COST FP1004

15-17 April 2015 – Lisbon, Portugal

Pull-compression tests on glued-in metric thread rods parallel to grain in different timber species and laminated veneer lumber

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Glued in rods

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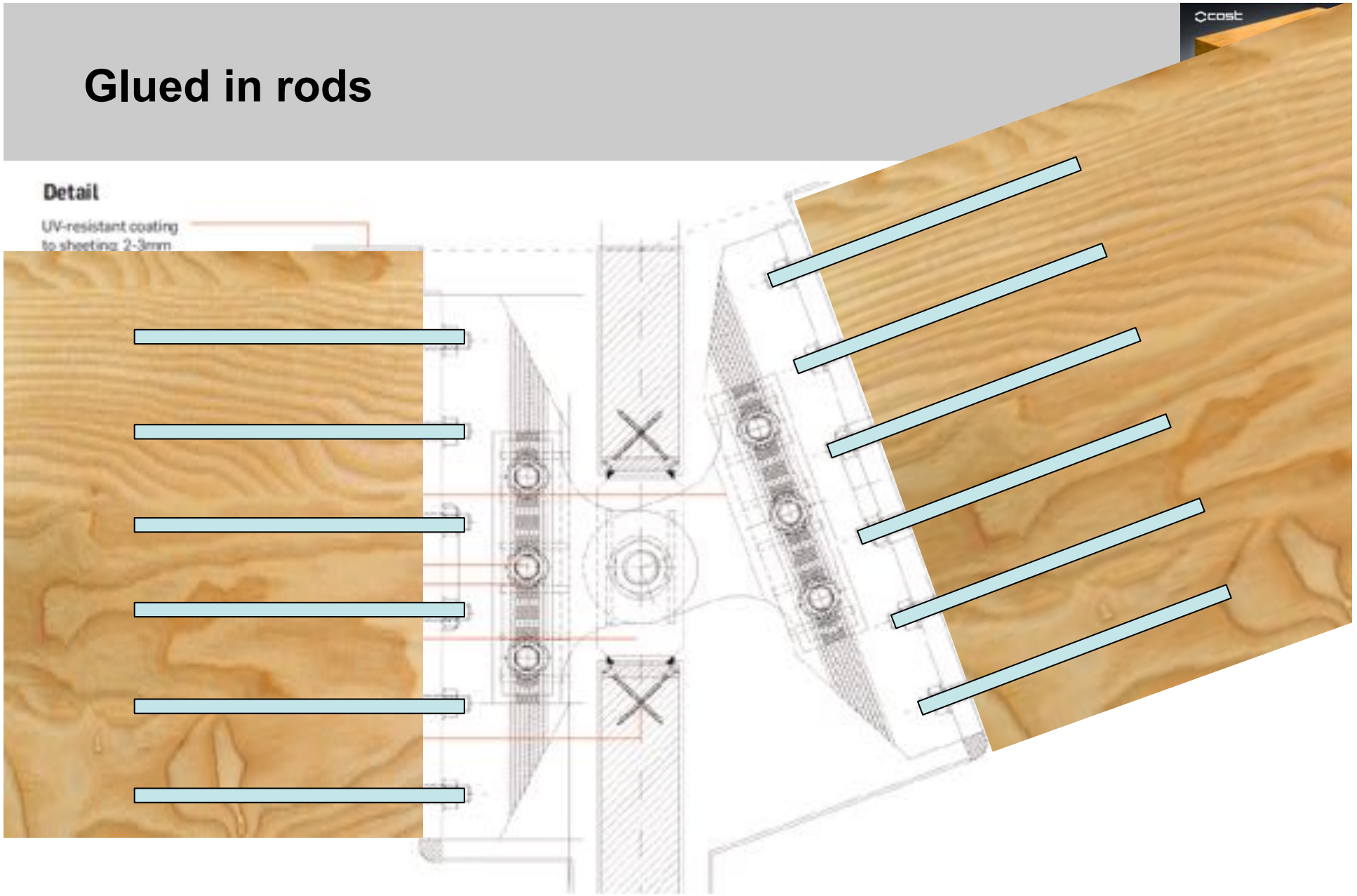
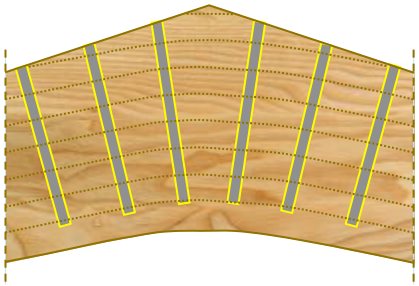
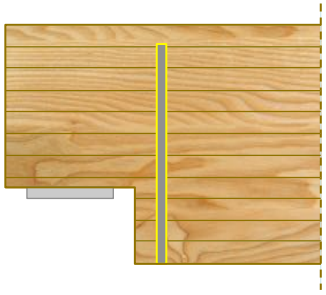


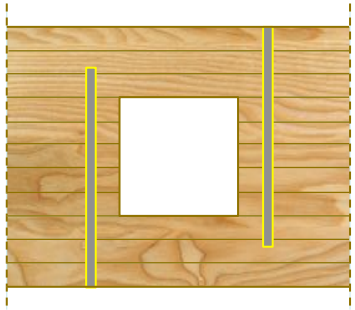
Glued in rods - reinforcement



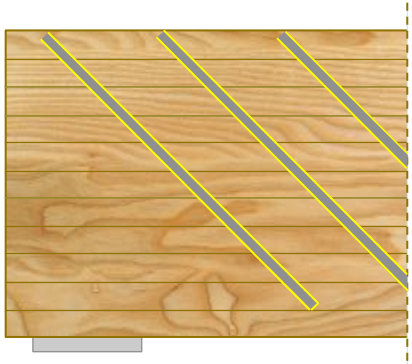
Curved and tapered beams



Notched beams



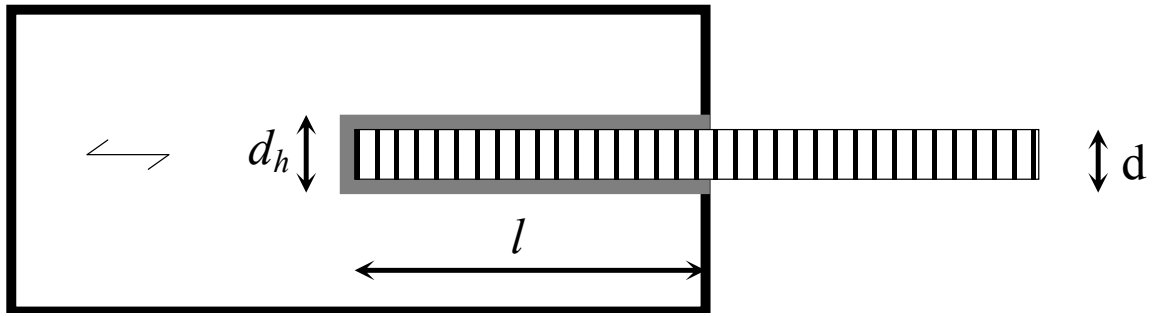
Beams with holes



zones of excessive
shear stresses

compression stresses perpendicular
to the grain at supports

Glued in rods



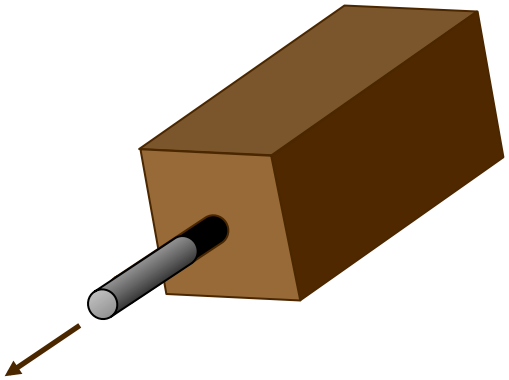
d = diameter of rod
l = anchorage length
d_h = diameter of hole
e = glue line thickness

Three materials:

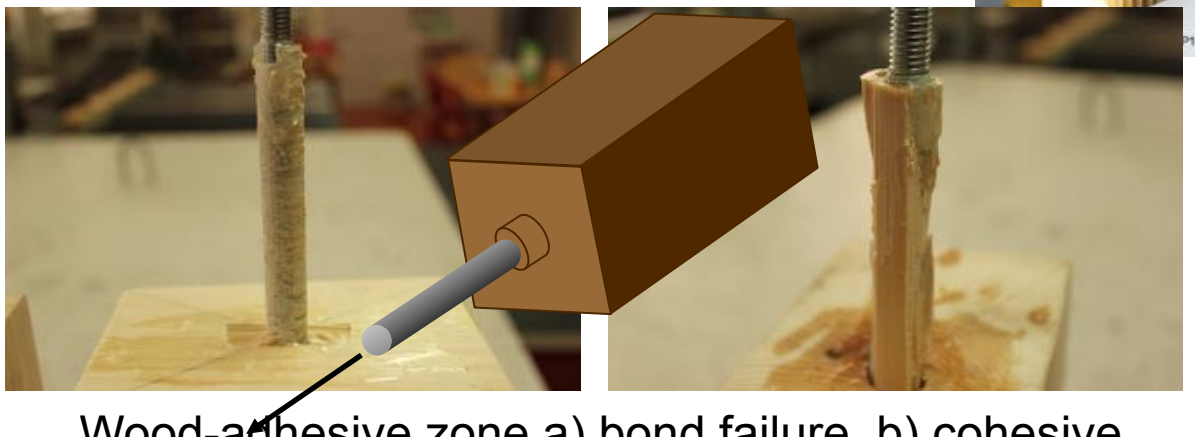
- Main body - Timber (hardwood, softwood, glulam, CLT, LVL)
- Rod – steel or FRP
- Adhesive – PUR, PRF, EPX

Design philosophy – failure modes

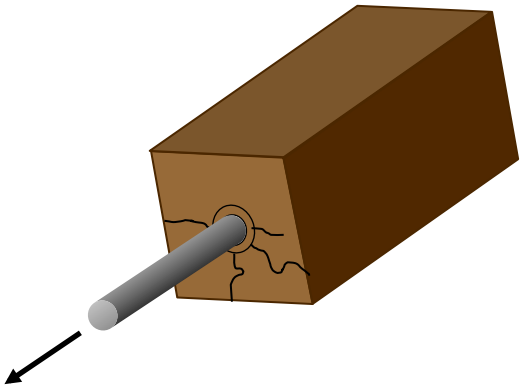
Design philosophy – failure modes



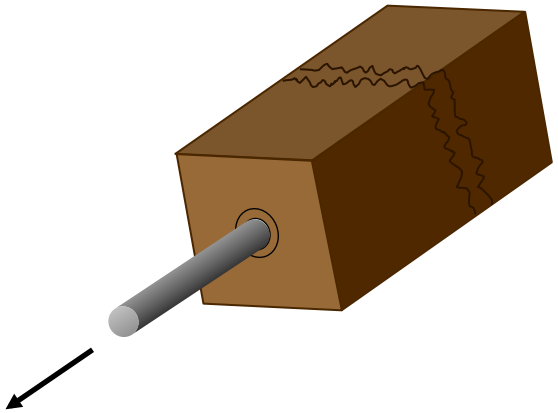
Steel-adhesive zone, yielding of the rod



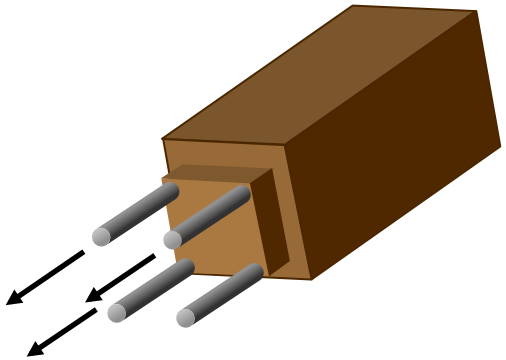
Wood-adhesive zone a) bond failure, b) cohesive failure in the wood near to the bond line



Splitting failure of the wood



Tensile failure - wood



Group shear failure

Design rules - history

1988.
- Riberholt

1990s
- German
- Russian
- New Zealand (Buchanan)
- Swedish

1993
- Kangas V-shape

1997.
- EC5, Part 2: Design of Bridges

1998.-2001.
- GIROD project
- French standards

2001.
- Bernasconi
- IRL/CNR rules
- EC5, final draft

2004.
- DIN1052:2004-08

2007.
- Steiger, Widmann, Gehri

2008.
- DIN1052:2008-12
- Rossignon, Espion

Möhler, Hemmer Riberholt, Turkovsky, Buchanan, Deng

Carling, Kangas, Gehri, Blass, Aicher, Johansson, Townsend, Gerold, Ehlbeck

Harvey, Ansell, Bainbridge, Bernasconi, Mettem, Faye

Gustafsson, Bengtsson, Serrano, del Senno, Piazza, Broughton

Feligioni, Lavisci Steiger, Widmann, Gehri, Tomasi

Rossignon, Espion, Otero, Yeboah, Gardele, Morlier

GiR in timber products?

- Hybrid glulam – outer zones made of LVL or CLT?
- Lack of information about GiR in hardwoods
- Lack of appropriate design rules
- Lack of defined test procedures

Materials and methods

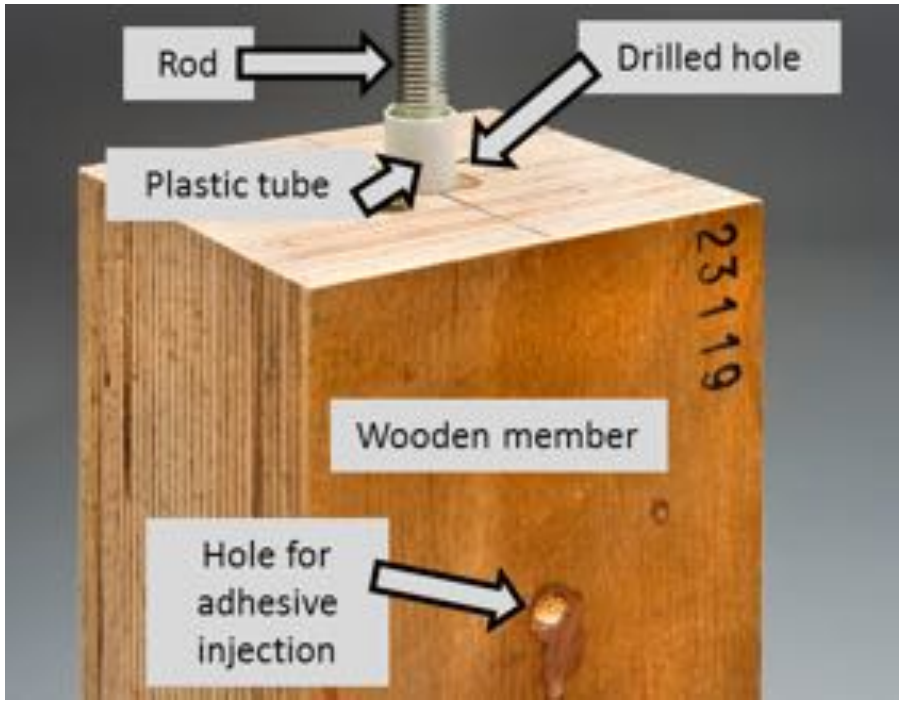
- 200 specimens
- Different timber material, adhesive and exposure to alternating climate

Timber:

- glulam made of Norway spruce
- European ash
- European beech
- LVL made of Norway spruce – Kerto S & Kerto Q (MetsäWood)
- LVL made of European beech (Pollmeier Massivholz GmbH)

Adhesive: EPX & PUR

Materials and methods



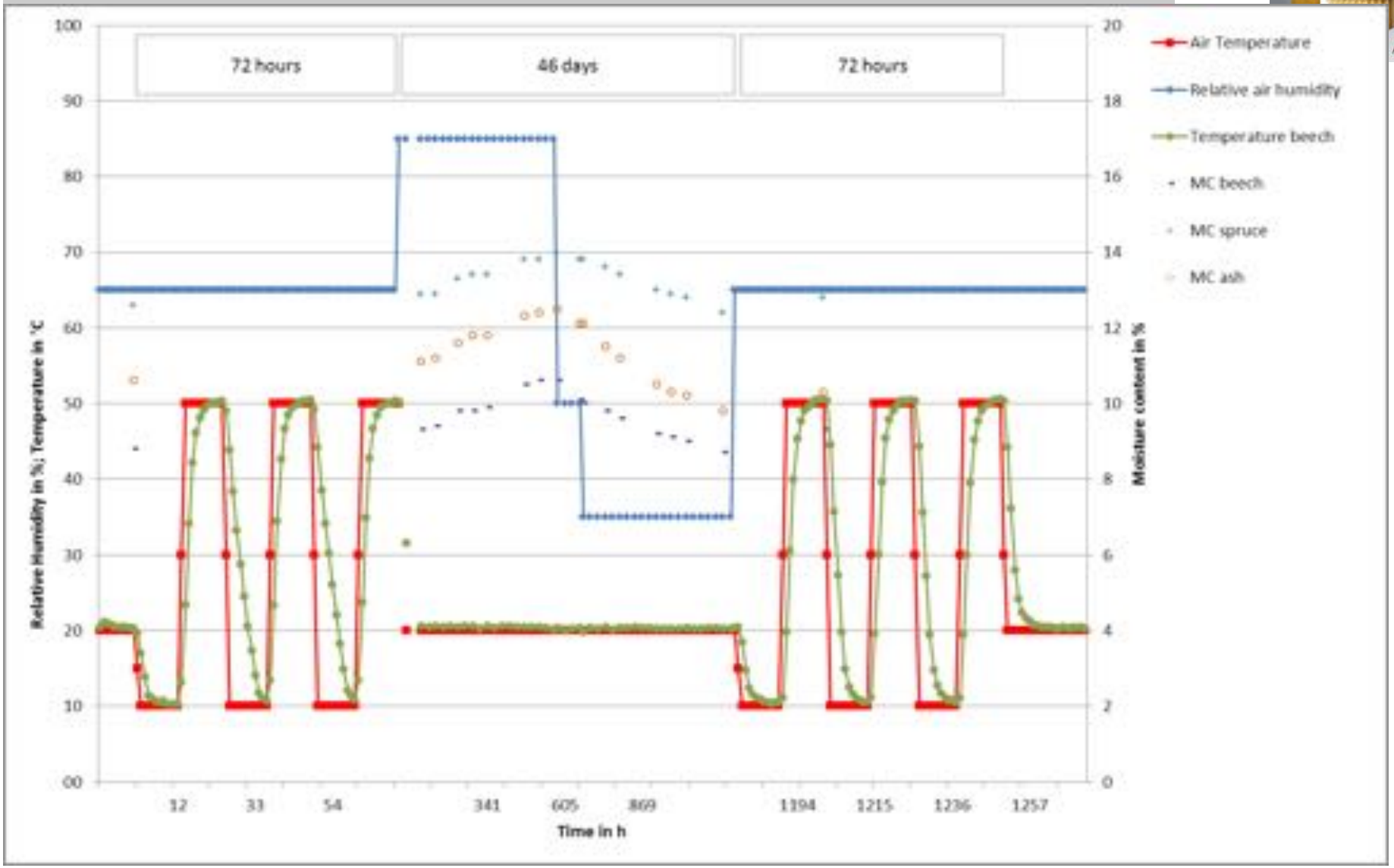
- M12 threaded steel rod, 8.8 & 10.9
- Timber cross section: 120×120mm
- Eff. anchorage length: 90 mm
- Diameter of hole: 16mm

Materials and methods – climate conditioning

Number of test specimens examined in the laboratory tests

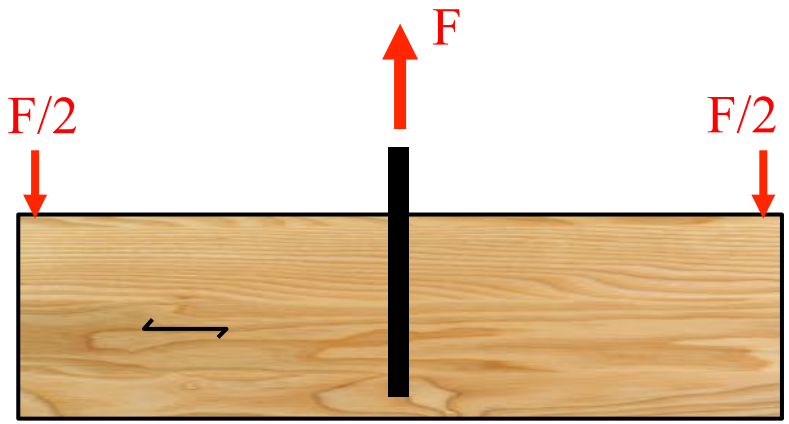
Material	Adhesive			
	Epoxy		PUR	
	standard climate	alternating climate	standard climate	alternating climate
Norway spruce	10	6	10	6
European beech	10	6	10	6
European ash	9	6	10	6
LVL spruce (Kerto S)	10	6	10	6
LVL spruce (Kerto Q)	11	6	10	6
LVL European beech	20	-	20	-

Climate conditioning

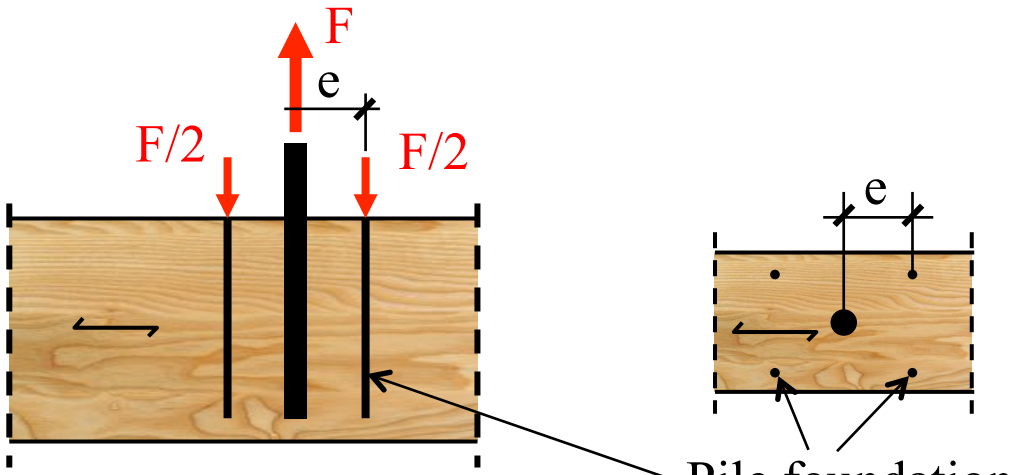


Test setup

pull - pull



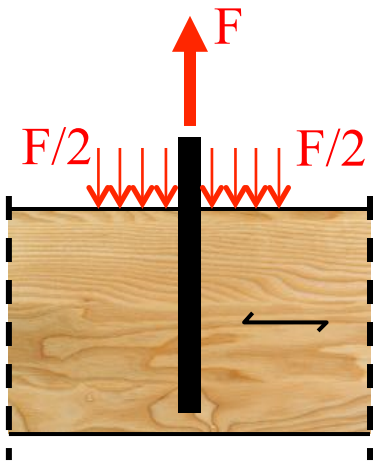
pull - beam



pull – pile foundation

Test setup – pull compression

- test protocol according to EN 1382:1999
- the load was applied at a constant rate between 0.5 mm/min and 1.5 mm/min until failure
- two displacement sensors for measuring displacement applied

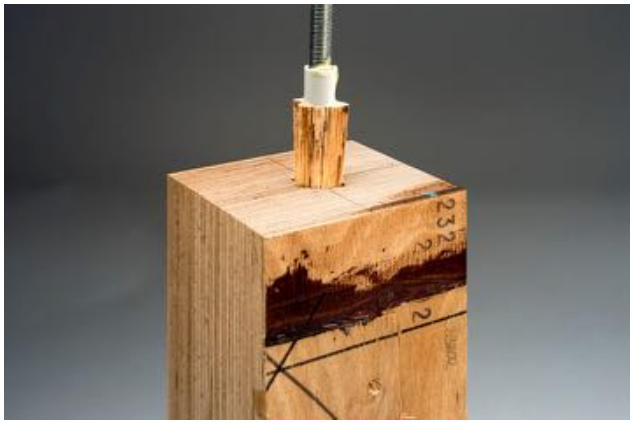


pull - compression

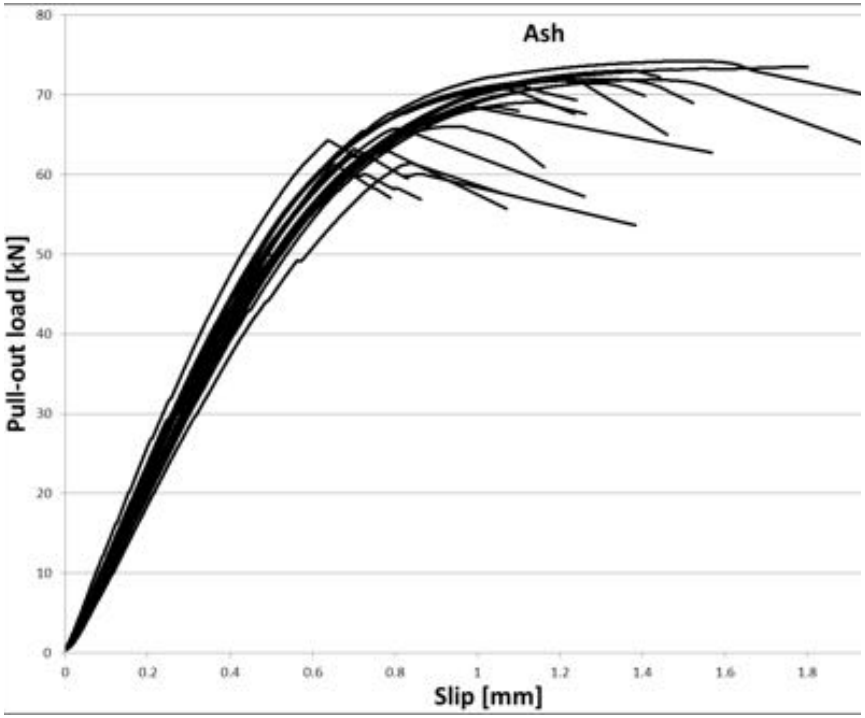
Results – failure modes

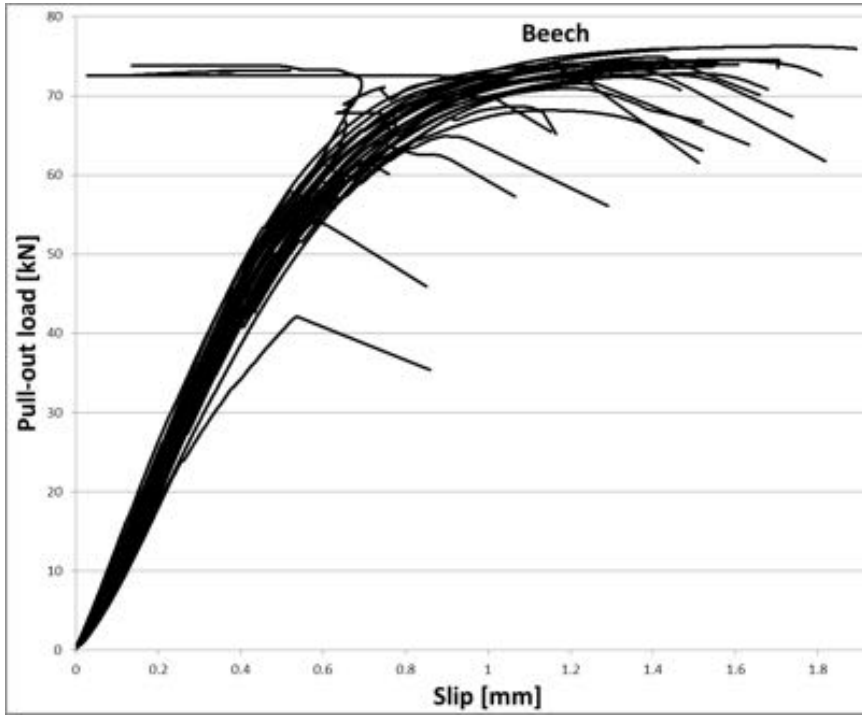
- Shear failure along the rod in the adhesive layer,
- Shear failure along the rod in the interface between the adhesive and the surrounding timber,
- Shear failure along the rod in the surrounding timber,
- Combined shear failure along the rod in the adhesive layer, in the surrounding timber and their interface or
- Failure of the rod.

Results – failure modes

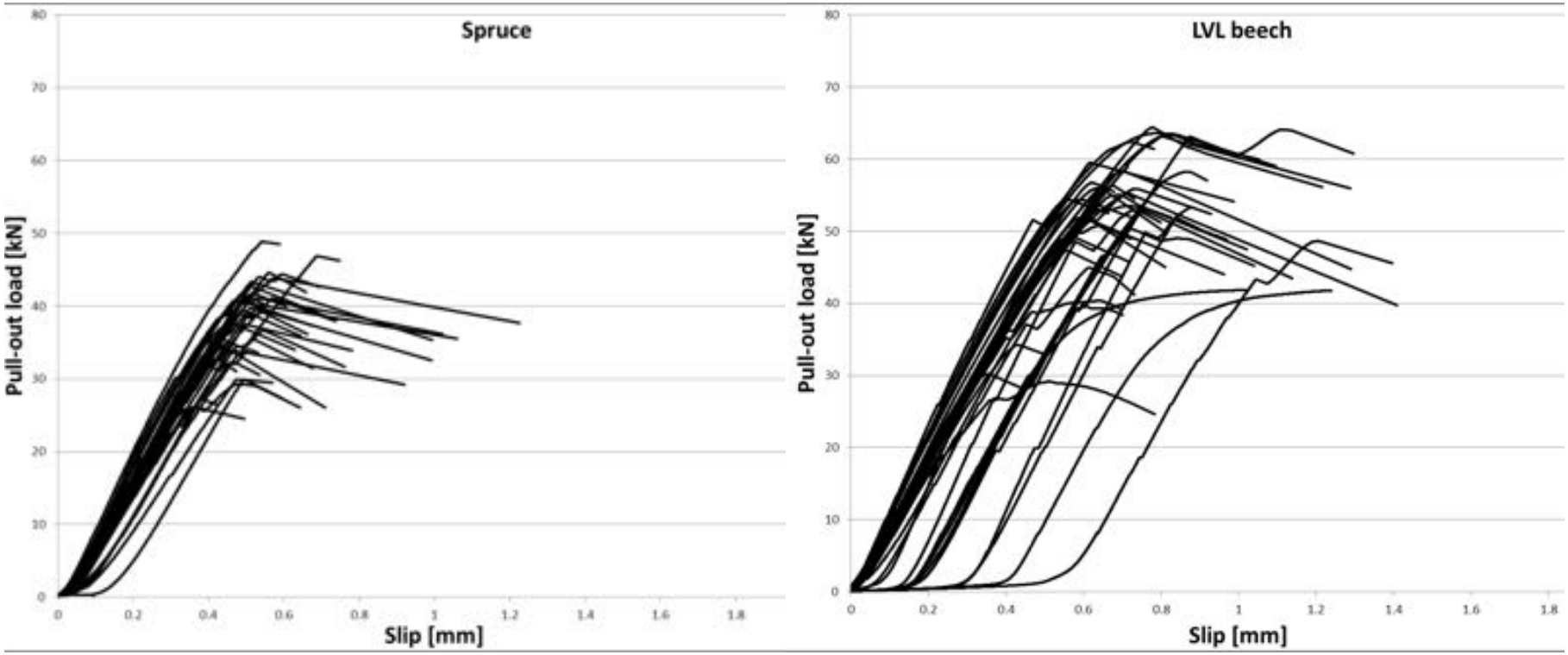


Results – Ash & beech

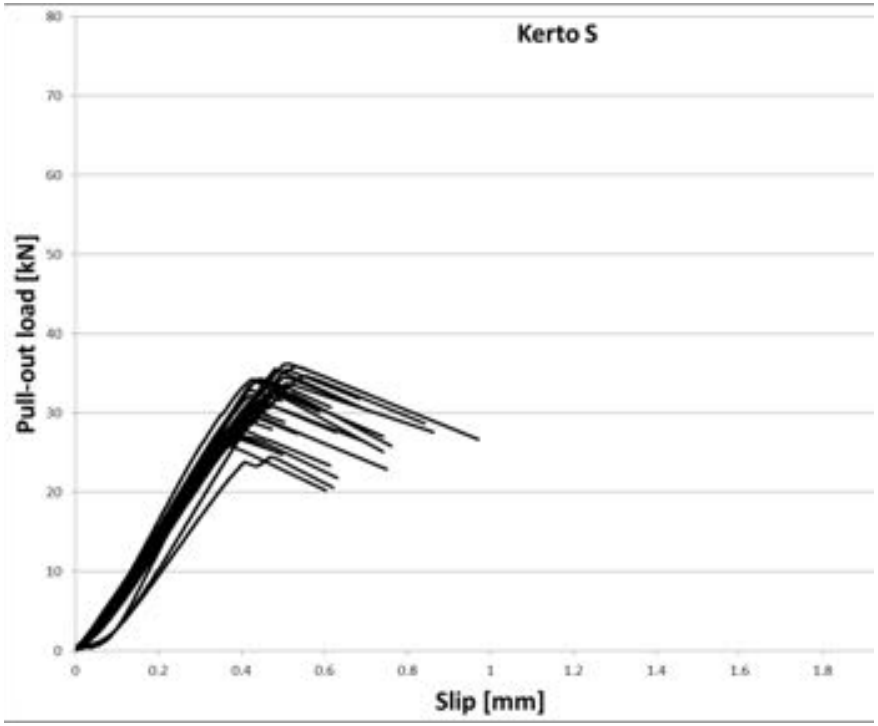


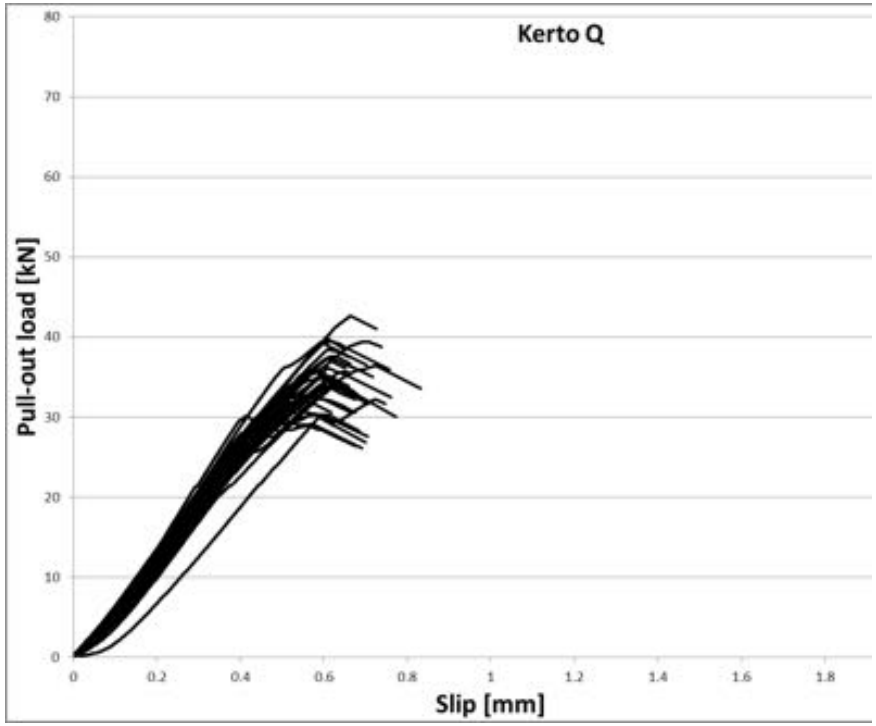


Results – Spruce & LVL beech

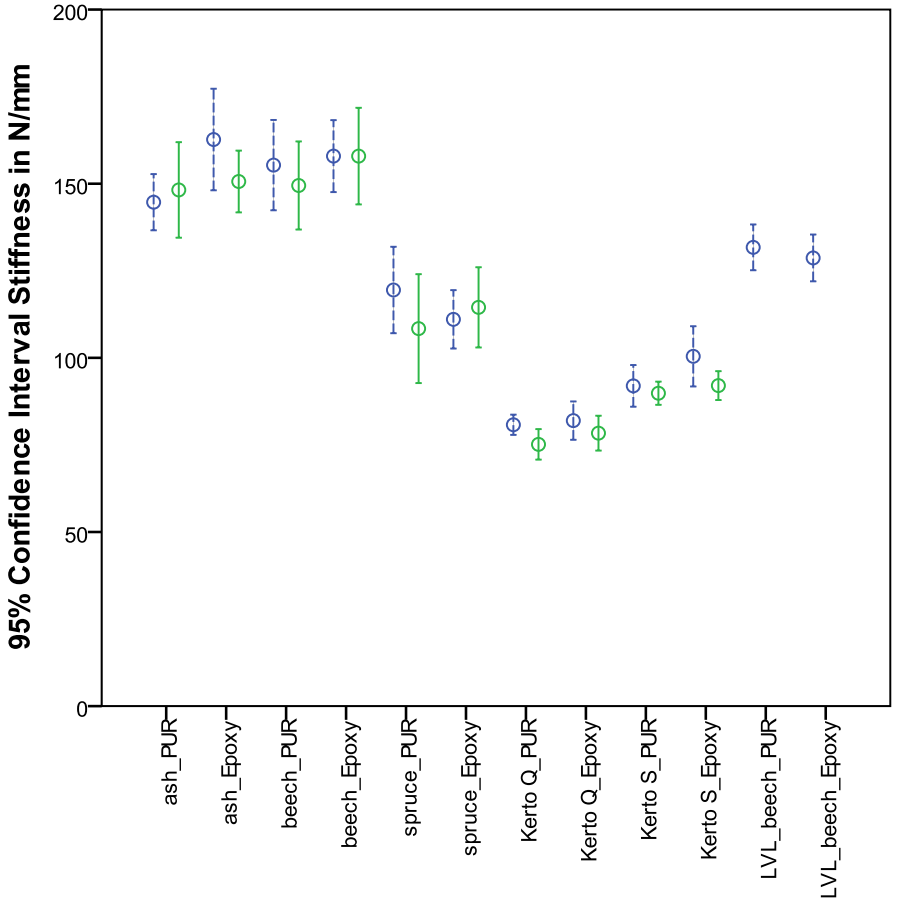


Results – Kerto S & Kerto Q

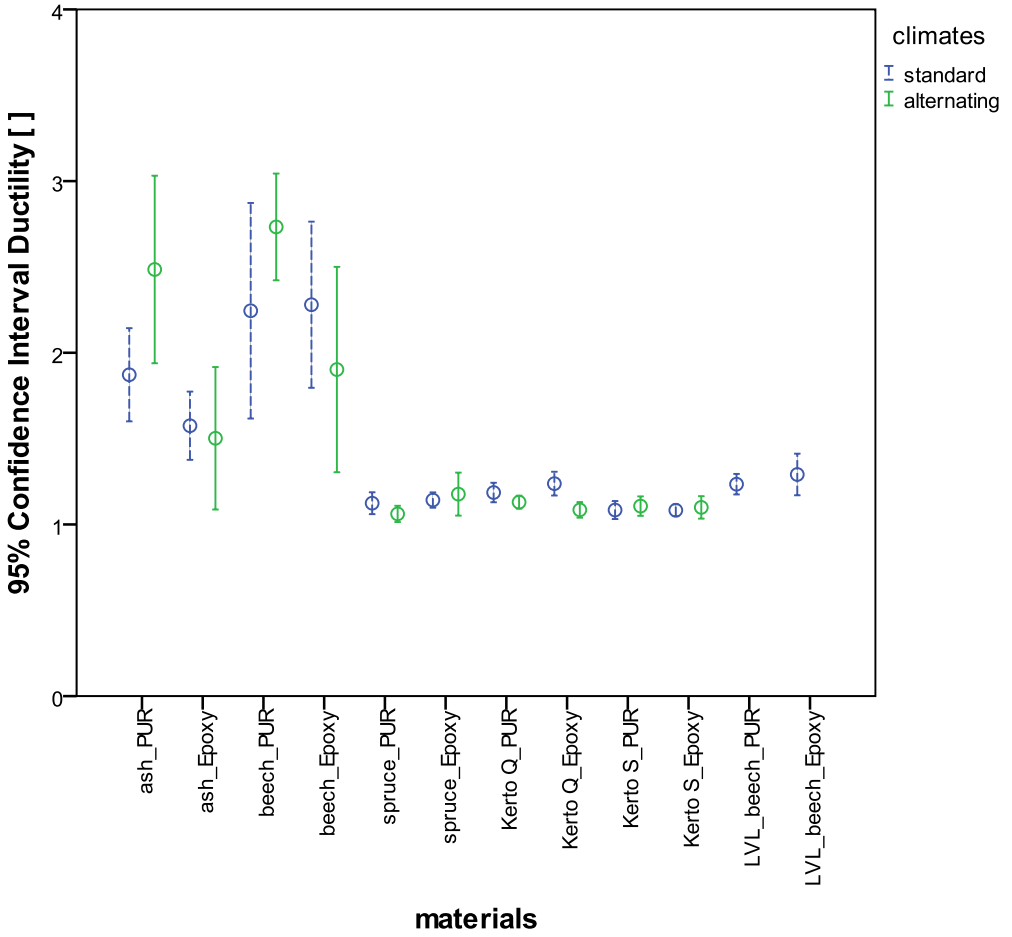




Results

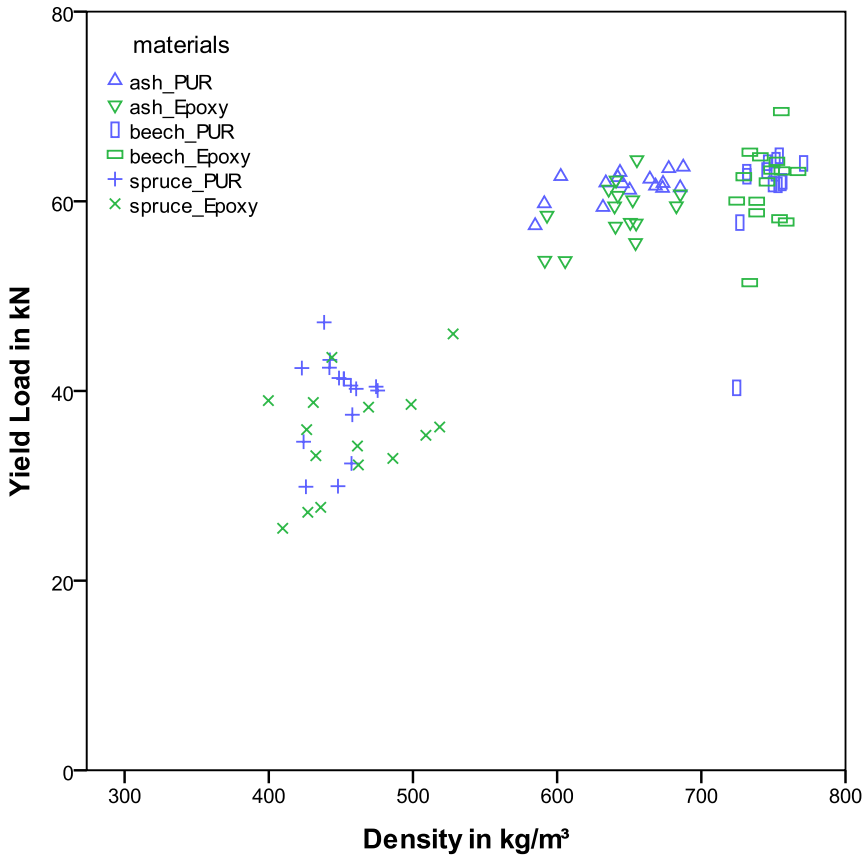


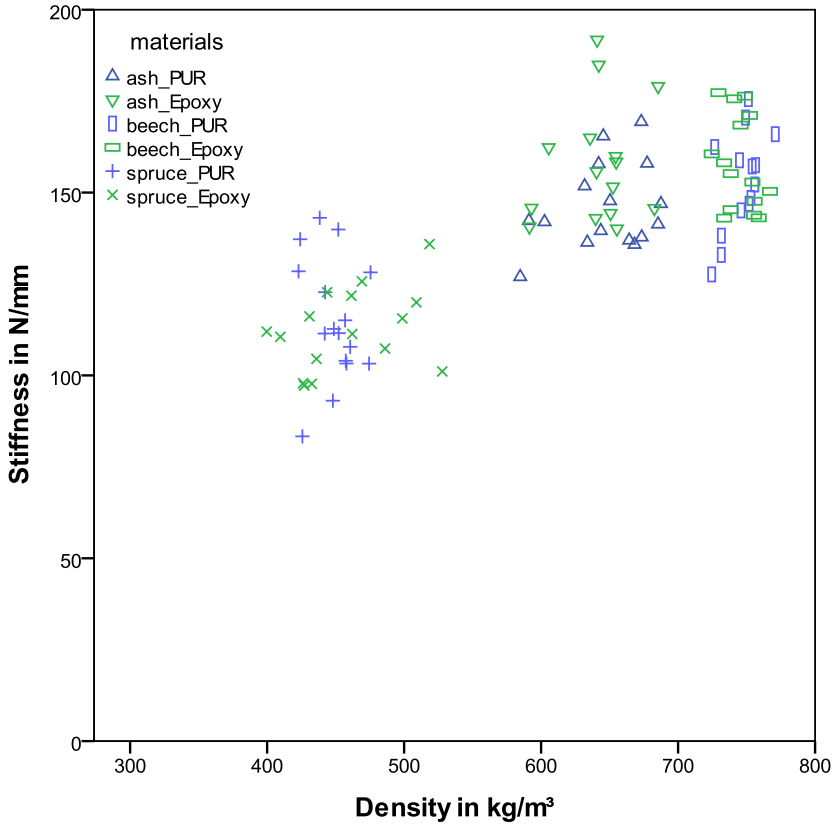
$$k_i = \Delta F / \varepsilon_i$$



$$D = V_u / V_y$$

Results





Yield load F_y (left) and stiffness of the joint k_{joint} (right) in the linear elastic range against the density of the solid timber test materials

Conclusions

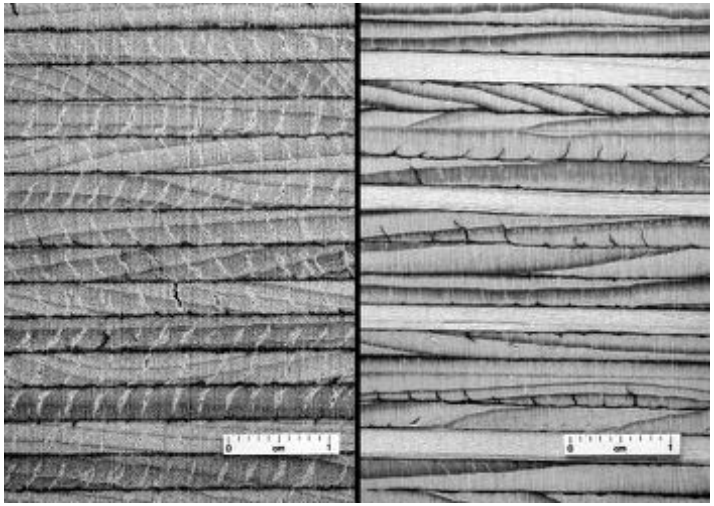
- The load-slip curves for European ash and European beech show a very small scatter
- For softwood and LVL the failure occurs at much lower loads
- In most cases the failure can be characterized as shear failure along the rod whereby a different ratio of timber and adhesive is involved
- Based on the results, cyclic humidity alone does not lead to a degradation of the load carrying capacity, nor does it lead to any delayed hardening of the adhesive
- Ductility of whole joint is different when using different timber materials
- Whereas the tested engineered wood products and Norway spruce do not show a ductile behavior, the specimens made of hardwoods allow a larger deformation until ultimate load is reached. Within hardwood a distinction should be made: European ash with epoxy show clearly lower ductility than European beech with polyurethane

Results

		solid						Engineered wood products					
		European beech		European ash		Norway spruce		Kerto Q®		Kerto S®		LVL beech	
		PUR	EPX	PUR	EPX	PUR	EPX	PUR	EPX	PUR	EPX	PUR	EPX
n		14	15	16	15	16	16	16	17	15	16	20	20
F_{max} (kN)	average	70.2	69.3	69.5	63.9	40.0	36.1	34.7	35.4	30.8	32.1	55.2	48.2
	5_{perc}	42.1	53.9	61.4	55.5	29.9	26.1	29.1	30.3	24.5	26.7	42.1	29.2

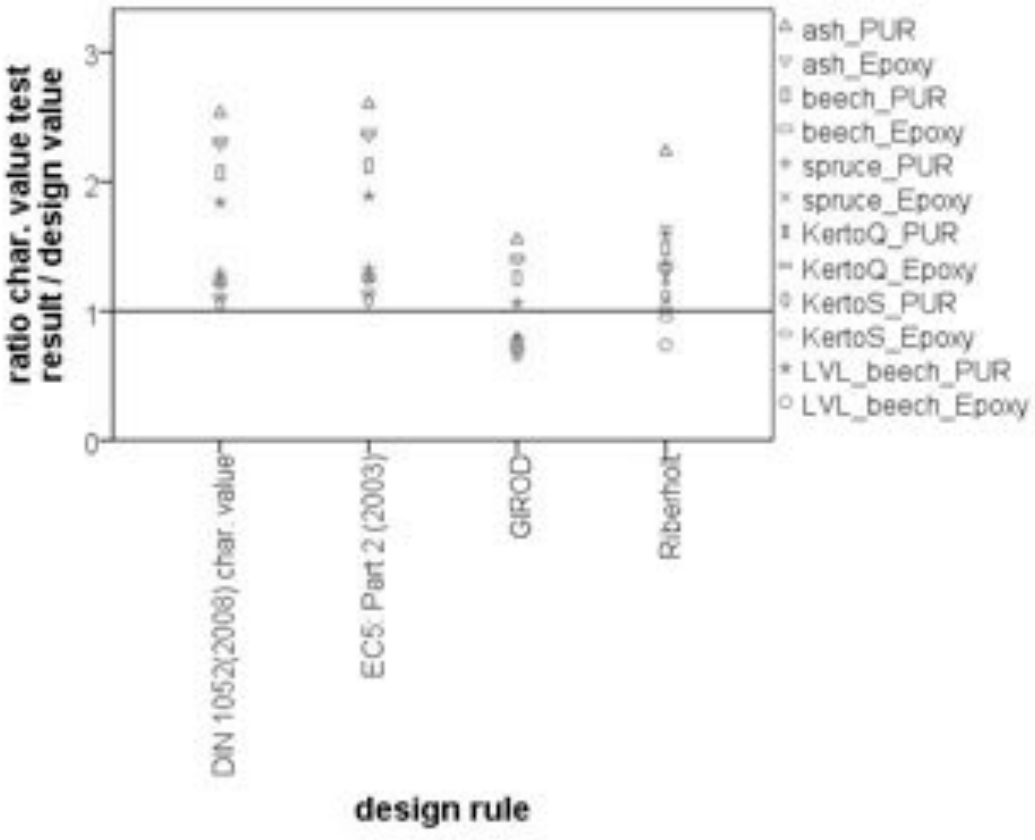
Conclusions

- Except for the LVL made of European beech, no clear differences between the two tested adhesives can be perceived
- engineered wood products show lower strength and stiffness values than the respective glulam
- The reason for the lower strength values of LVL made of European beech in comparison to solid beech might be explained by the production process



Example of open cracks (appears bright) in European beech LVL (left) and filled with adhesive (appears dark) in Norway spruce LVL (right).

Comparison with design rules



Whilst all values for pull-out strength are higher than the values obtained by DIN 1052:2008 in all cases, values for LVL made from beech and from Norway spruce differ a lot. The pull out strength of glued-in rods in LVL made of beech is always underestimated, while obtained results for engineered wood product as LVLs are much smaller than the ones calculated with all design proposals.

Present situation

- Despite a huge number of different design rules and approaches the basic principle is always similar but the problem is to define the shear strength parameter that should include the timber and the adhesive properties
- **The implementation of a design rule in Eurocode 5 can only be achieved if some technical guideline is made before the implementation itself**
- CEN/TC 250/SC5 work programme for the next five years ("towards a 2nd generation of EN Eurocodes") – GiR included in action plan

Conclusions

For now “The sad story about bonded-in bolts” (Larsen 2011)
is still reality,
but lately a significant effort have been made to turn it into,
if not a happy saga, at least a less sad story.

Thank you for your attention