COST E55 - 5th Workshop

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A proposal for simulation of crack growth in glulam under sustained loads and moisture variations

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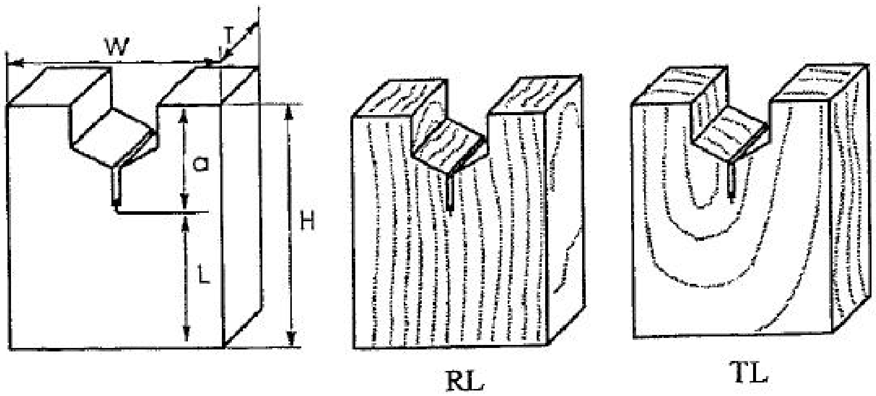
Project: Improved Moisture (WoodWisdom-Net)

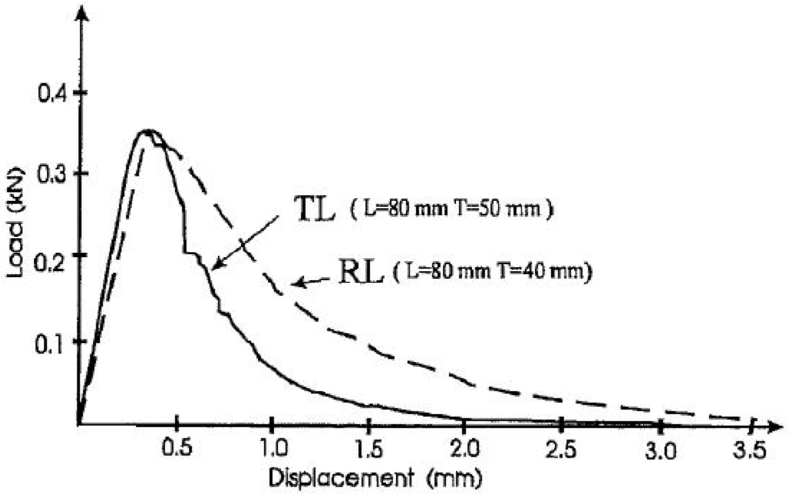
Business from technology

Background

- Viscoelastic creep, mechanosorption and used adhesives can affect the crack propagation in glulam structures.
- Lack of specimens suitable to study crack growth at sustained loads with eventual impact of moisture variation (for both solid wood and glue-lines).
- Relatively few publications on the viscoelastic creep crack growth of wood.

Wedge-splitting specimen, Stanzl-Tschegg, 1995





For T >= 40 mm → no size effect for G_f

G_f (RL) = 240 J/m^2,
G_f (TL) = 150 J/m^2

Experimental curves

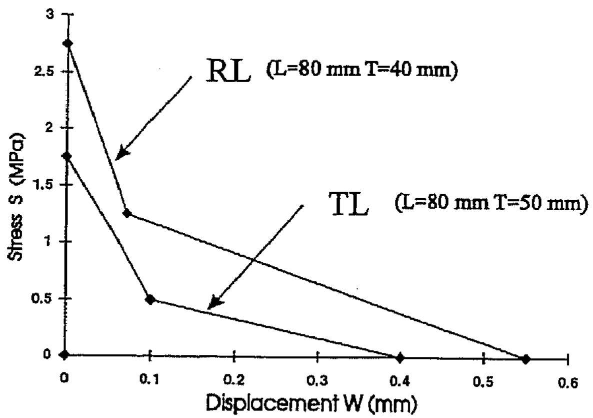


Fig. 15. Bilinear stress-displacement diagrams as obtained with FEM calculations with SOFTFIT/FRACTURE program

Parameters Identification by Abaqus (Zagari & Fortino, 2009)

Tools for the "Parametric identification":

- Abaqus cohesive elements, exponential damage law, Riks analysis
- Abaqus Scripting

Parametric Analysis:

- a certain number of nonlinear analyses for monotonically proportional loads scaled with G_f (experimental fracture energy);
- minimization of the difference between calculated FEM curve and experimental curve (least square approach or more complicated statistical approaches).

Note:

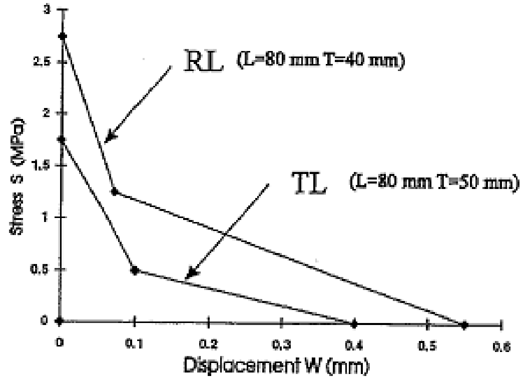
- Experimental load-displacement curves needed.

- Lack of experimental data for glulam.

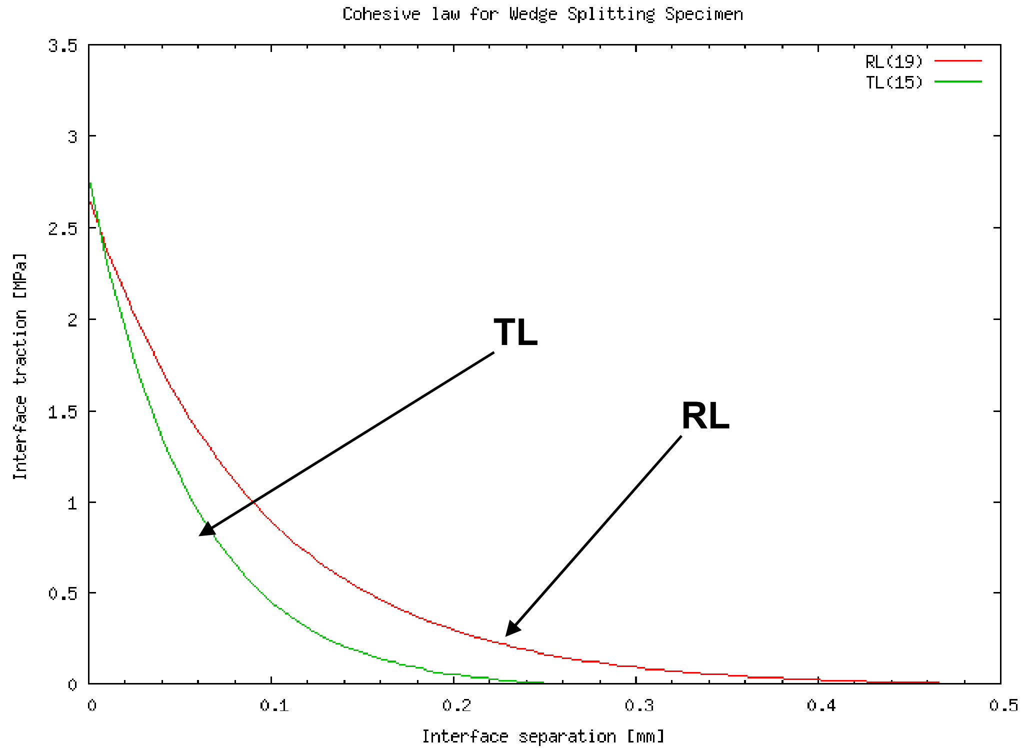
Parametric analysis (Zagari & Fortino, 2009)

- **Optimal parameters obtained by identification process:**

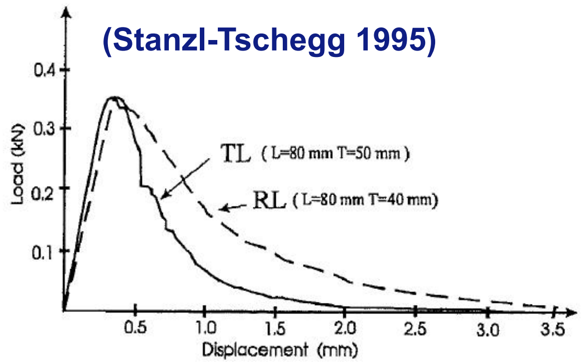
	Tmax [MPa]	*Wmax [mm]*	α	Jcrit [kJ/m^2]
RL	$2.66 \cdot 10^6$	0.49	5.34	0.240
TL	$2.66 \cdot 10^6$	0.25	4.53	0.150

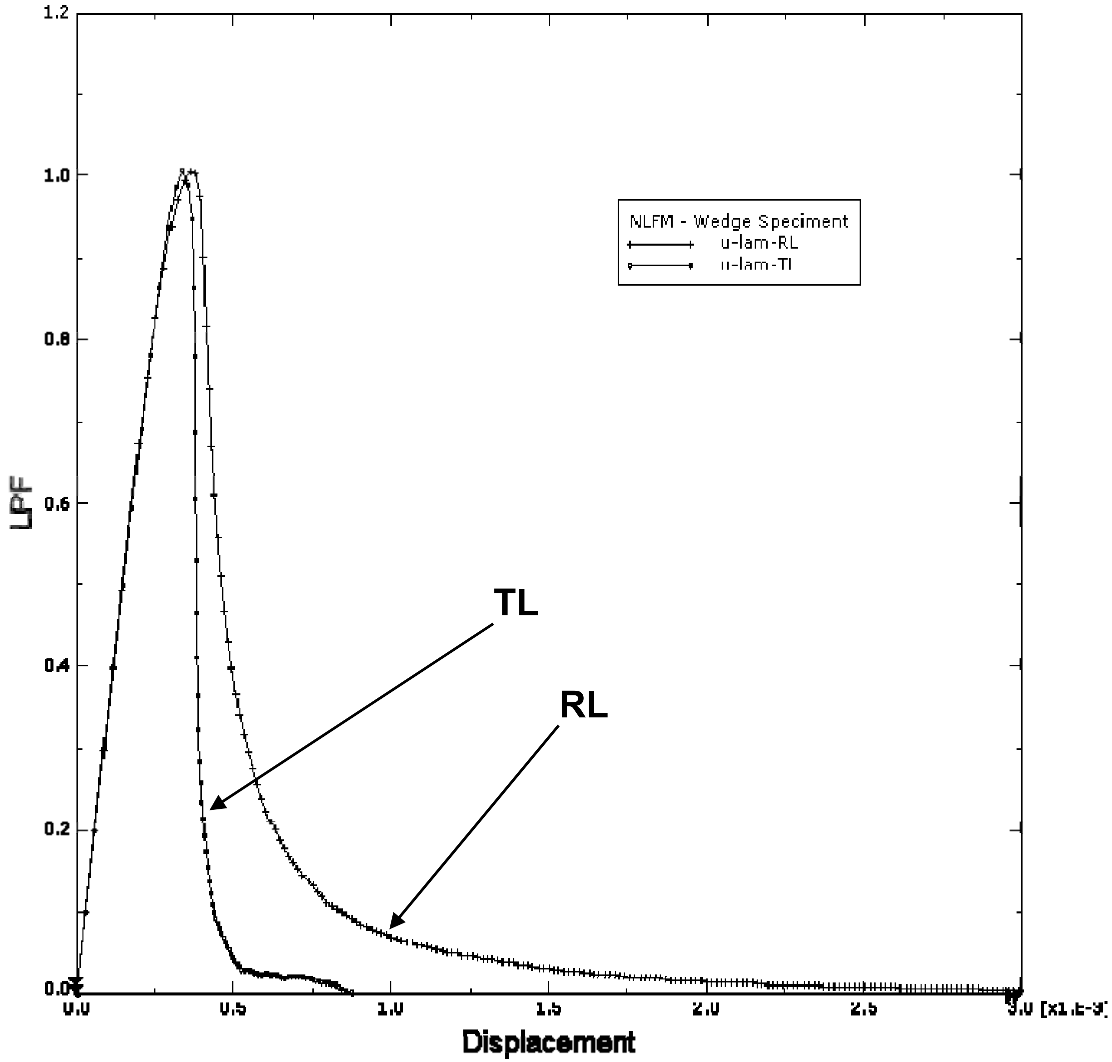


(Stanzl-Tschegg 1995)

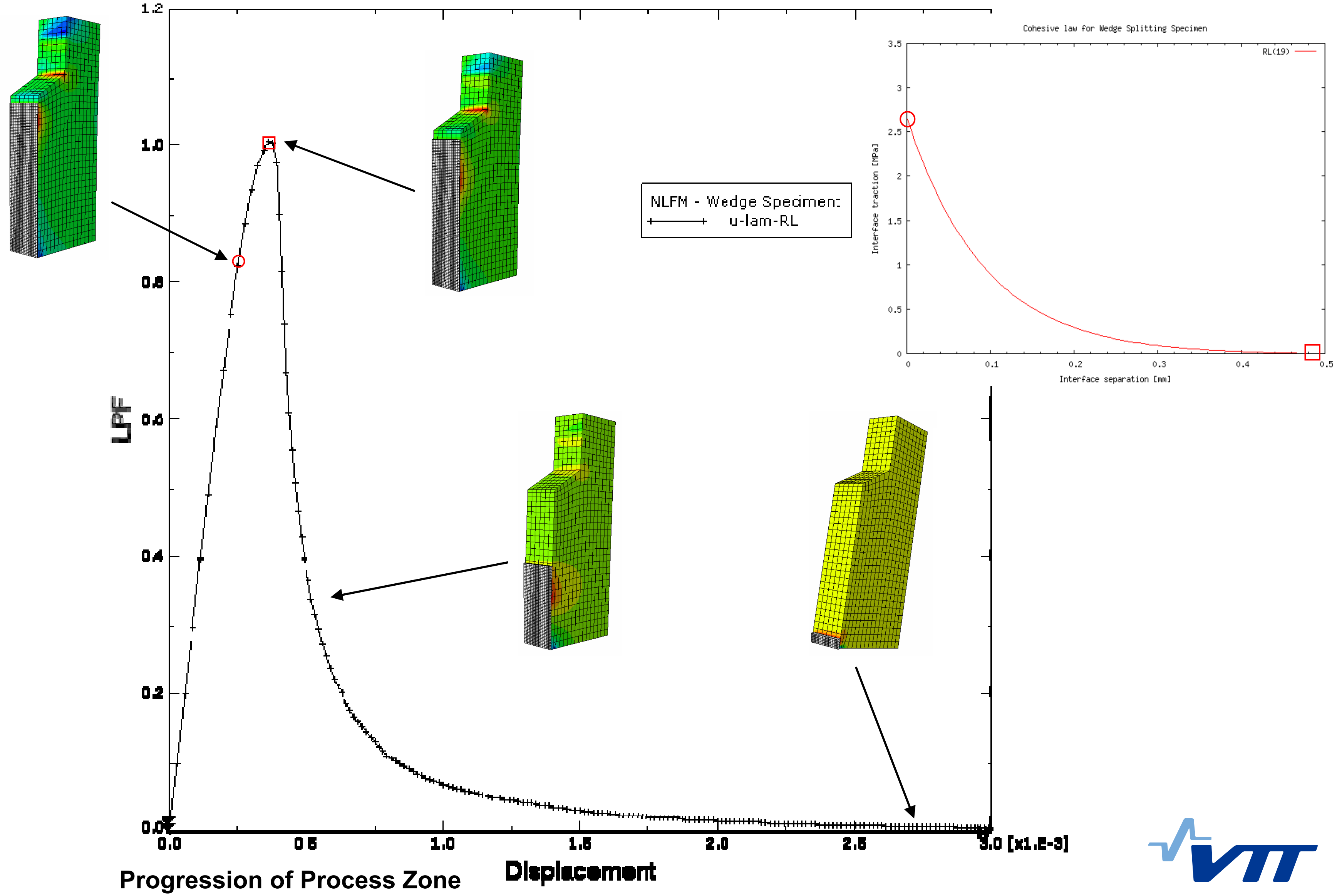


Load-displacement curve in NLFM



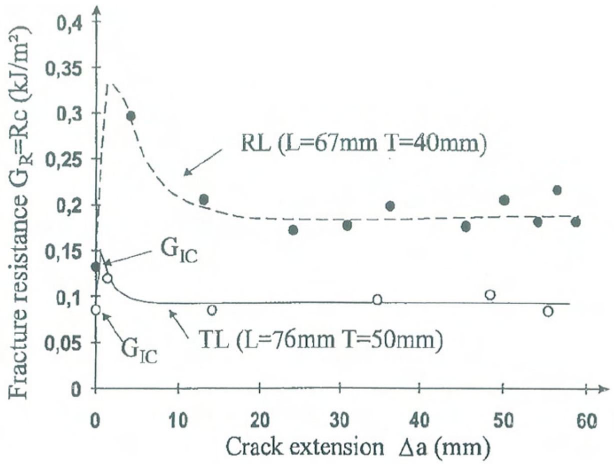


Opening of the wedge-splitting specimen during loading

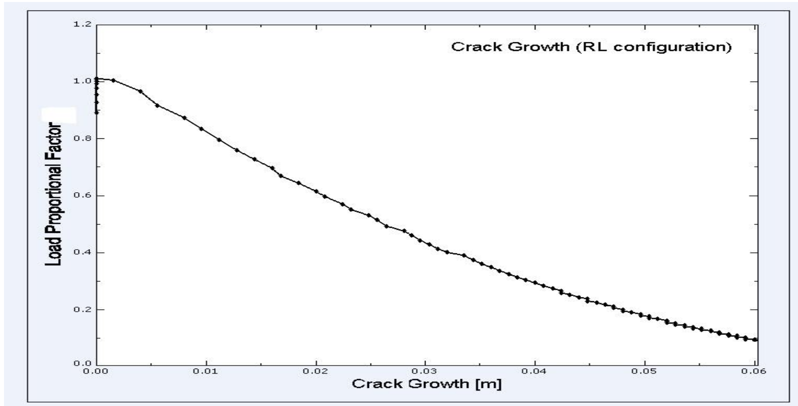


Progression of Process Zone

J integral-crack growth curve (R-curve)

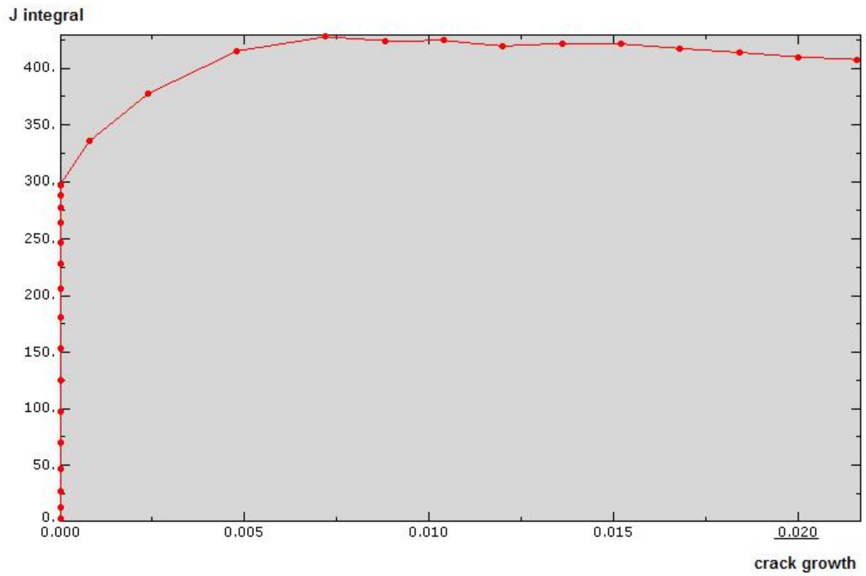


Stanzl (1996), computational curves



LPF-Crack Growth curve

Note: curves obtained by using Abaqus Scripting tools:
new J-integral calculation for each equilibrium point in LPF-CrackGrowth curve.



RL configuration: Computational curve (qualitative)

Crack initiation - Viscoelastic J integral

Constant moisture conditions

- Mechanical strain:

$$\varepsilon^{ve}_{mech} = \varepsilon^{e} + \sum_{i=1}^{p} \varepsilon_i^{ve}$$

- Viscoelastic path–independent integral J_{ve}:

$$J_{ve} = \lim_{\Gamma \to 0} \int_{\Gamma} \left(W_{ve} n_1 - \mathbf{n} \cdot \boldsymbol{\sigma} \cdot \mathbf{u}_{,1} \right) d\Gamma$$

where W_{ve} is the stress work:

$$W_{ve} = \sigma \, d\varepsilon^{ve}_{mech}$$

Crack initiation - Mechanosorptive J integral

Varying moisture conditions

- Mechanical strain:

$$\varepsilon_{mech}^{ve,ms} = \varepsilon^{e} + \sum_{i=1}^{p} \varepsilon_{i}^{ve} + \sum_{j=1}^{q} \varepsilon_{j}^{ms} + \varepsilon^{ms,irr}$$

- Strain due to hygroexpansion:

$$\varepsilon_{u} = \alpha \dot{\mathbf{u}}$$

- Viscoelastic–mechanosorptive path–independent integral $J_{ve_{m}s}$:

$$J_{ve,ms} = \lim_{\Gamma \to 0} \int_{\Gamma} \left(W_{ve,ms} n_1 - \mathbf{n} \cdot \boldsymbol{\sigma} \cdot \mathbf{u}_{,1} \right) d\Gamma$$

where $W_{ve,ms}$ is the stress work:

$$W_{ve,ms} = \boldsymbol{\sigma} d\varepsilon_{mech}^{ve,ms}$$

Implementation of the generalized J integral

Generalized J integral (Shih, 1986)

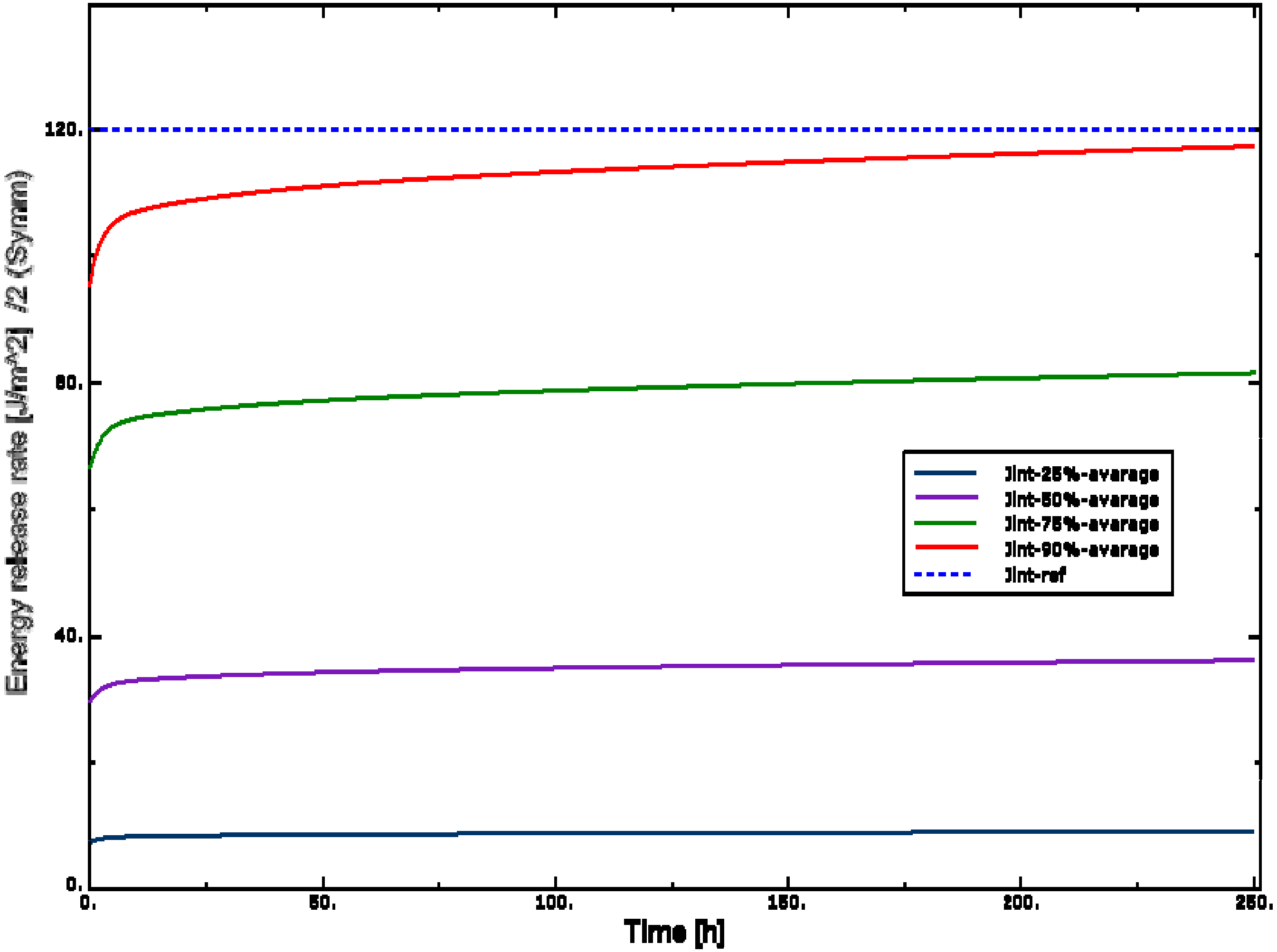
- By rewriting the viscoelastic–mechanosorptive path integral on a domain through the divergence theorem, the part including the hygroexpansion furnishes a path dependent integral (!)
- A correction integral has to be added (see Meith et al., 2002). This correction is done in Abaqus.
- Abaqus/Umat: stress increment at the current time step without the hygroexpansion strain increment:

$$\Delta\boldsymbol{\sigma}_{k+1} = \mathbf{C}_{\mathrm{T}} : (\Delta\varepsilon_{k+1} - \cancel{\Delta\varepsilon^{u}_{k+1}} - \Delta\varepsilon^{ms,irr}_{k+1} + \sum_{i=1}^{n} \mathbf{R}^{ve}_{i,k} + \sum_{j=1}^{m} \mathbf{R}^{ms}_{j,k})$$

Tangent operator of the model:

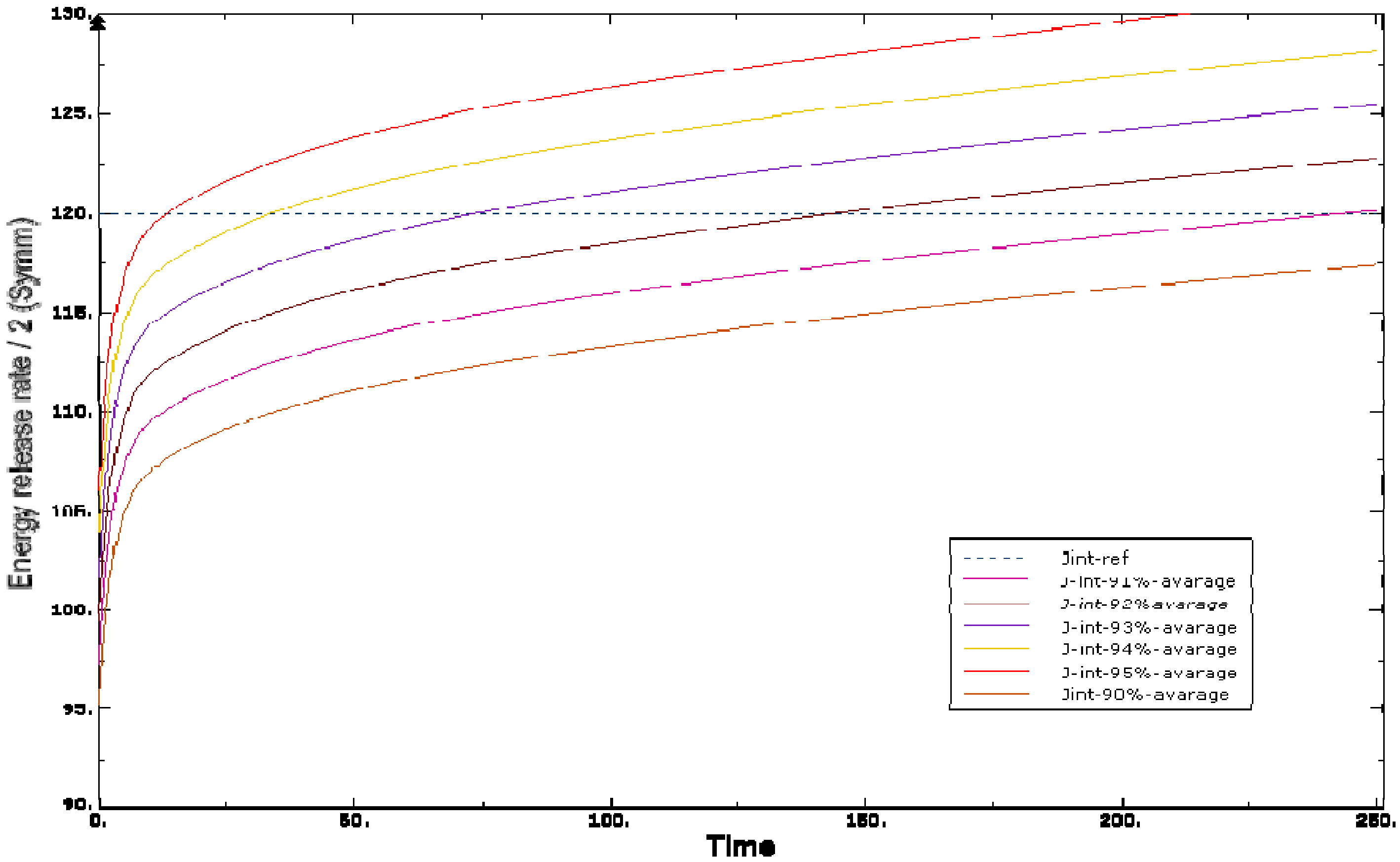
$$\mathbf{C}_{\mathrm{T}} = \left(\mathbf{C}^{e-1} + \sum_{i=1}^{k} \mathbf{C}_{i}^{ve-1} + \sum_{j=1}^{m} \mathbf{C}_{j}^{ms-1} \right)^{-1}$$

Viscoelastic J integral for constant load ($P<P_{crit}$)



Calculation of the "critical time" ---> onset of crack propagation: reaching of the elastic fracture energy value?

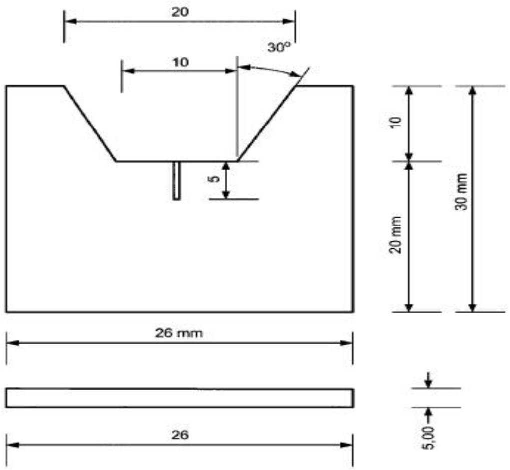
Viscoelastic J integral for constant load ($P<P_{crit}$)



The elastic fracture energy and the "critical times" are reached for values of P near to $P_{crit.}$

Full model for varying moisture cases: critical time and critical moisture during a moisture varying process

Micro wedge-splitting specimen – Vasic and Stanzl_Tschegg (2007)



Geometry of the micro-wedge-splitting specimens.

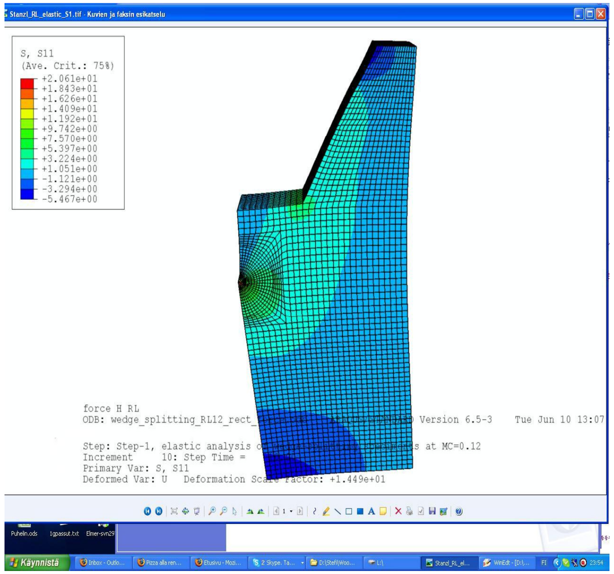


Table 3 Characteristic parameters for *ex situ* experiments in the RL and TR directions at 65% RH. MC=12%

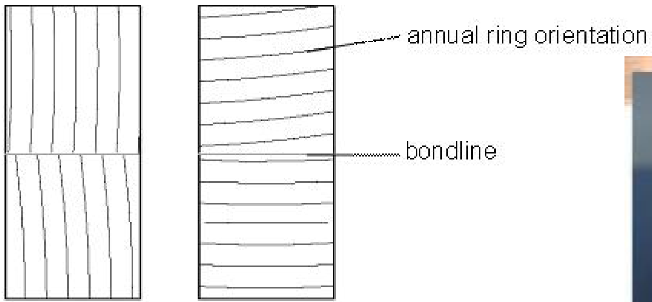
M	F_{max} [N]	s_{max} [μm]	k_{init} [N mm^{-1}]	G_f [N m^{-1}]	G_{Ic} [N m^{-1}]	K_{Ic} [kN m$^{-3/2}$]
RL						
Spruce	68.52 (14.1%)	348 (69.8%)	269.5 (55.2%)	261.49 (13.1%)	241.49 (14.1%)	464.98 (7%)
Pine	54.19 (11.9%)	401 (65.8%)	216.2 (77.9%)	247.78 (26.6%)	190.97 (11.9%)	413.71 (6%)
Beech	141.14 (21.6%)	186 (65.7%)	1325.6 (21.2%)	495.46 (16.22%)	314.65 (21.6%)	620.96 (10.5%)
Oak	110.07 (11.5%)	123 (46.6%)	1187.04 (65.8%)	369.41 (30.2%)	245.4 (11.5%)	550.25 (5.8%)
TR						
Spruce	35.01 (17.8%)	1515 (19%)	24.02 (28.7%)	429.38 (19.3%)	418.62 (17.8%)	328.67 (8.6%)
Pine	64.91 (40.5%)	1726 (37.2%)	37.2 (11.1%)	923.55 (57.7%)	550.22 (40.5%)	364.15 (24.6%)
Beech	84.47 (16%)	612 (12.9%)	141.89 (25.7%)	955.64 (35.1%)	681.9 (16%)	507.22 (7.9%)
Oak	70.38 (15.7%)	648 (89.4%)	226.21 (77.4%)	322.83 (26.8%)	228.7 (15.7%)	293.76 (7.8%)

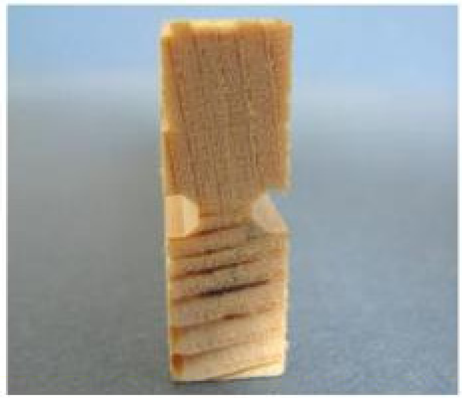
Results are presented as mean (COV).

Vasic and Stanzl-Tschegg (2007)

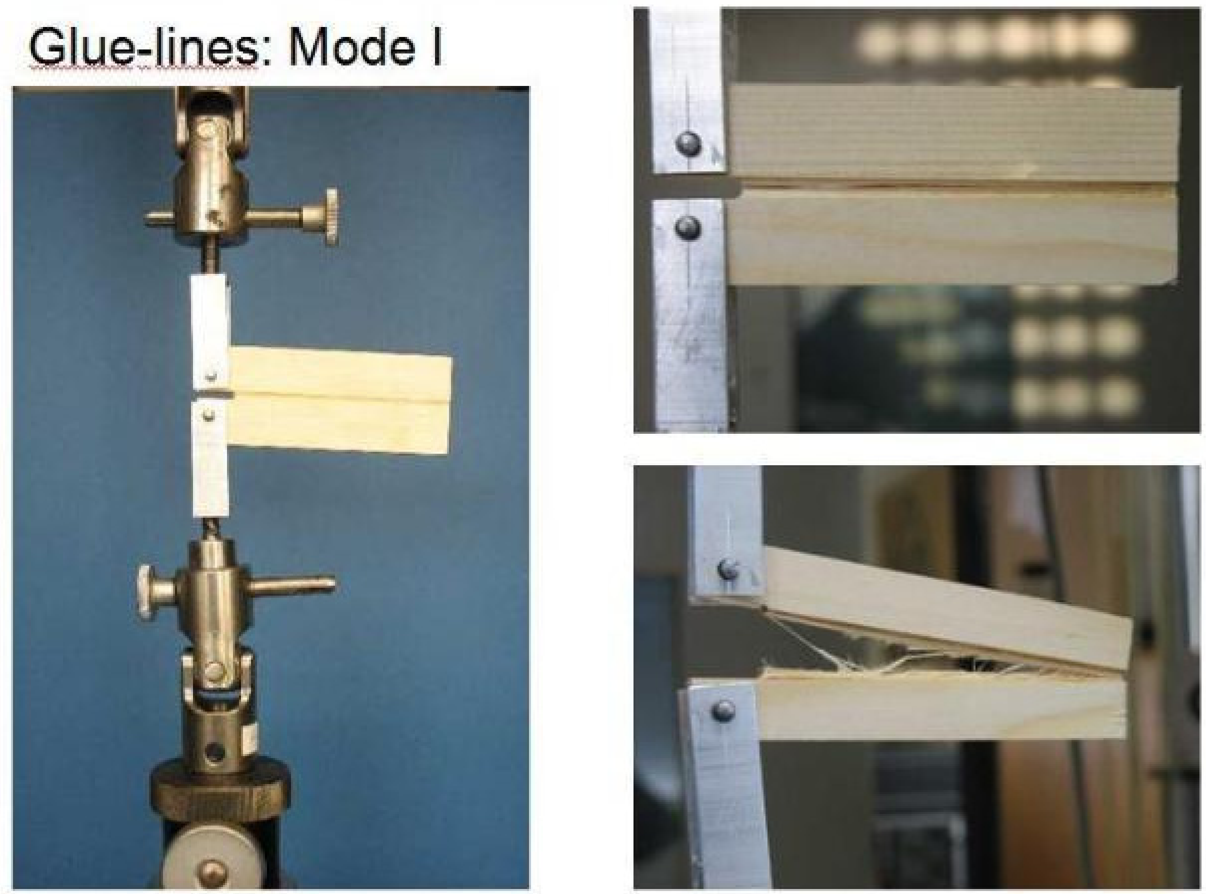
Applications of the proposed method to glulam

- **Modified DCB-specimen, Mode I (MPA, Germany).**
- **Modelling of the the glue through cohesive elements.**
- **Definition of a damage model per each glue on the basis of its energy fracture. NLFM analysis.**

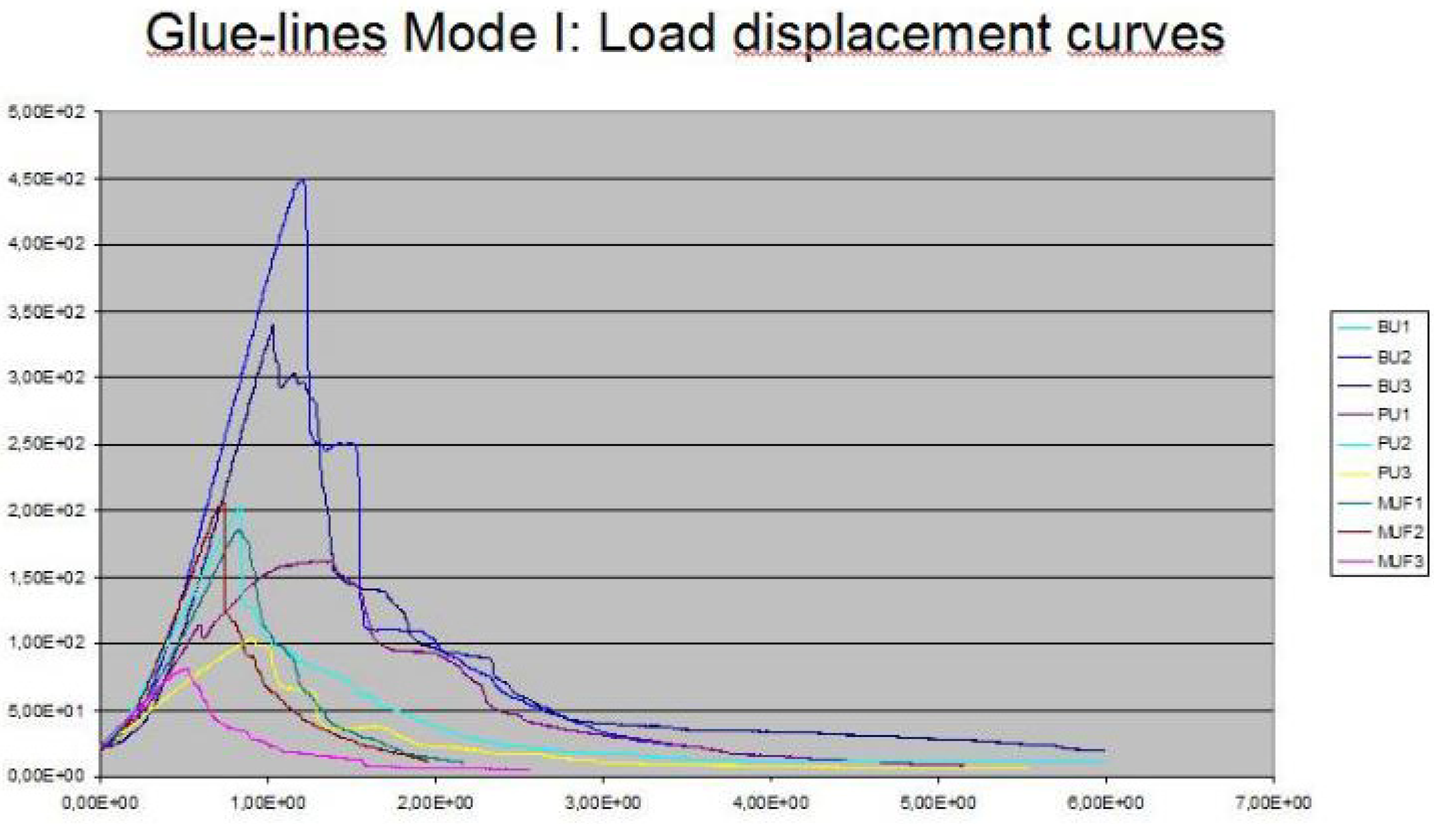




Modified DCB specimen - Short term test



Modified DCB specimen - Short term test



Conclusions and Future work

Conclusions on crack initiation modelling:

- Importance of the viscoelastic and mechanosorptive models of wood for calculating the critical time (and the critical moisture) at the onset of crack propagation. Interesting theoretical results in terms of generalized J integral.
  Difficulty to perform experimental tests.

Future work on crack propagation:

- Simulation of crack growth under sustained loads: viscoelastic model for wood and cohesive elements.
- Simulation of crack growth under varying moisture content: viscoelastic-mechanosorptive model and cohesive elements.
- Definition of suitable damage models in both cases starting from the elastic ones already proposed. Transient analysis.
- Experimental work: application of sustained load and/or moisture variation after the initiation of crack growth. Long-term tests.