

COST FP1004

Short-term scientific missions

15-17 April 2015 – Lisbon, Portugal



Load-carrying capacity and failure modes of glulam beams with reinforced notches

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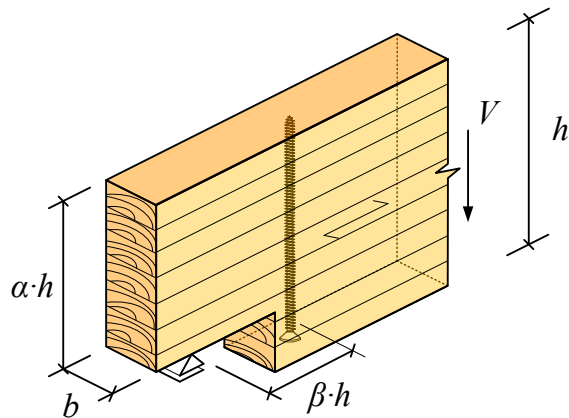
ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Background



- STSM during PhD studies at ETH Zurich
- Supervisors:
René Steiger (Empa), Andrea Frangi (ETH), Erik Serrano (LNU)
- Topic: Structural behaviour of glued laminated timber beams with unreinforced and reinforced notches



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Materials Science & Technology



Planing of the STSM



- Idea of STSM
 - Having a closer colaboration with Erik Serrano
 - Benefit from the expertise in fracture mechanics in Sweden
 - Erik Serrano and Bertil Enquist in Växjö
 - Per-Johan Gustafsson in Lund

Materials and Structures (2006) 40:87–96
DOI 10.1617/11527-006-9121-0

ORIGINAL ARTICLE

Fracture mechanics in timber engineering – Strength analyses of components and joints

Erik Serrano · Per Johan Gustafsson

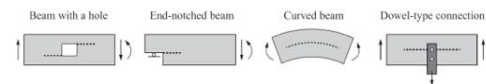
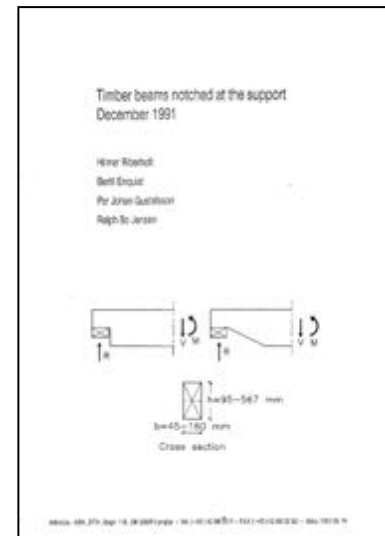


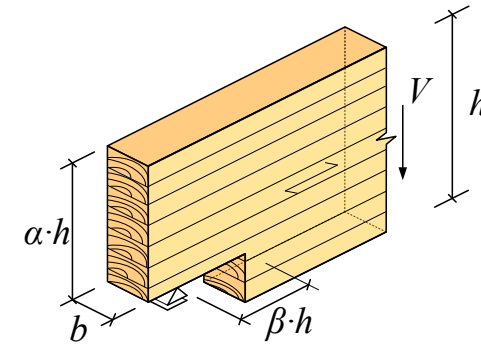
Figure 1.1: Examples of structural elements with risk for perpendicular to grain fracture.



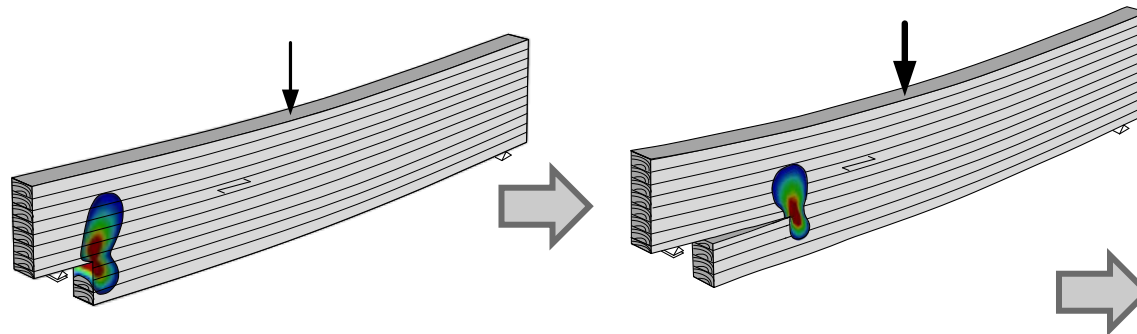
Introduction



- Reduced beam height at the support



- Stress concentration in shear and tension perpendicular to the grain in the notch corner

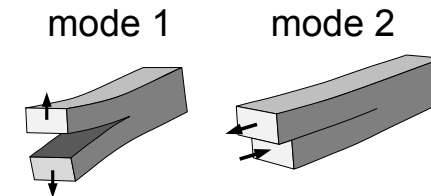
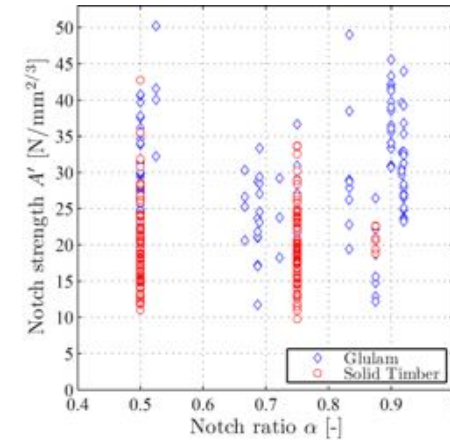


1. Avoid!
2. Reinforce!
3. Reduce capacity!

Need for research



- Identification of the parameters influencing the variation of load-carrying capacity
- Evaluation of the practical relevancy of design approaches and experiments from literature
- Setting the design of notched beams on a more reliable basis
- Harmonization of design approaches with relevant failure mechanisms
- Evaluate possible means to increase the load-carrying capacity
- Accounting for the progress in reinforcement techniques

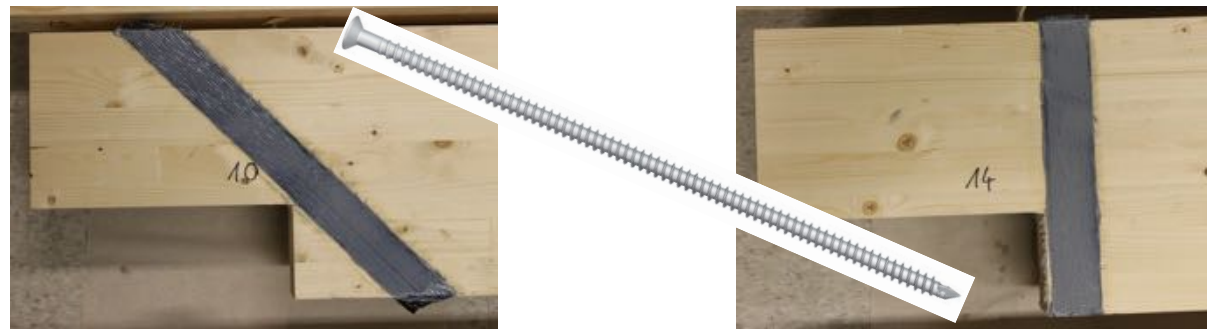


Tests on notched beam

Material



- Aim: Influence of angle of reinforcement on load carrying behaviour
- Tested at Linnaeus University in Växjö, Sweden
- Glulam
 - 10 beams $b/h = 90/315$ mm Strength grade L40
- Reinforcement:
 - Self tapping screws:
SFS WRT-13 $d = 13$ mm $l = 400$ mm 45° and 90°
 - Carbon fibres:
SikaWrap $t = 1$ mm $b = 50$ mm 45° and 90°



Tests on notched beam Measurements



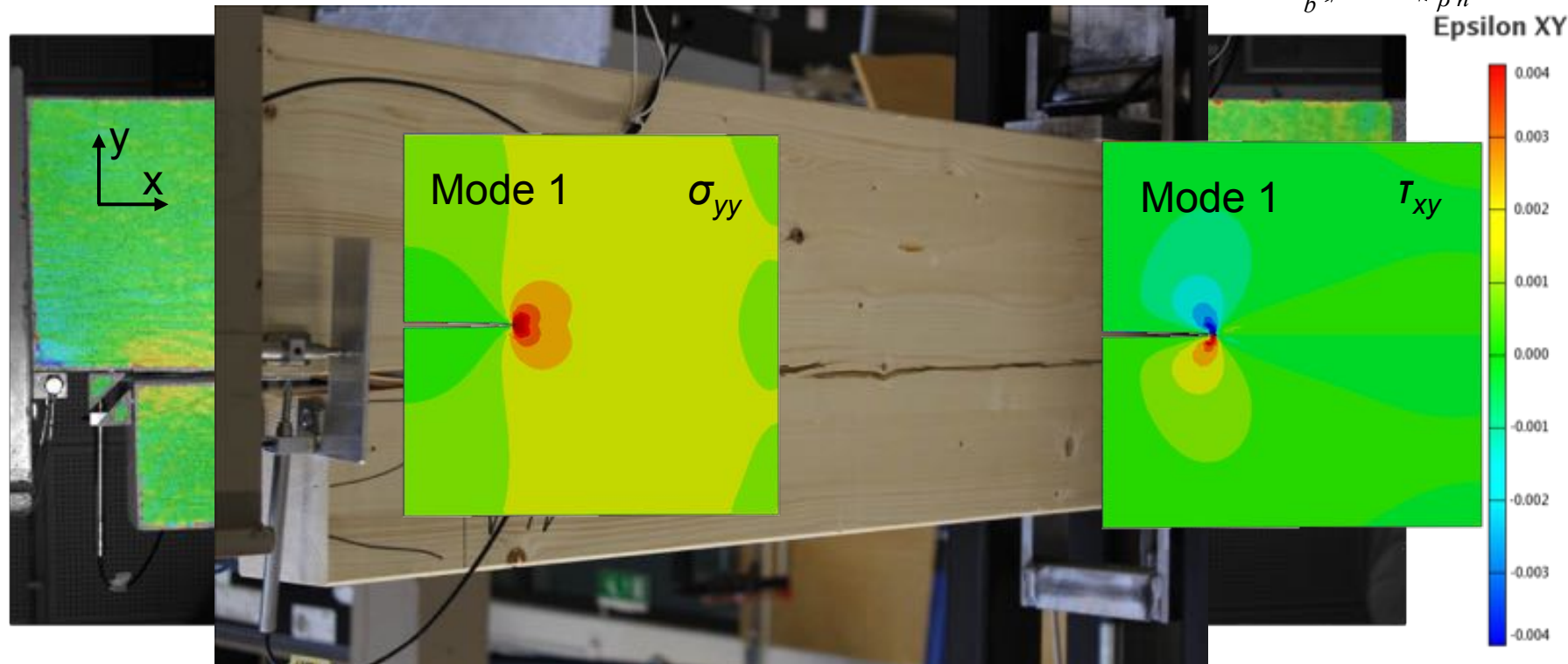
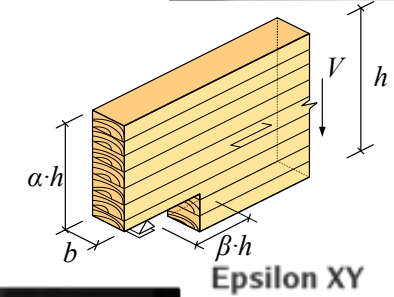
- Measuring parameters
 - Crack opening/ shearing
 - ARAMIS deformation measurements
 - Load / deflections



Results ARAMIS



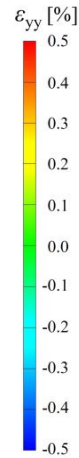
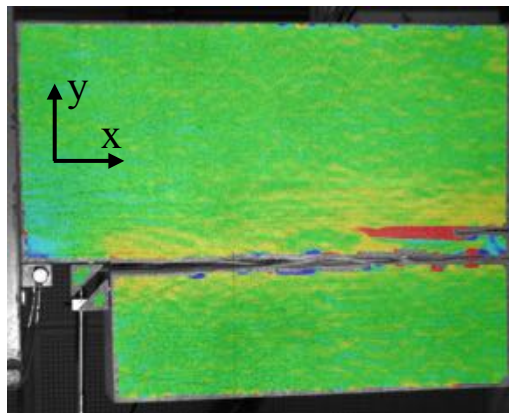
- Unreinforced notch
 - Normal strain perp. to grain
 - Shear strain



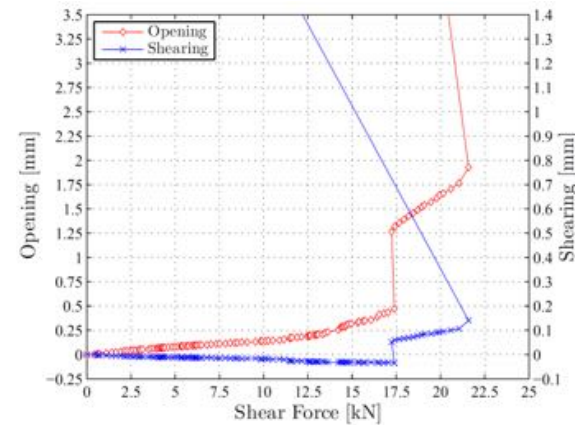
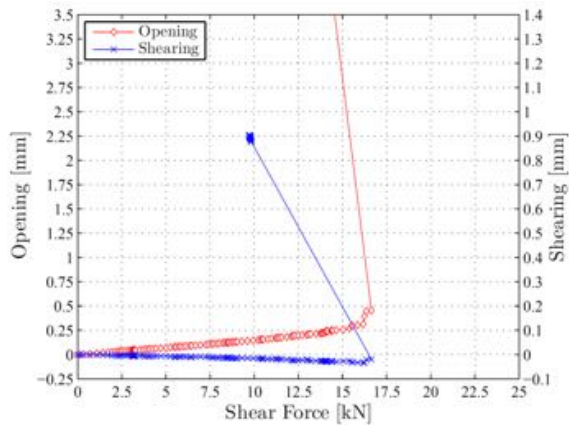
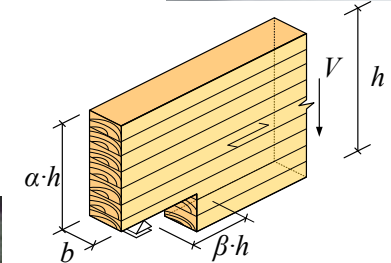
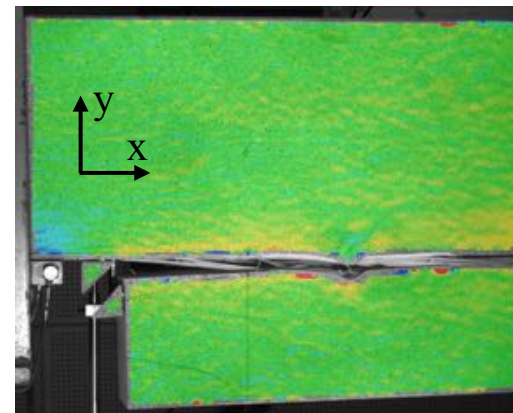
Results ARAMIS



- Normal strain perp. to grain
 - clear crackpath



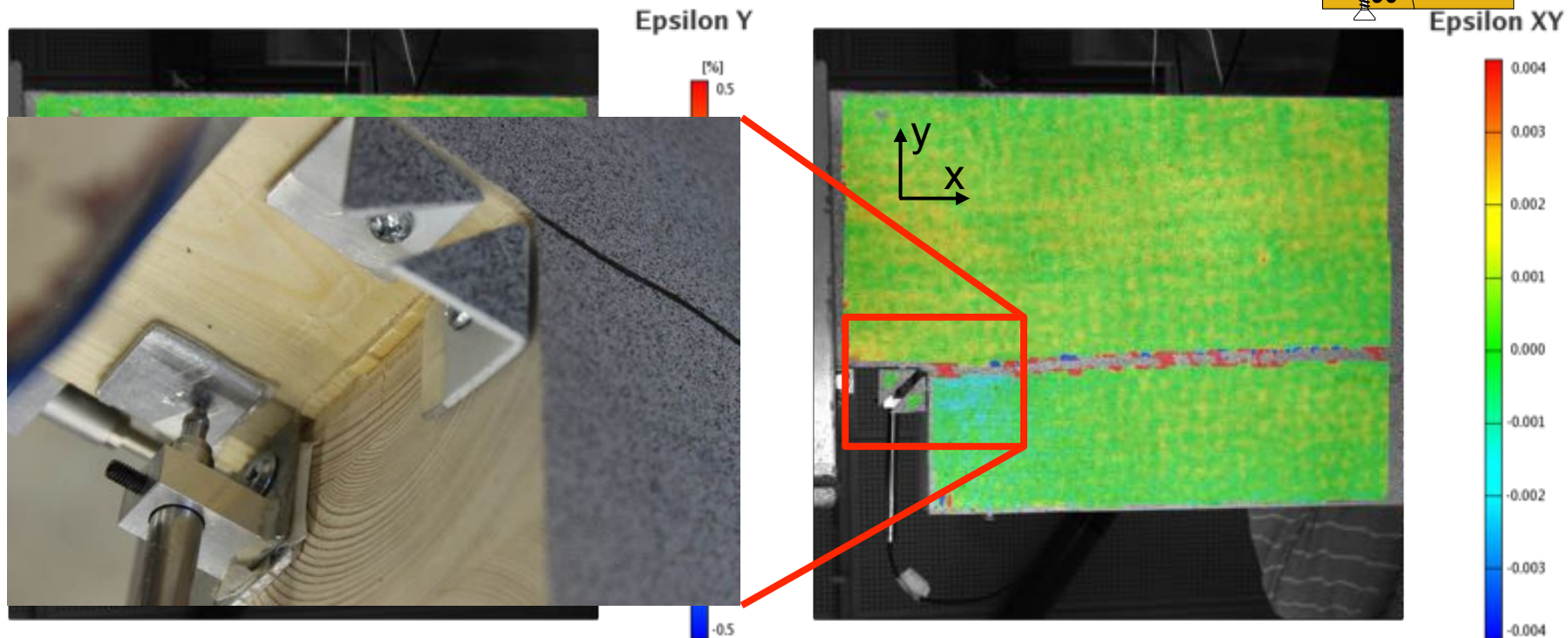
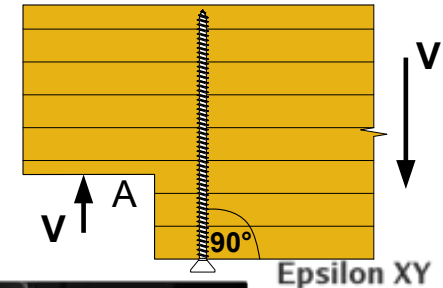
- knot



Results ARAMIS



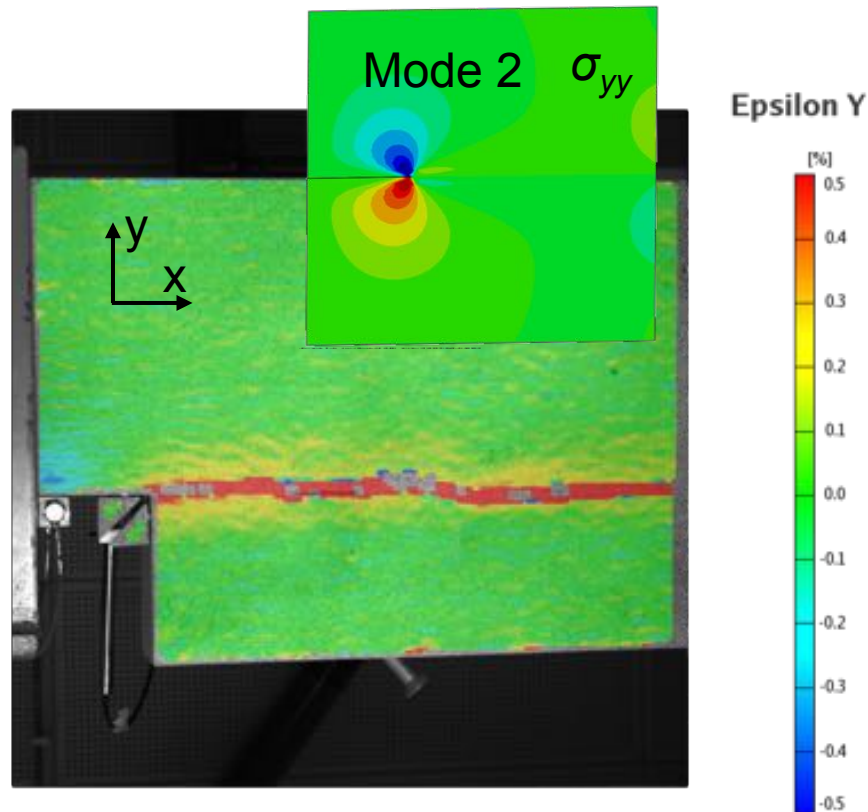
- Reinforced notch: Screw 90°
 - Normal strain perp. to grain
 - Shear strain



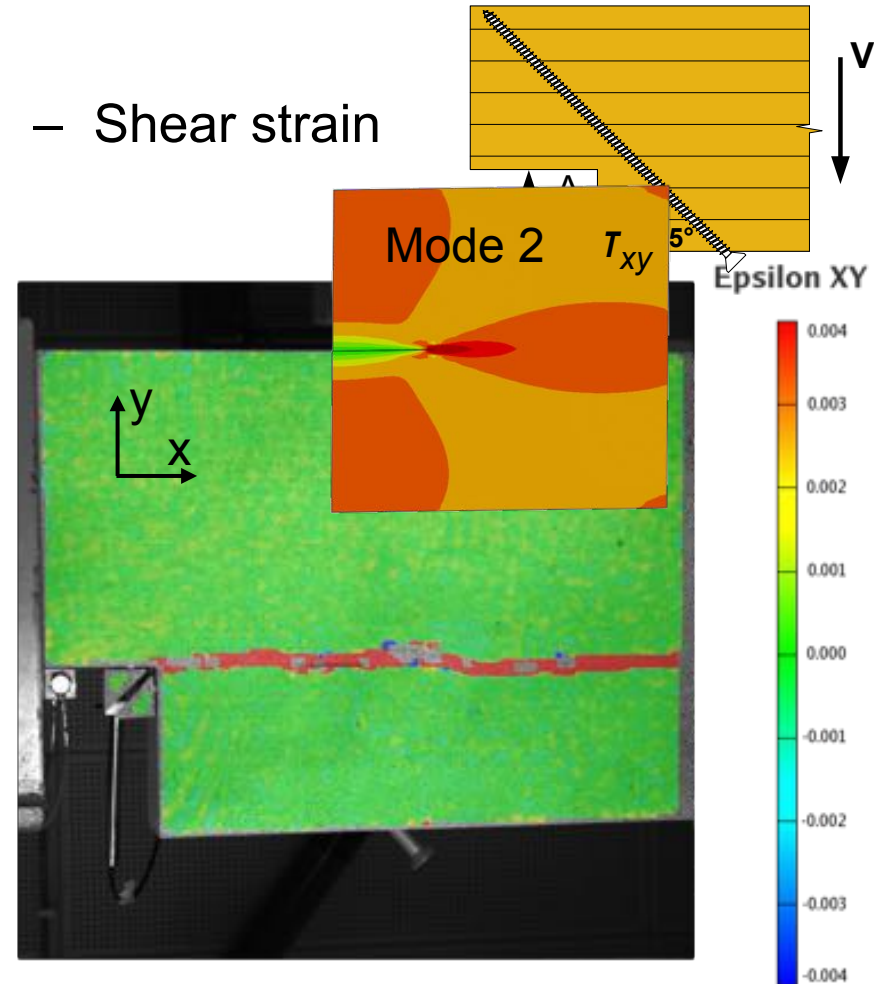
Results ARAMIS



- Reinforced notch: Screw 45°
 - Normal strain perp. to grain



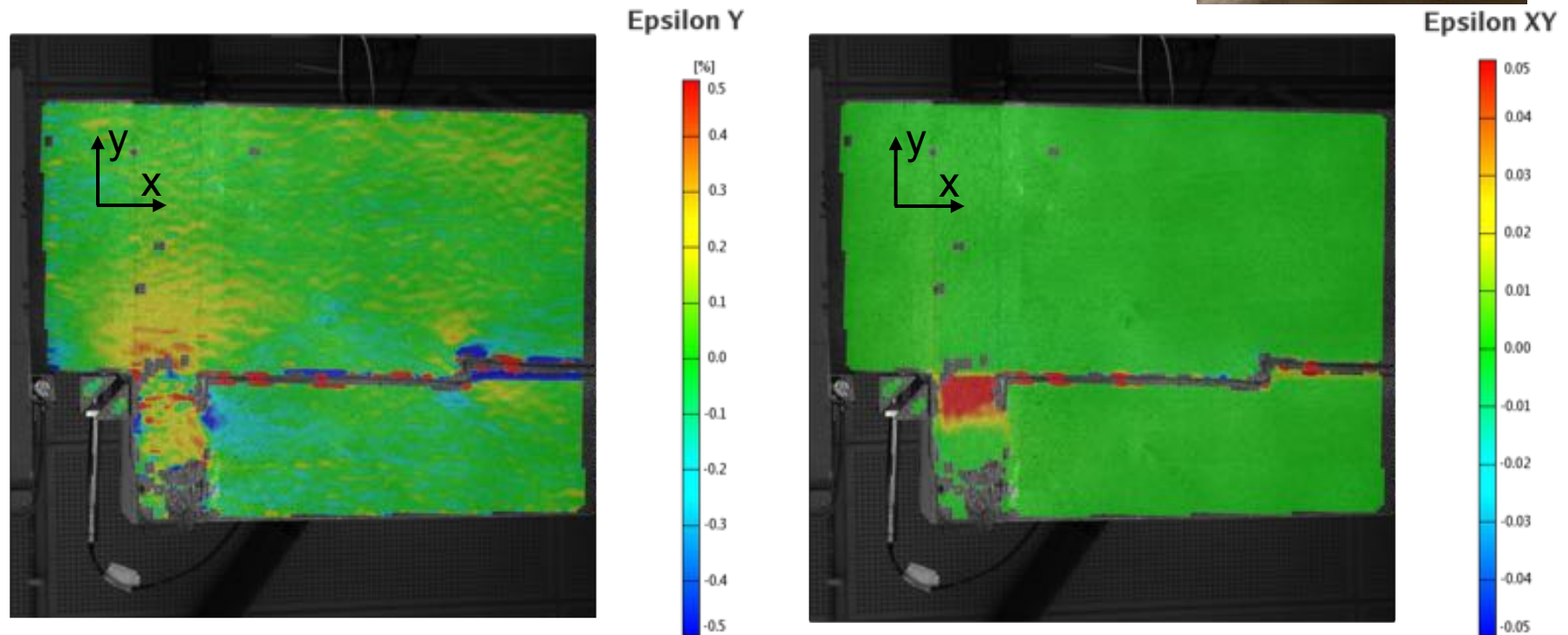
- Shear strain



Results ARAMIS



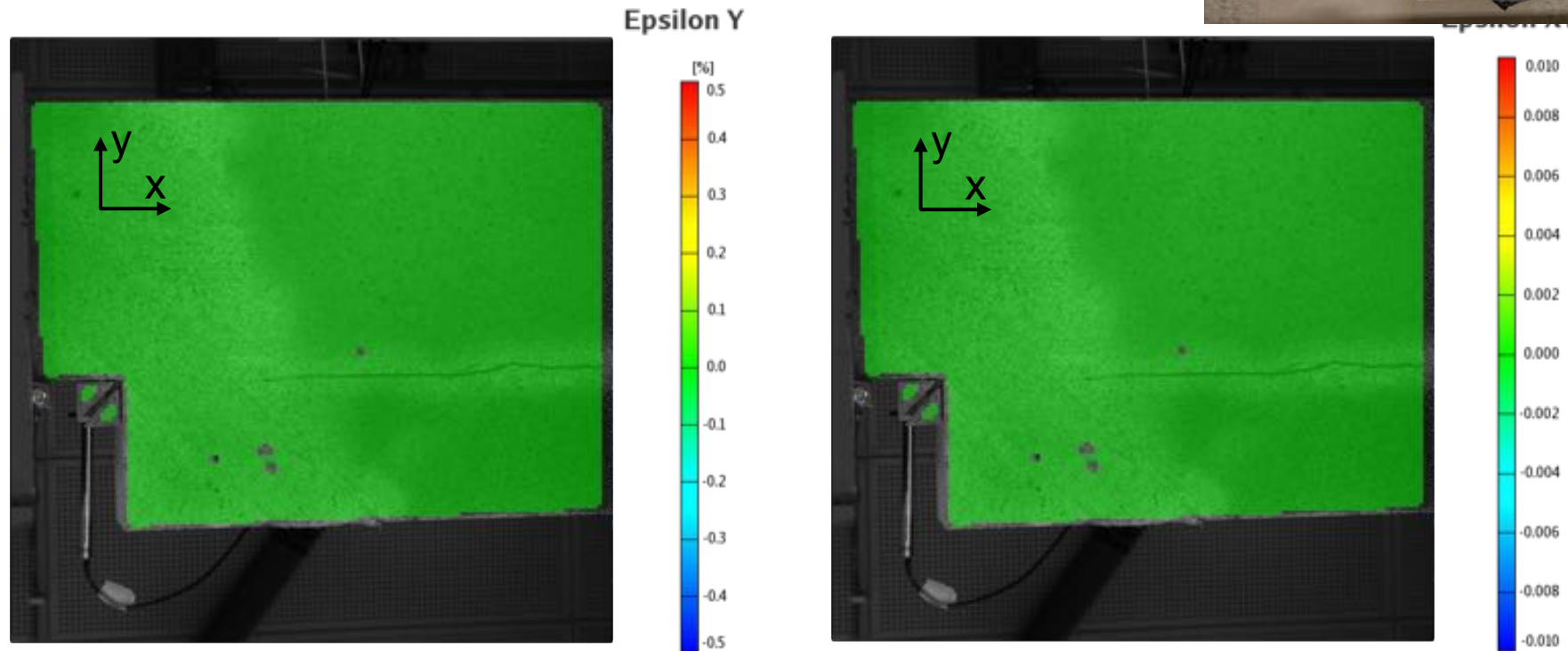
- Reinforced notch with existing crack: CFR 90°
 - Normal strain perp. to grain
 - Shear strain



Results ARAMIS

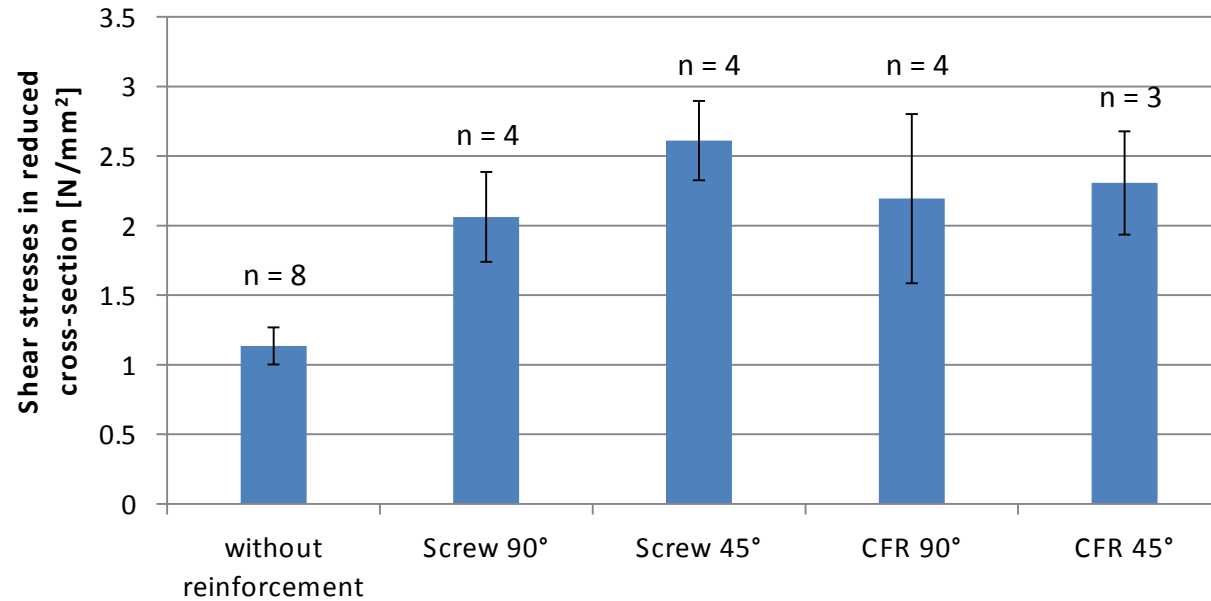


- Reinforced notch with existing crack: CFR 45°
 - Normal strain perp. to grain
 - Shear strain



Results

Load-carrying capacities



- Considerably higher capacities of reinforced notches
- Tendentially higher capacities of inclined reinforcement

Results

Estimated capacities



- without reinforcement:
Gustafsson (EN 1995-1-1:2004)

$$\frac{V}{b\alpha h} = \frac{\sqrt{G_{f,I}}}{\sqrt{h \left(\sqrt{0.6(\alpha - \alpha^2) / G_{xy}} + \beta \sqrt{6 \left(\frac{1}{\alpha} - \alpha^2 \right) / E_x} \right)}}$$

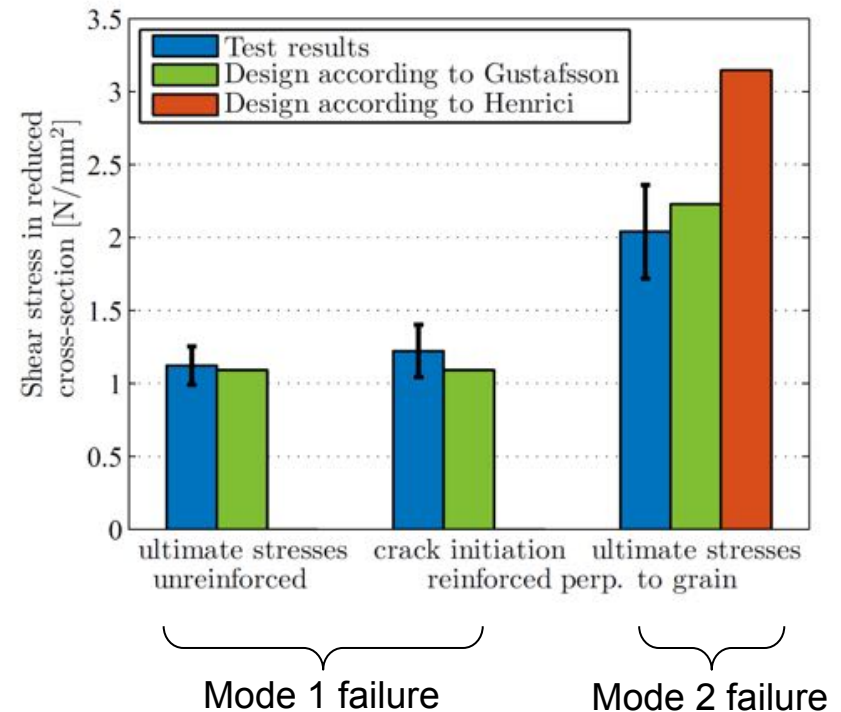
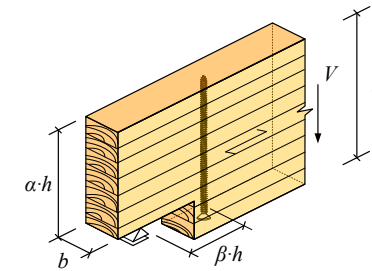
- reinforced perp. to grain:
Henrici (DIN 1052:2008)

$$\frac{V}{b\alpha h} = \frac{F_{t,90,Rd}}{1.3(3(1-\alpha)^2 - 2(1-\alpha)^3) b\alpha h}$$

➔ Early failure in shear $\sqrt{\frac{G_{f,II}}{G_{f,I}}} \approx 2$

Load-carrying capacity of notches reinforced perp. to grain is limited to:

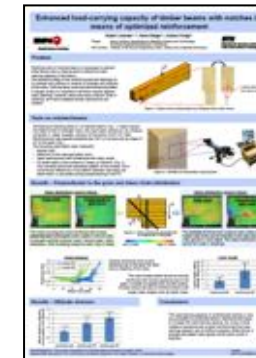
$$V_{f,Mode II} \approx 2 \cdot V_{f,Mode I} = 2 \cdot \frac{2}{3} k_v f_v b\alpha h$$



Outcomes



- Publication of the results
 - STSM report
 - Dissertation
 - Poster: COST-FTP Young Researchers Forum
 - CIB-W18 Paper
 - Korrigenda for Swiss standard SIA 265:2012
- Ongoing collaboration between ETH/Empa and Lund/LNU!
- Outlook
 - Recommendations for EC 5



46th CIB-W18 Meeting, 26 to 29 August 2013, Vancouver, Canada

Enhanced design approach for reinforced notched beams

96	D.3.1	T	Rechteckige Ausklinkungen gemäss Figur 12 sind zu verstärken, wenn der Nachweis gemäss Gleichung (57) nicht erfüllt ist.	Rechteckige Ausklinkungen gemäss Figur 12 sind zu verstärken, wenn der Nachweis gemäss Gleichung (57) nicht erfüllt ist. Wird die Ausklinkung gemäss Gleichung (141) verstärkt, ist der Tragwiderstand der verstärkten Ausklinkung auf den doppelten Wert des Tragwiderstands der unverstärkten Ausklinkung gemäss Gleichung (57) beschränkt.	XXXX
96	D.3.2 Figur 44	T			XXXX



Thanks to COST FP 1004 for making the STSM possible!



Many thanks to Prof. Erik Serrano and Bertil Enquist from Linnaeus University Växjö for hosting me and helping me performing and analysing the tests!

Thank you for your attention!