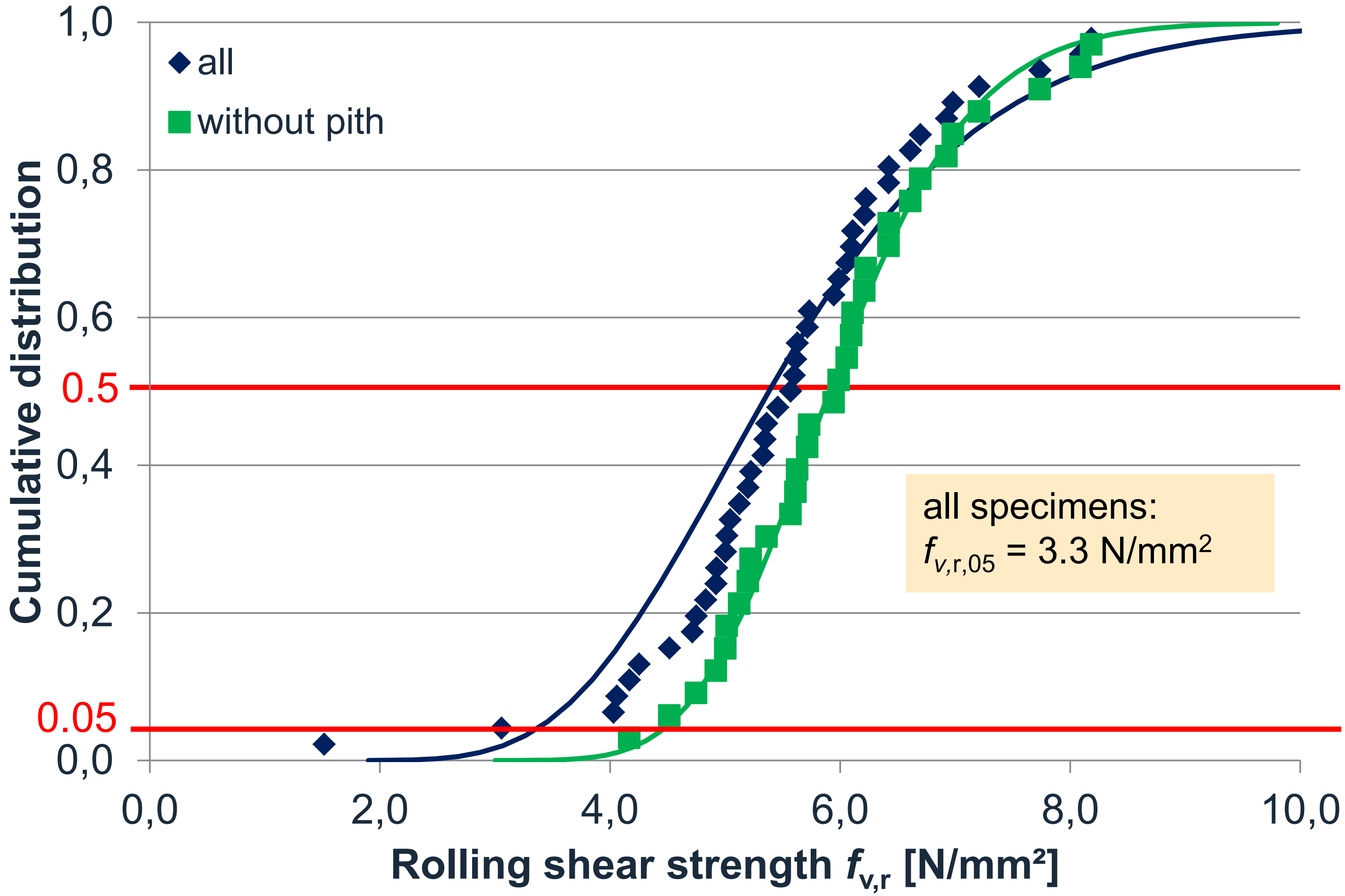


3. Rolling shear properties of beech boards

3c. Results – Rolling shear strength

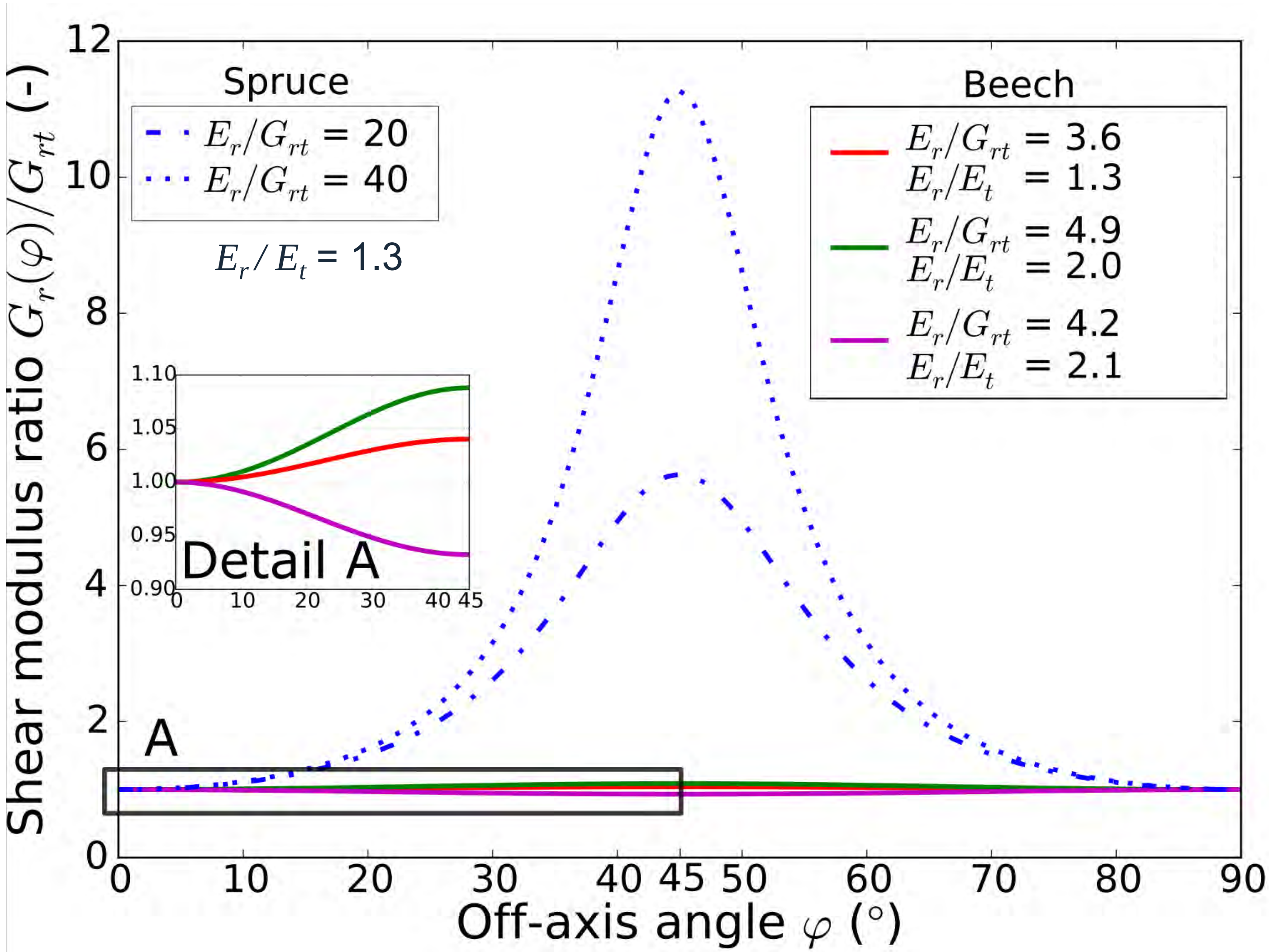


3c. Results – Rolling shear strength, pith vs. no pith



3. Rolling shear properties of beech boards

3c. Theoretical considerations



4. Production of beech-spruce hybrid CLT

4a. Manufacture of beech-spruce hybrid CLT plates

(One-component Polyurethane + Primer)

➔ 2x 2.5 m x 6.0 m plates

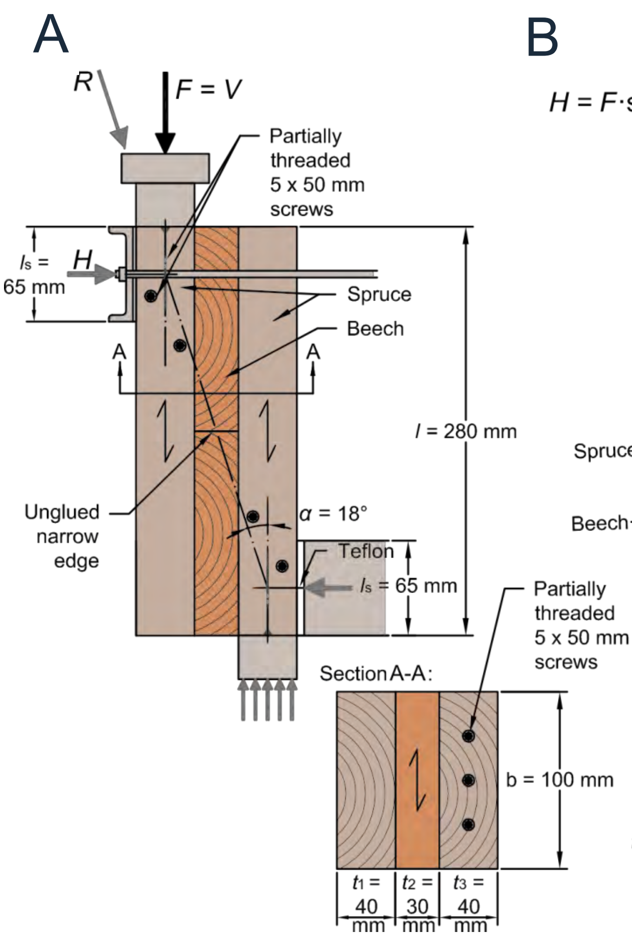
40 mm
30 mm
40 mm

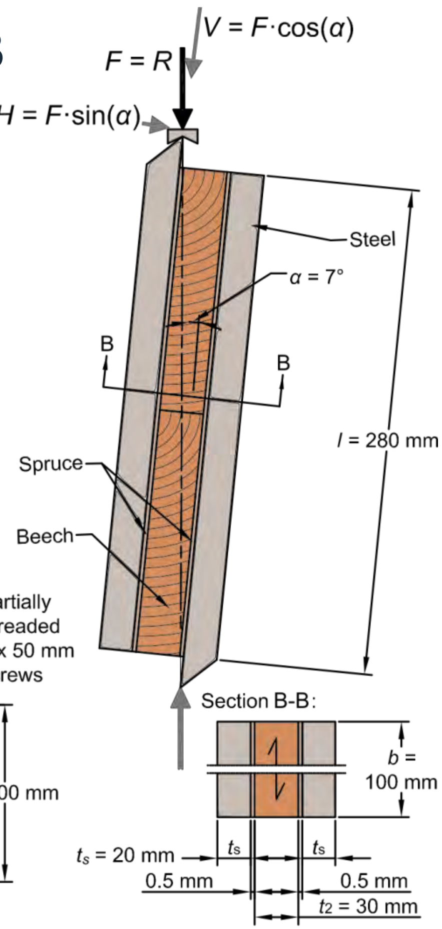
Compression shear

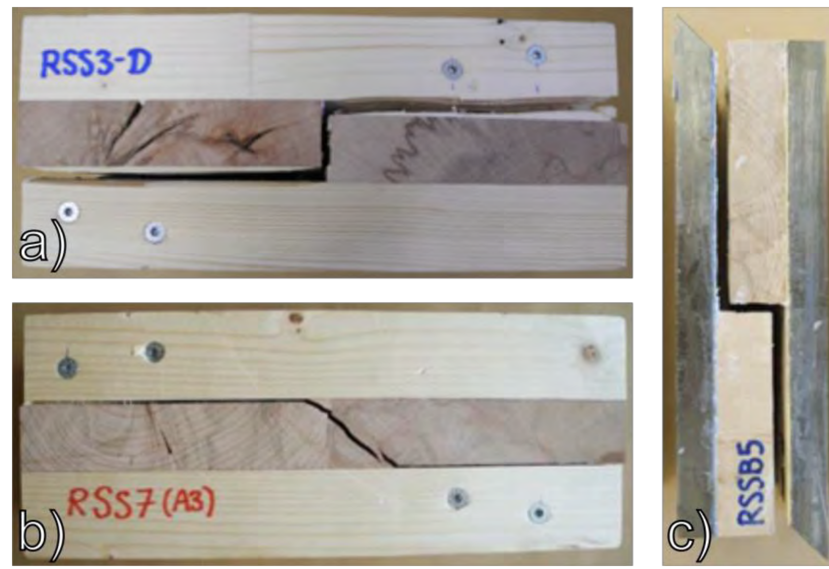
Bending shear

Bond strength and integrity

5a. Compression shear tests





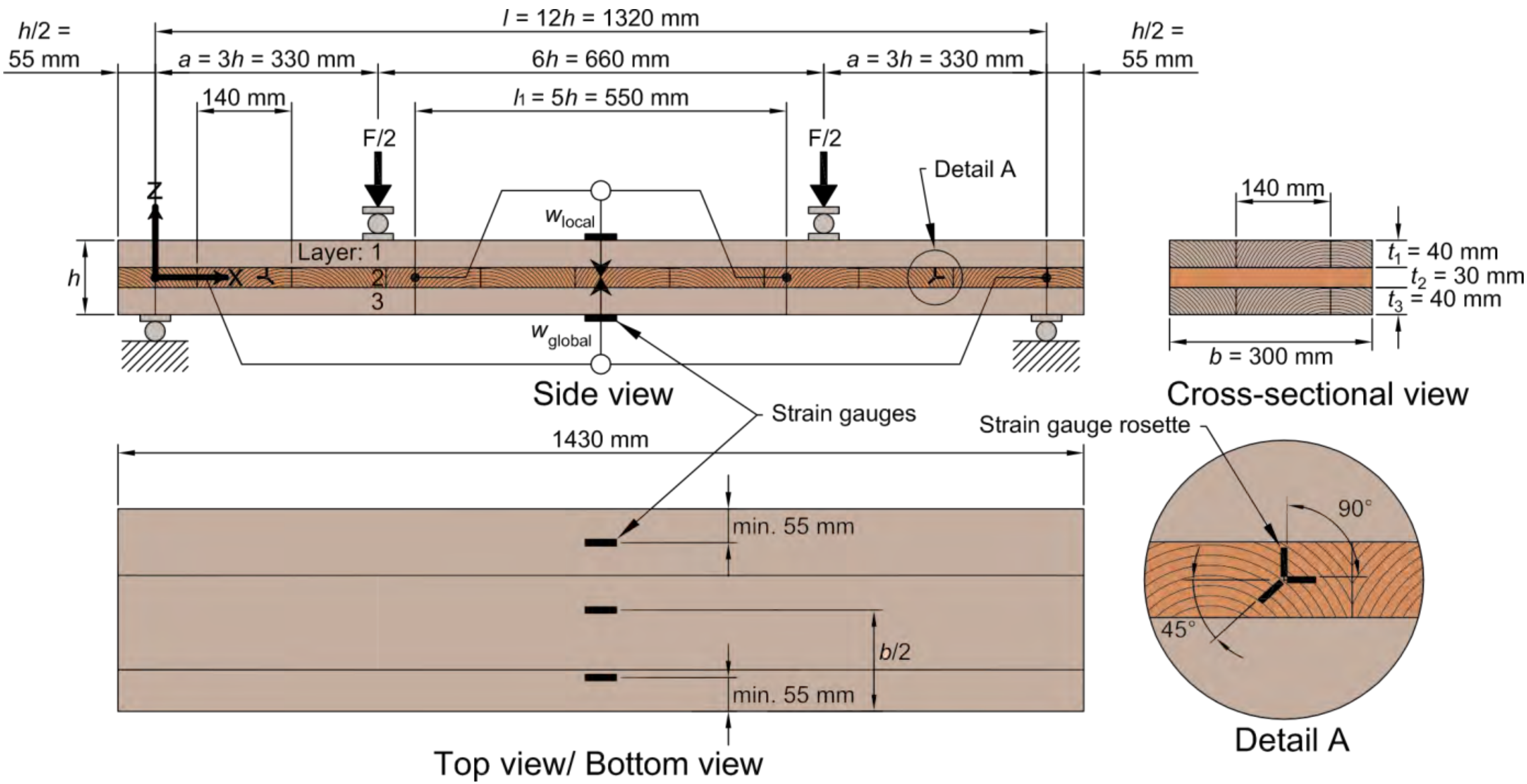


$f_{v,r,A,mean}$ = 3.31 N/mm^2
$f_{v,r,A,05}$ = 2.30 N/mm^2

$f_{v,r,B,mean}$ = 4.38 N/mm^2
$f_{v,r,B,05}$ = 3.54 N/mm^2

5. Testing of beech-spruce hybrid CLT

5b. Flatwise bending shear tests - Setup



5. Testing of beech-spruce hybrid CLT

5b. Flatwise bending shear tests - Failures

5b. Flatwise bending shear tests – Results

Rolling shear modulus G_r [N/mm²]

Bending shear:	$G_{r,strain}$	419
	$G_{r,def,E0,def}$	349
	$G_{r,def,E0,strain}$	250
2-plate shear:	$G_{r,2\text{-}plate}$	370

$G_{r,spruce} = 50$ N/mm²

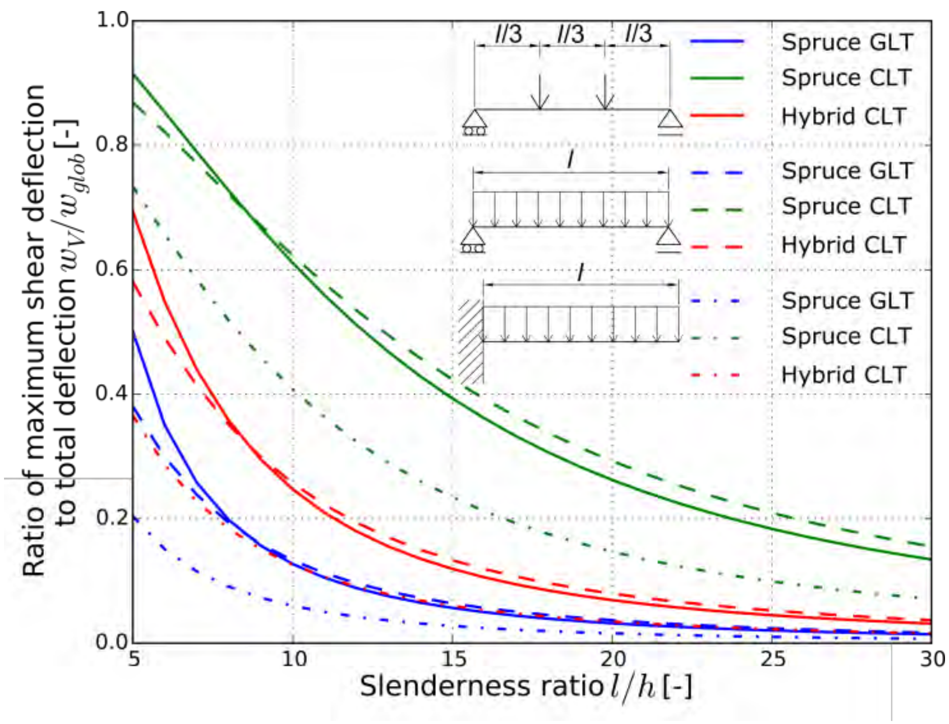
Rolling shear strength $f_{v,r,05}$ [N/mm²]

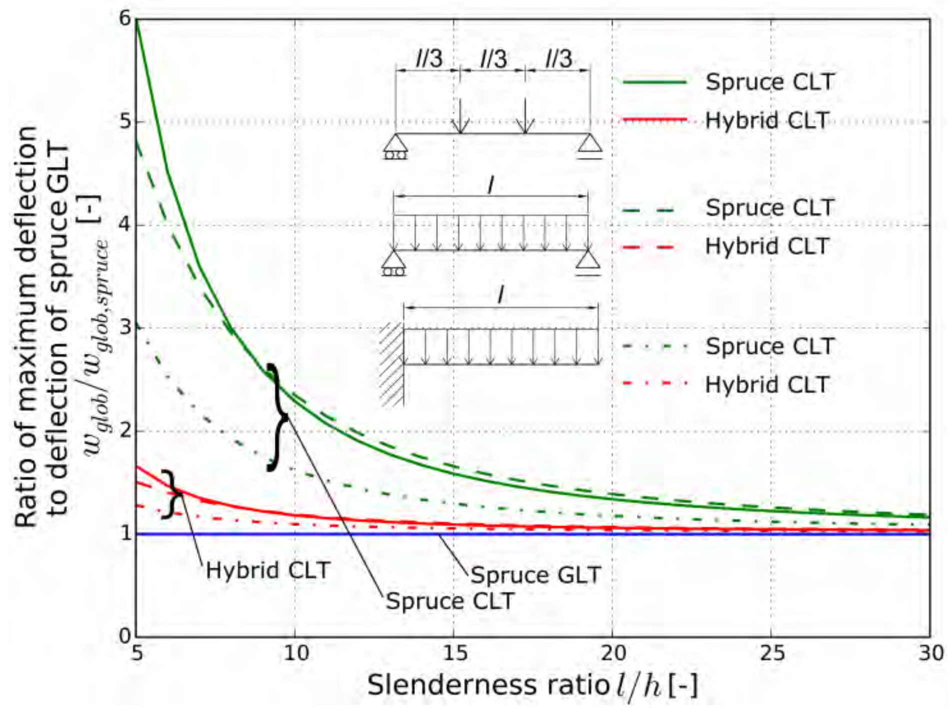
Bending shear:	$f_{v,r,2,05}$	2.61
Compression shear:	$f_{v,r,A,05}$	2.30
	$f_{v,r,B,05}$	3.54
2-plate shear:	$f_{v,r,05(\text{with pith})}$	3.30

$f_{v,r,spruce} = 0.9$ N/mm²

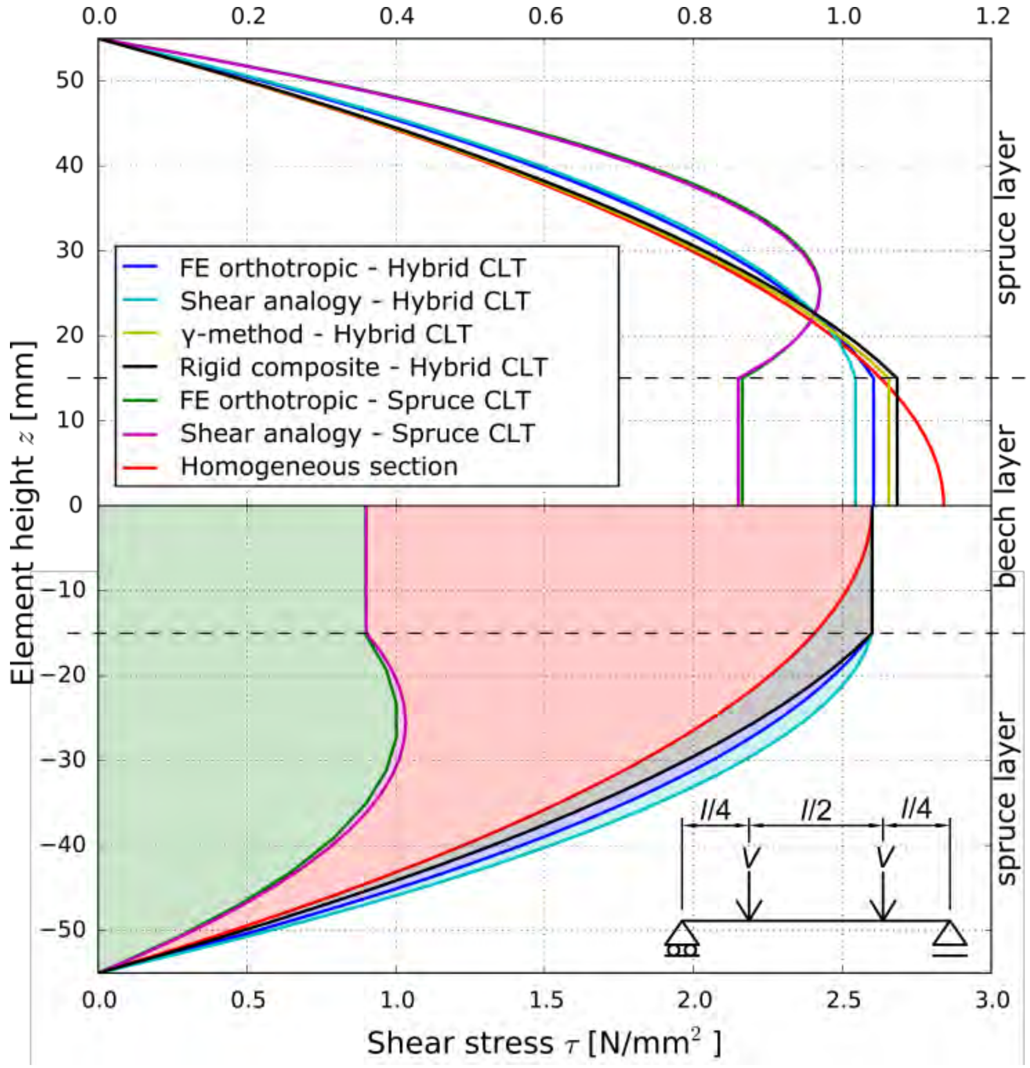
6. Design implications – flatwise bending

6a. Deflection



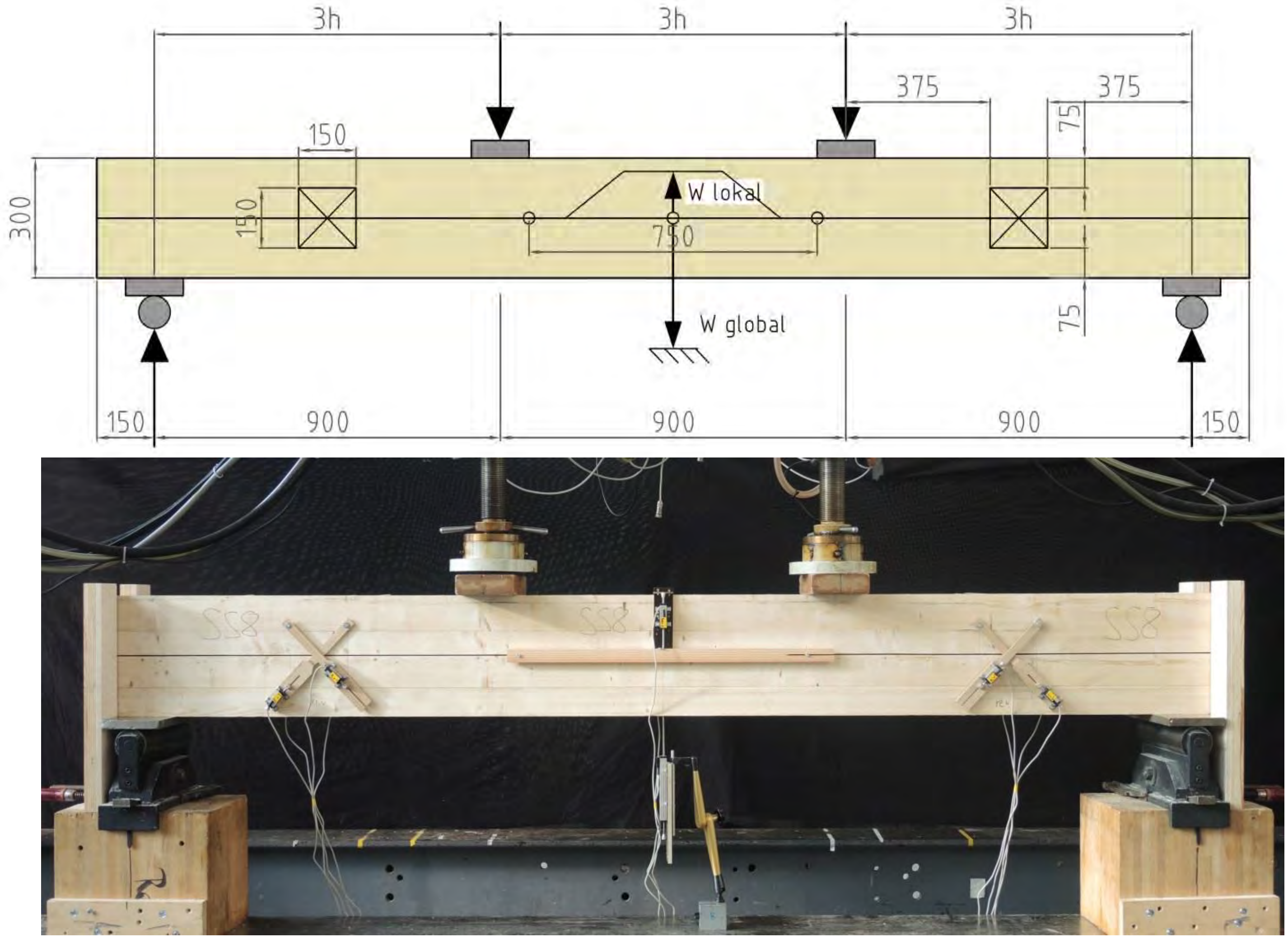


6b. Shear stresses



7. Edgewise Tests

7a. Edgewise bending shear - Test setup



7. Edgewise Tests

7a. Edgewise bending shear - Failure types

Mostly bending (tensile) failures in the spruce layers, typically starting at finger joints within the peak moment area

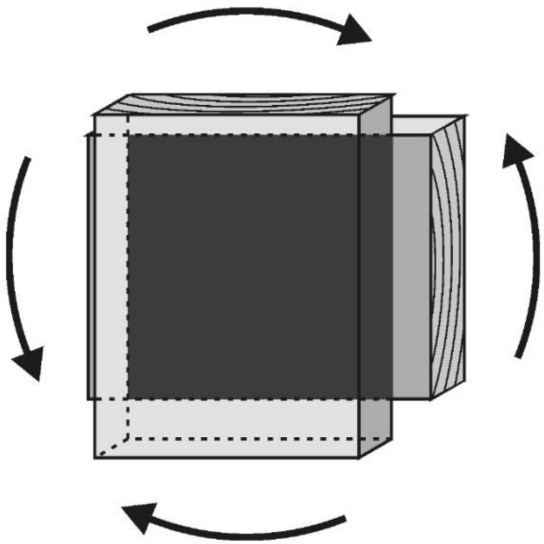
In one instance, a shear failure of the gross cross section occurred

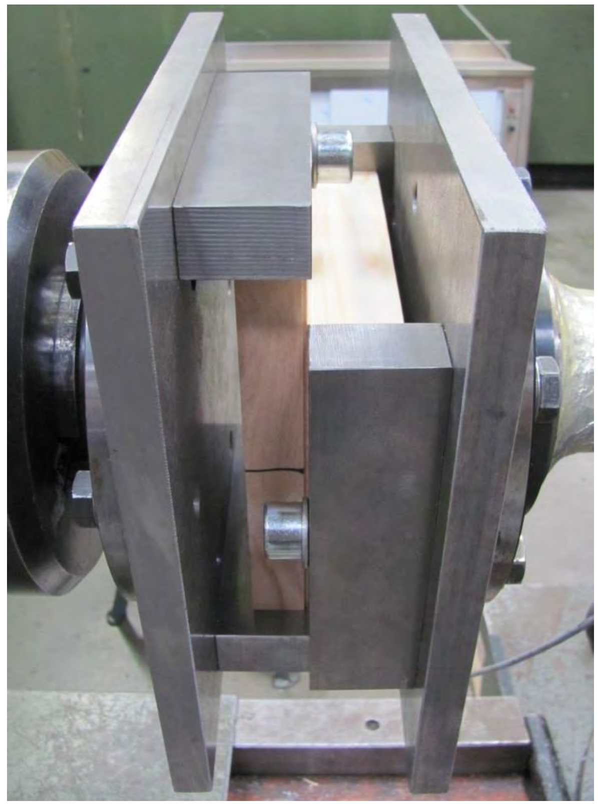
7. Edgewise Tests

7b. Net cross section – shear tests

7. Edgewise Tests

7c. Torsional shear





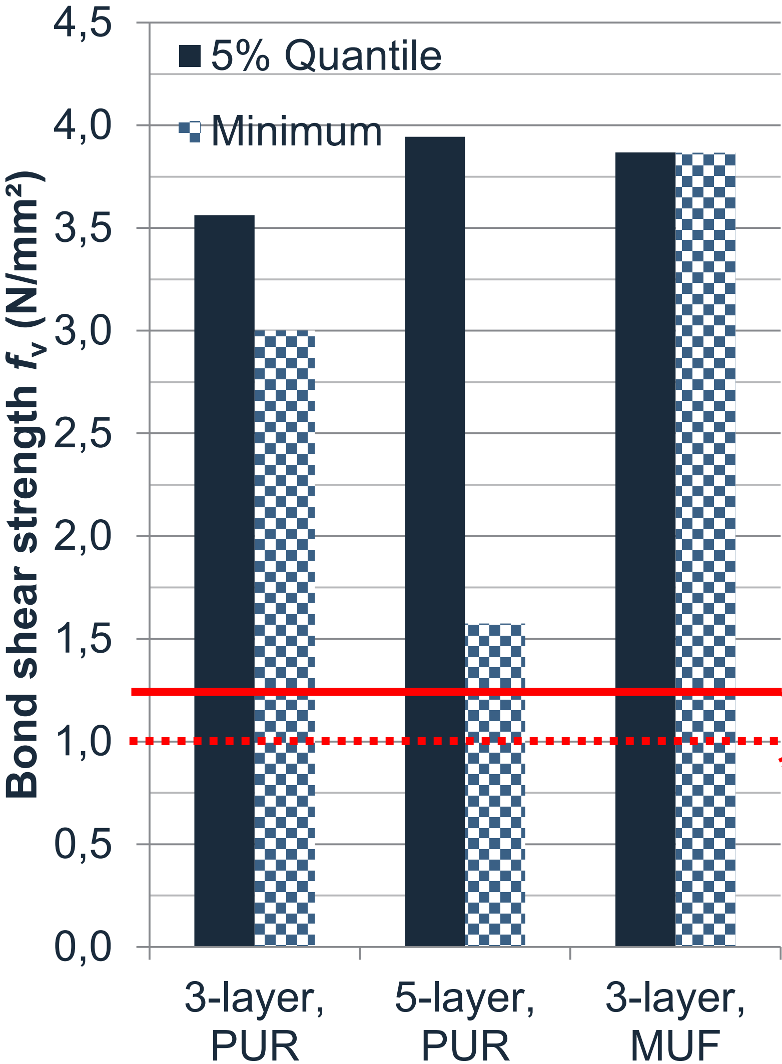
7. Edgewise Tests

7d. Results

		Hybrid beech-spruce CLT:	Homogeneous spruce CLT:
Bending strength $f_{m,05}$ [N/mm2]			
Bending shear:	$f_{m,net,05}$	33.5	18.5-29.0
	$f_{m,gross,05}$	24.3	
Shear strengths $f_{v,05}$ [N/mm²]			
Bending shear:	$f_{v,gross,05}$	3.8*	4.0
Net cross-sect.:	$f_{v,net,comp,05}$	12.15	6.7
Torsional shear:	$f_{v,tor,05}$	2.33	2.4 – 2.8
Shear stiffness G_{090} [N/mm²]			
Bending shear:	G_{090}	509	220 - 310

8. Further tests

8a. Block shear tests with hybrid CLT



Requirements according to EN 16351 fulfilled

characteristic shear strength ≥ 1.25 N/mm²

minimal shear strength ≥ 1.0 N/mm²

8. Further tests

8b. Delamination tests

High swelling/shrinkage coefficients of beech leads to high delaminations, nevertheless the requirements according to EN 16351 have been fulfilled!

9. Initial findings for 5-layer hybrid CLT/ Outlook

- **Rolling shear properties just as good as the tests with 3-layered elements**
- **Edgewise shear stiffness (effective) increased to 740 N/mm^2**

→Enormous potential for increasing height of CLT tall buildings!!!

- **Industrial application - EAD in preparation**

Thank you for your attention!

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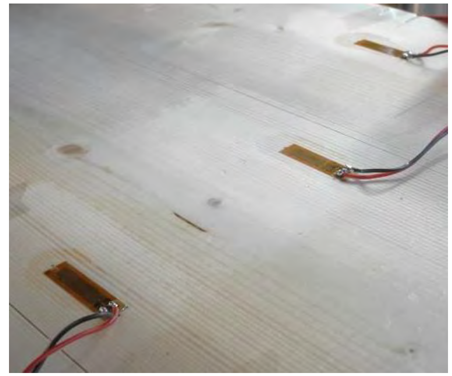
Department of Timber Constuctions

5. Testing of beech-spruce hybrid CLT

5b. Flatwise bending shear tests – Calculation method

(from strain gauge measurements)



$$G_{r,2} = \frac{\tau_{r,2}}{\gamma_{r,2}}$$

$$\tau_{r,2} = \frac{V \cdot \gamma \cdot t_{1,3} \cdot (t_{1,3} + t_2)}{2I \cdot \eta} \approx \frac{V \cdot t_{1,3} \cdot (t_{1,3} + t_2)}{2I}$$

simplification:

$\gamma = \eta \approx 1$

$$E_{0,1,3} = E_{0,\text{strain}} = \frac{\sigma_{m,1,3}\left(\pm \frac{h}{2}\right)}{\varepsilon_{1,3}\left(\pm \frac{h}{2}\right)}$$

$$\sigma_{m,1,3} = \pm \frac{M}{I_{\text{eff}}}\left[\pm \frac{t_{1,3}}{2} \pm \gamma \cdot \left(\frac{t_{1,3} + t_2}{2}\right)\right]$$

$$I_{\text{eff}} = b \cdot \left[\sum_{1,3} \frac{t_{1,3}^3}{12} + \gamma \cdot \sum_{1,3} \left(t_{1,3} \cdot \left(\frac{t_{1,3} + t_2}{2}\right)^2\right)\right]$$

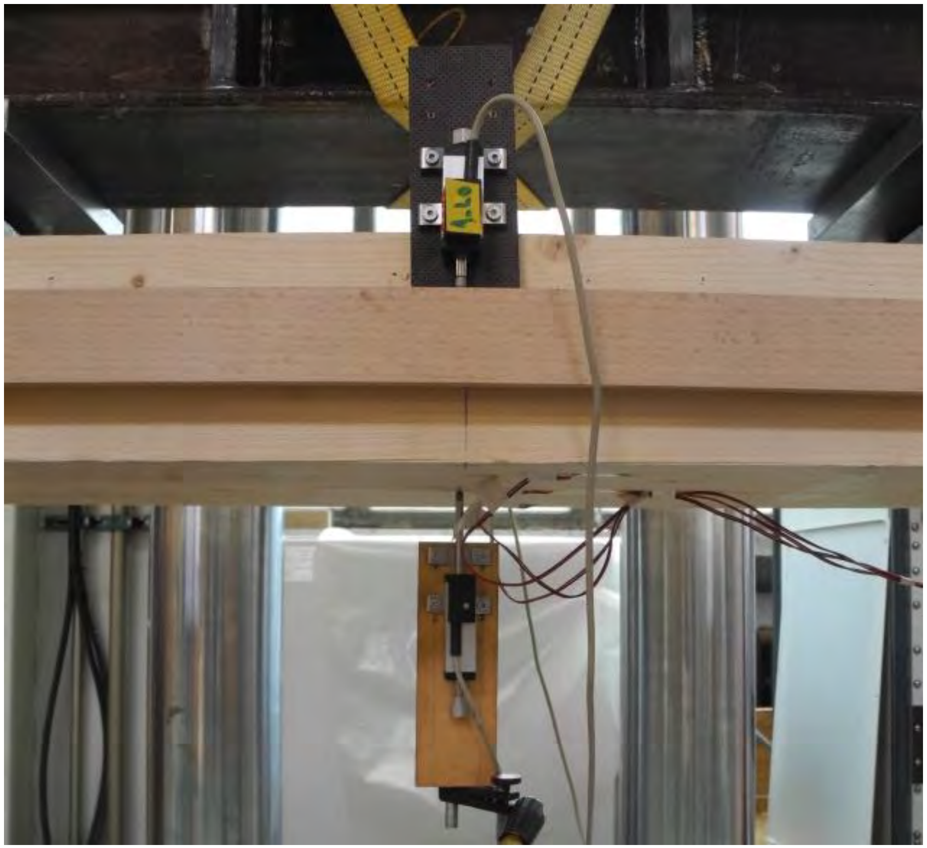
$$\gamma = \frac{1}{1 + k}$$

$$k = \frac{\pi^2 (E_{0,1} \cdot t_1 + E_{0,3} \cdot t_3)/2}{2l^2 \cdot G_{r,2}/t_2} = \frac{\pi^2 \cdot E_{0,1,3} \cdot t_{1,3}}{2l^2 \cdot G_{r,2}/t_2}$$

5. Testing of beech-spruce hybrid CLT

5b. Flatwise bending shear tests – Calculation method

(from deflection measurements)



$$w_{\text{global}} = w_{\text{M}}(E_{0,1,3}, I) + w_{\text{V}}((GA)_{\text{eff}})$$

$$(GA)_{\text{eff}} = b \cdot d^2 \cdot \left(\frac{t_{1,3}}{G_{1,3}} + \frac{t_2}{G_{\text{r},2}}\right)^{-1}$$

$$G_{\text{r},2} = t_2 \cdot \left[\frac{b \cdot d^2}{(GA)_{\text{eff}}} - \frac{t_{1,3}}{E_{0,1,3}/\eta_{\text{EG}}}\right]^{-1}$$

$$\eta_{EG} = \frac{E_0}{G} = 16$$