Methodology to simulate veneer-based structural components for static and crash load cases

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DLR

DLR – Overview

Locations

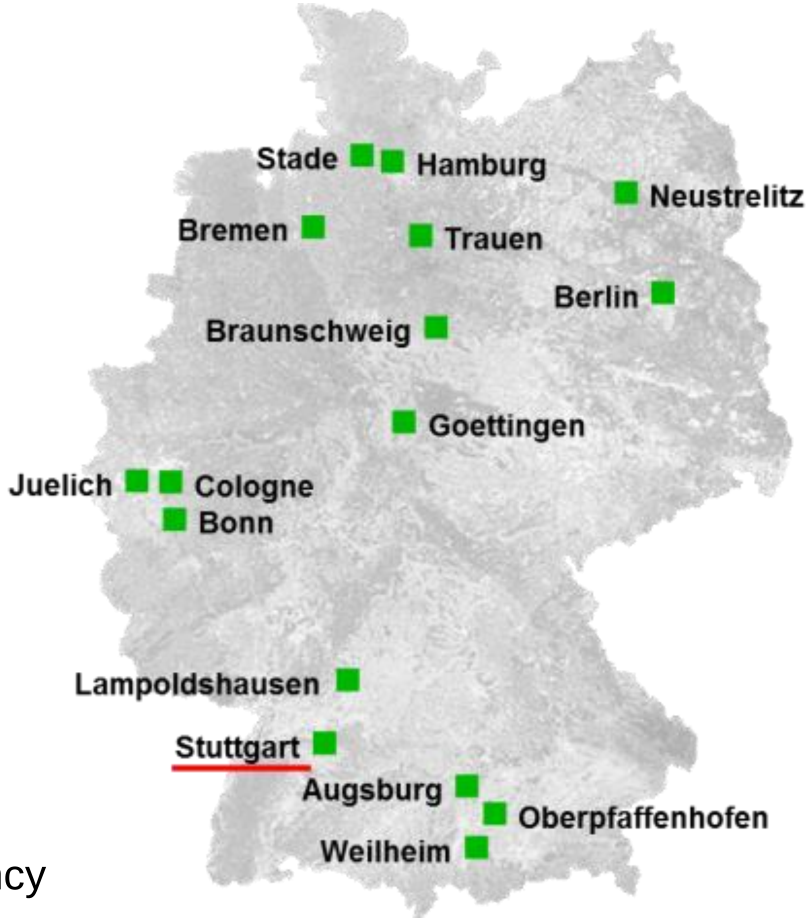
- Approx. 8000 employees across 33 institutes and facilities at 16 sites
- Offices in Brussels, Paris, Tokyo and Washington

Research Areas

- Aeronautics
- Space Research and Technology
- **Transport**
- Energy
- Defence and Security

In addition

- Space Administration
- Project Management Agency



Outline

- Introduction
- Properties of veneer-based components
- Modelling of veneer-based layered composites
  - Material Model *MAT_054
  - Layered composites
- Simulation of generic veneer-based components
  - Calibration of intralaminar behavior
  - Validation of simulation and material model
  - Expansion of dynamic behavior
- Summary and outlook

Introduction
Project "For(s)tschritt"

Project duration:

- March 2017 – August 2020 (3.5 years)

Project content:

- **Development of veneer-based hybrid materials for vehicle structures**
    - Road vehicles
    - Rail vehicles
- Development, testing and **simulation**
- Demonstrators
  (Front Door, Train Door, Train Side Panel)

Goal

- Qualification of wood for the usage in vehicle structures

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Introduction
Motivation to use beech-based materials in structural components

Requirements:
- Lightweighting due to emission guidelines
- Reduction of GWP during production phase

Advantages of beech:
- Very good specific material characteristics especially for bending load cases (Ashby [1])
- Ecological with low CO_2-emissions
- High availability and renewable
- Economical
- High flexibility regarding production technologies

Challenges:
- Scatter of material characteristics
- Protection from environmental influences needed

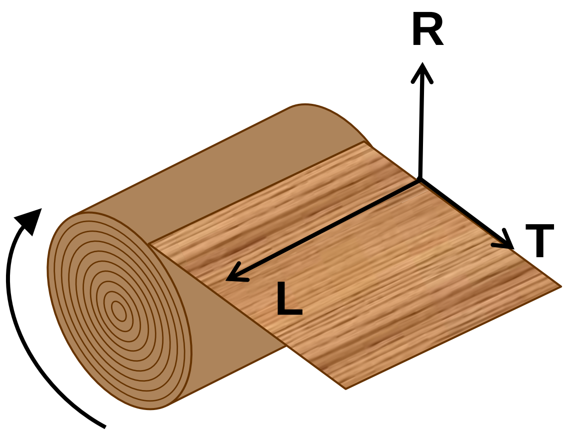
Technical and economic comparison of materials [2] [3]

Parameter	Density	Young's Modulus	Ultimate strength	Spez. stiffness	Spez. strength
Symbol	ρ	E	UTS	$\frac{E^{1/2}}{\rho}$	$\frac{UTS^{2/3}}{\rho}$
Unit	[g/cm³]	[MPa]	[MPa]	$\frac{MPa^{1/2}}{g/cm^3}$	$\frac{MPa^{2/3}}{g/cm^3}$
Aluminum	2,30-2,80	70.000	45-500	95 - 115	5 - 27
Beech	0,54-0,91	14.350(l)	100-140(l)	132 - 222	24 - 50
CFRP	~1,50	~140.000(l)	~1.700(l)	~250	~95
GFRP	~2,00	~44.500(l)	~1.100(l)	~105	~53
Magnesium	~1,74	45.000	100-300	122	12 - 26
Steel	~7,85	210.000	340-1.800	58	6 - 19

Properties of veneer-based components

Veneer:

- Produced by peeling of stem
- Orthotropic material properties
- Scatter in material characteristics



Longitudinal (∥), Tangential (⊥)
and Radial direction of veneer

Veneer-based layered composites:

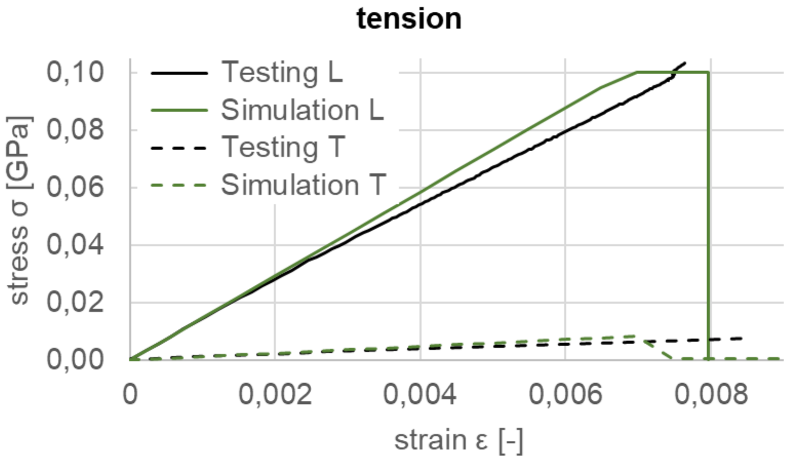
- Multiple veneer layers glued together
- Free selection of orientation, thickness, material of each layer
- Reduction of scatter:
  - Preselection of veneer with little to none imperfections
  - Statistically averaging due to usage of multiple veneers

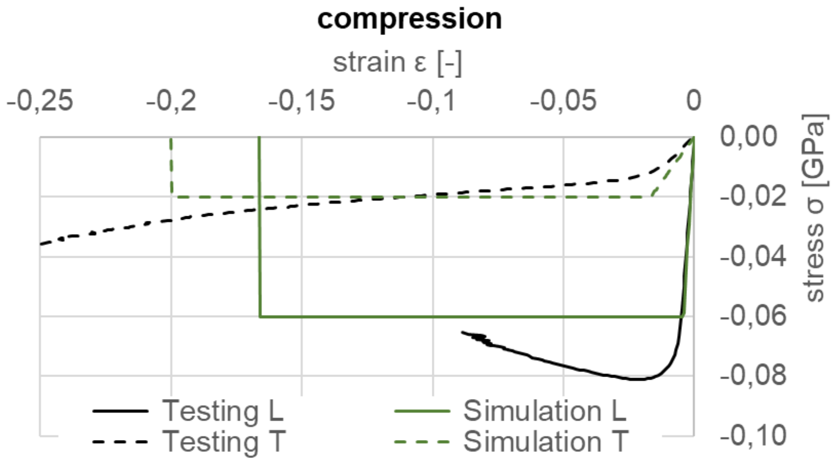
Modelling of veneer-based layered composites
Material Model

- FEM-Solver LS-Dyna

- **MAT_ENHANCED_COMPOSITE_DAMAGE (*MAT054)* [4]
  - Orthotropic material model
  - Failure Modell after Chang/Chang or Hashin

- Comparison with data from testing shows:
  - UTS and failure strain in tension ∥ met quite well
  - UTS and failure strain in tension ⊥ met quite well
  - UTS in compression ∥ met quite well
  - UTS in compression ⊥ met quite well
  - But: failure strain in compression ∥ and compression ⊥ is a tradeoff





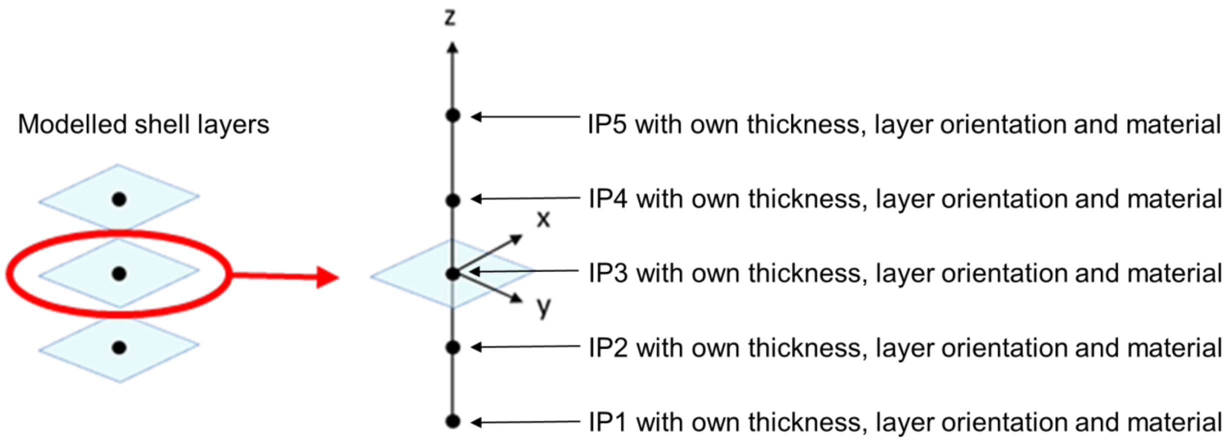
Modelling of veneer-based layered composites
Layered Composites

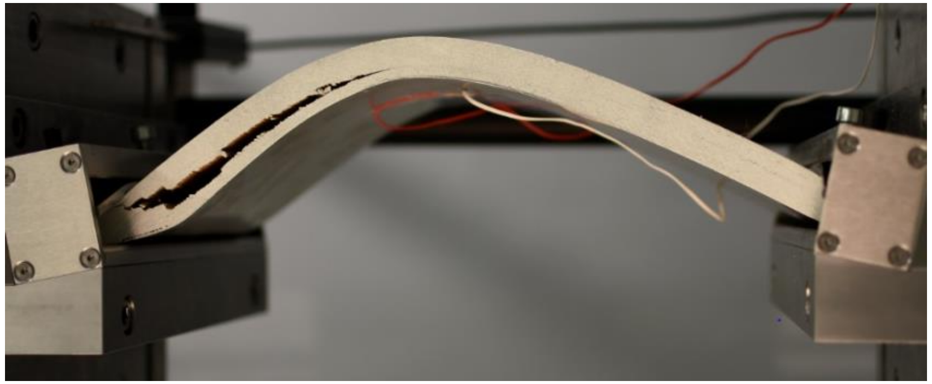
- Delamination in the middle due to exceeding of shear stress possible

→ Component is discretized with 2 Shell-layers or more

- Each shell layer represents a sub-laminate

- Characteristics from true layers stored in numerical integration points (IP)



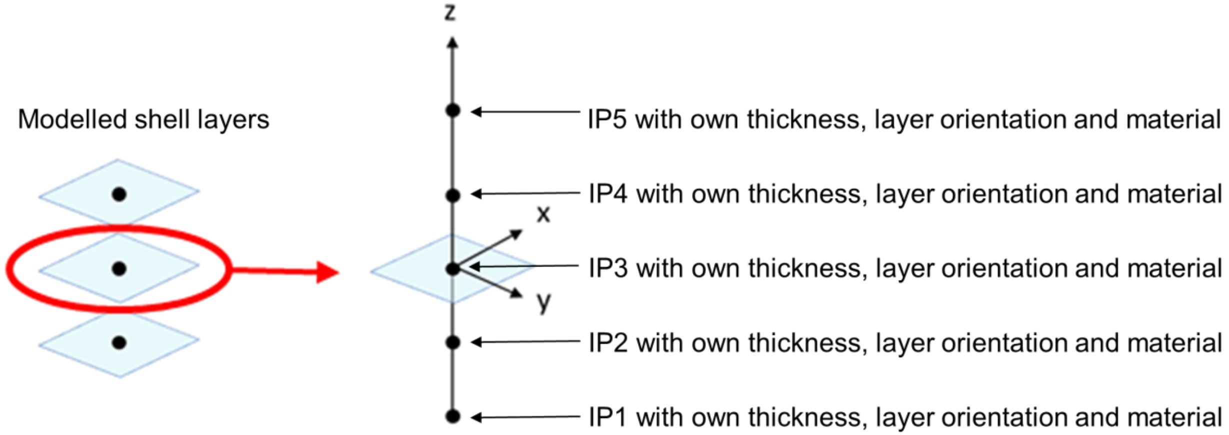


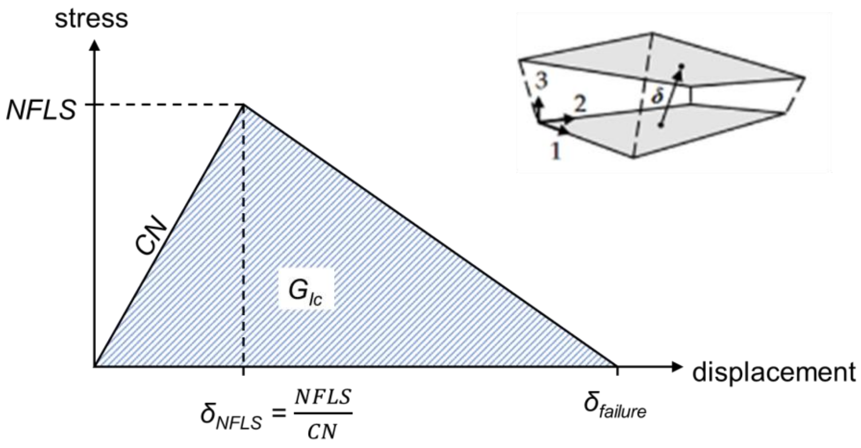
Modelling of veneer-based layered composites
Layered Composites

- Delamination in the middle due to exceeding of shear stress possible

→ Component is discretized with 2 Shell-layers or more

- Each shell layer represents a sub-laminate
- Characteristics from true layers stored in numerical integration points (IP)
- Delamination based on a bilinear traction-separation law



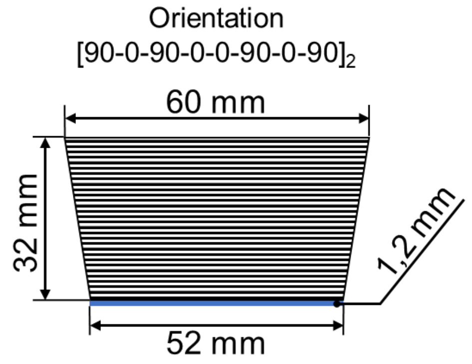


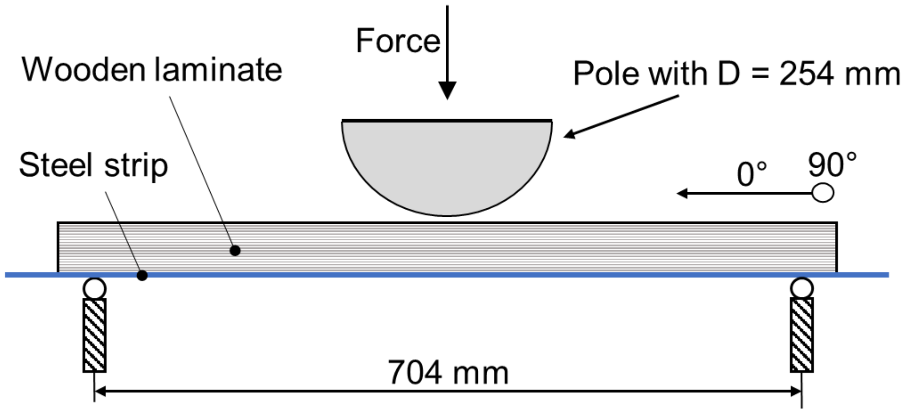
Simulation of veneer-based layered composites
Calibration of intralaminar behavior – setup

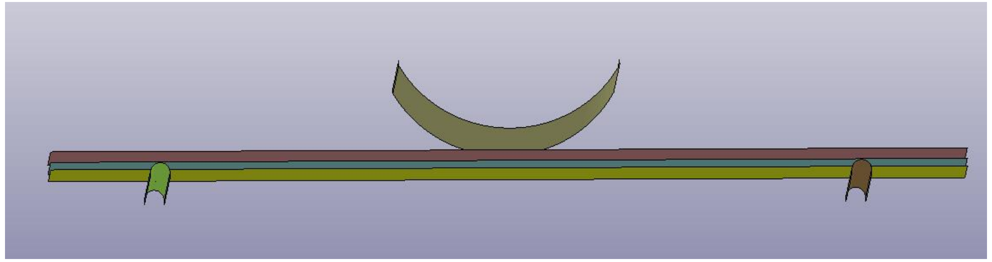
- **Generic structure comparable to a door impact beam:**
  - Wooden part made of 16x 2,0 mm veneer layers
  - Steel strip with 1,2 mm thickness

- **Testing:**
  - Quasi-static three-point bending flexural test
  - Usage of 10” pole (254 mm diameter)
  - Force measurement at pole
  - Displacement measured at pole

- **Simulation:**
  - 2 shell layers for wooden part and 1 shell layer for strip
  - Material model as developed
  - **Aim: Calibration of intralaminar behavior (delamination)**

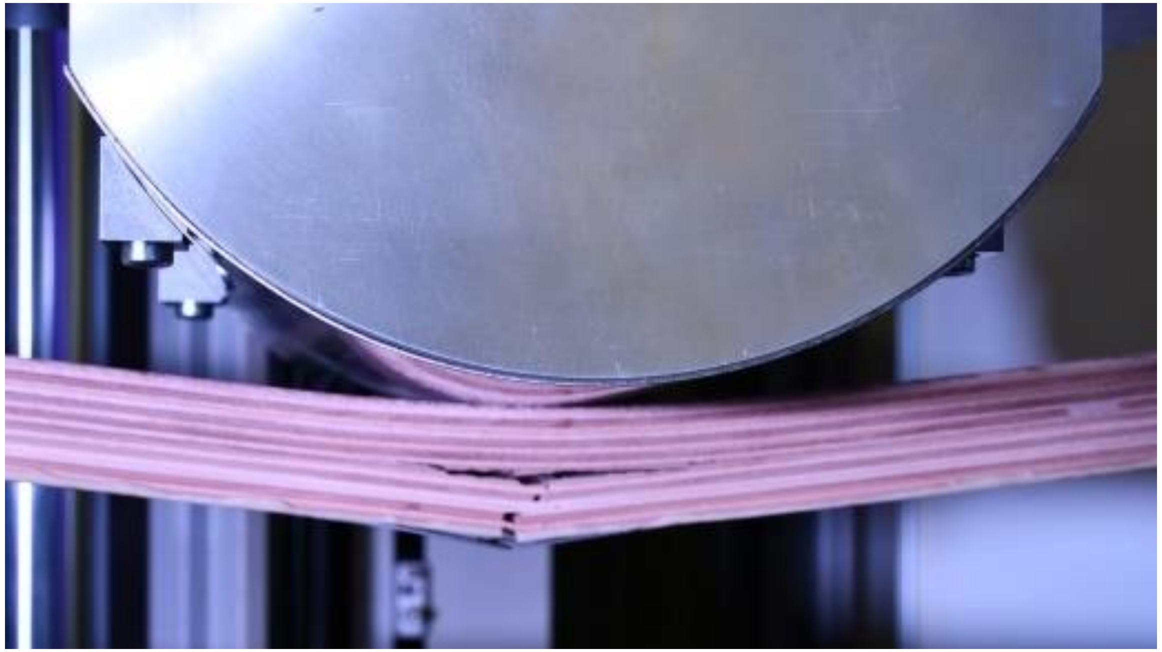




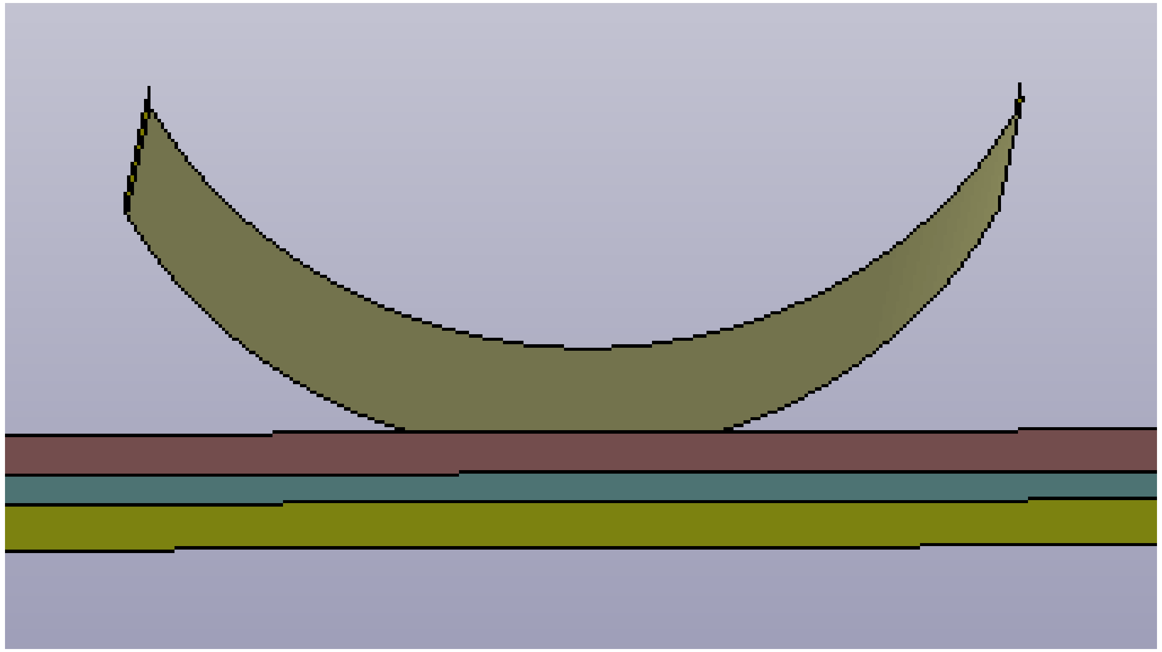


Simulation of veneer-based layered composites
Calibration of intralaminar behavior – comparison

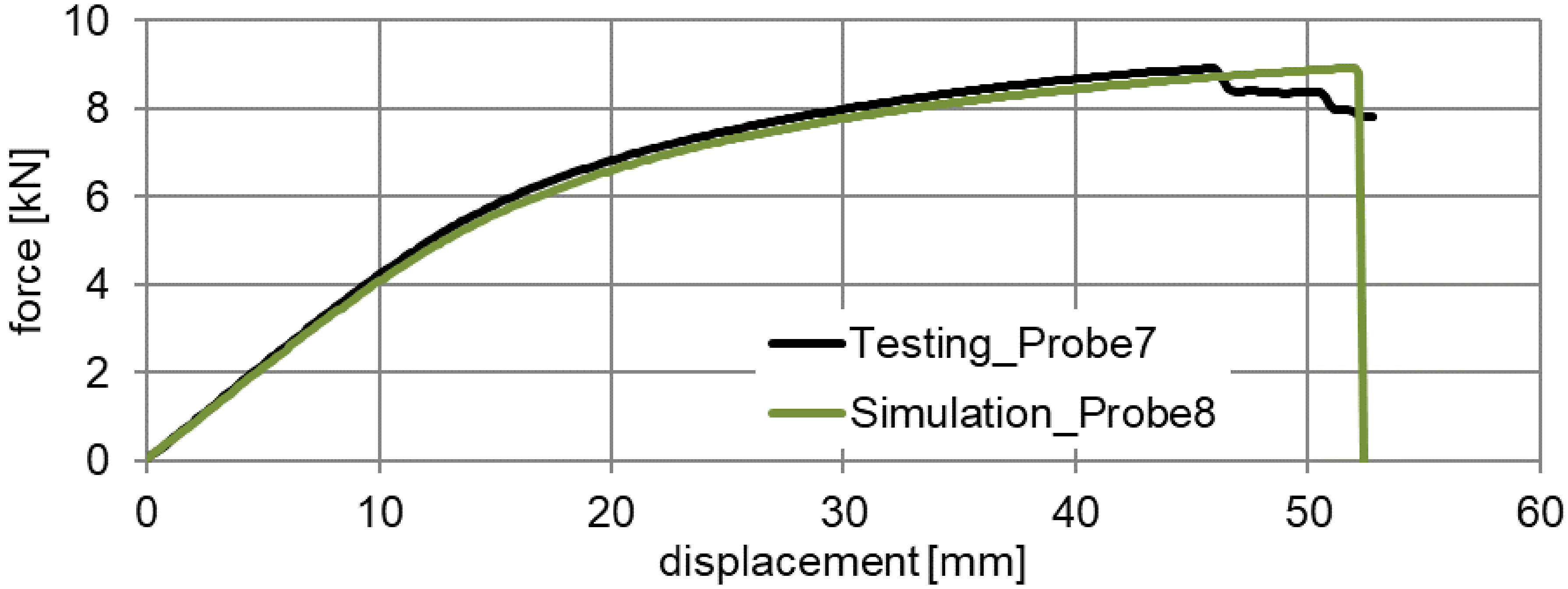
Testing



Simulation



Simulation of veneer-based layered composites
Calibration of intralaminar behavior – results

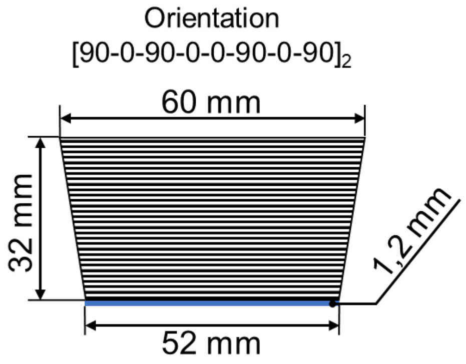


Calibration of intralaminar failure:

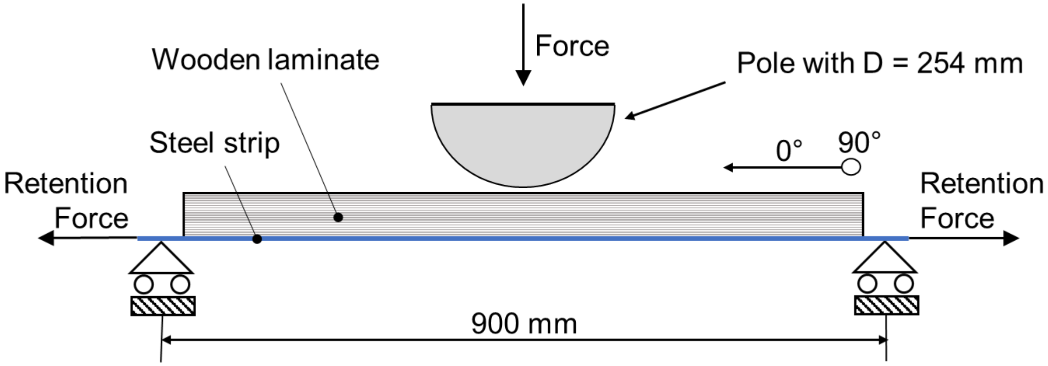
→ similar course of the force-displacement curve

→ fracture pattern could be mapped to good approximation

Simulation of veneer-based layered composites
Validation of simulation and material model – setup

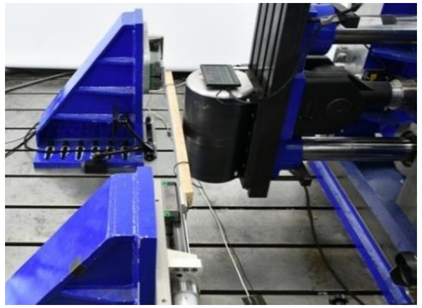


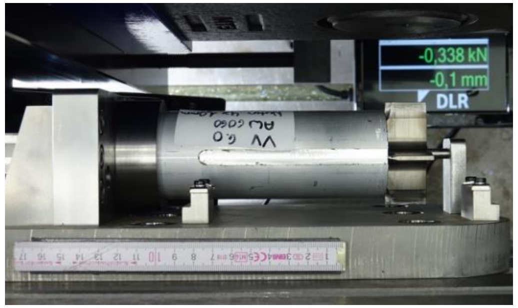
- **Generic beam:**
  - Same geometry
  - Different orientation of layers



- **Testing:**
  - Quasi-static three-point bending flexural test
  - Usage of absorber units (AU) for retention force
  - Force measurement at pole and at AU
  - Displacement measurement at pole and at AU

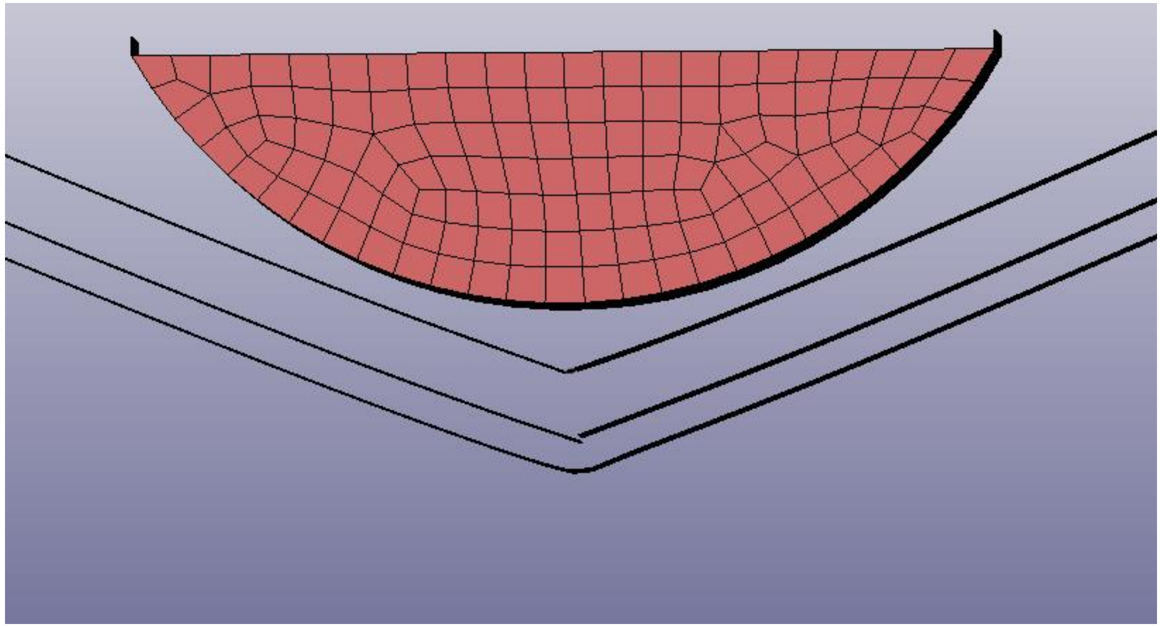
- **Simulation:**
  - 2 shell layers for wooden part and 1 shell layer for strip
  - Material model and sim. model as developed
  - **Aim: Validation of simulation and material model**



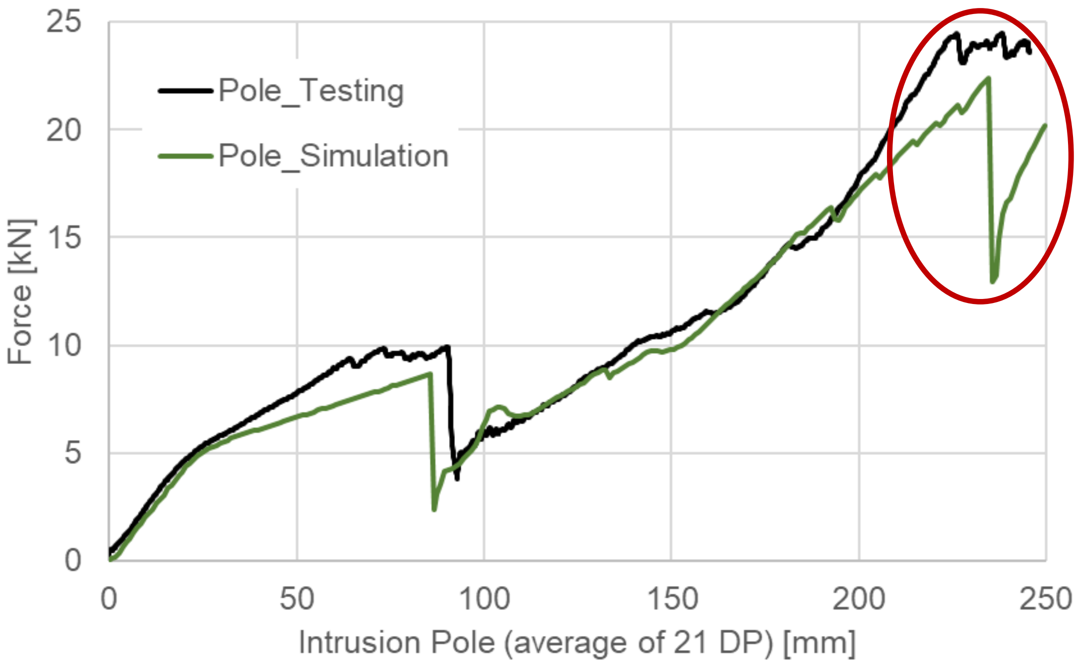


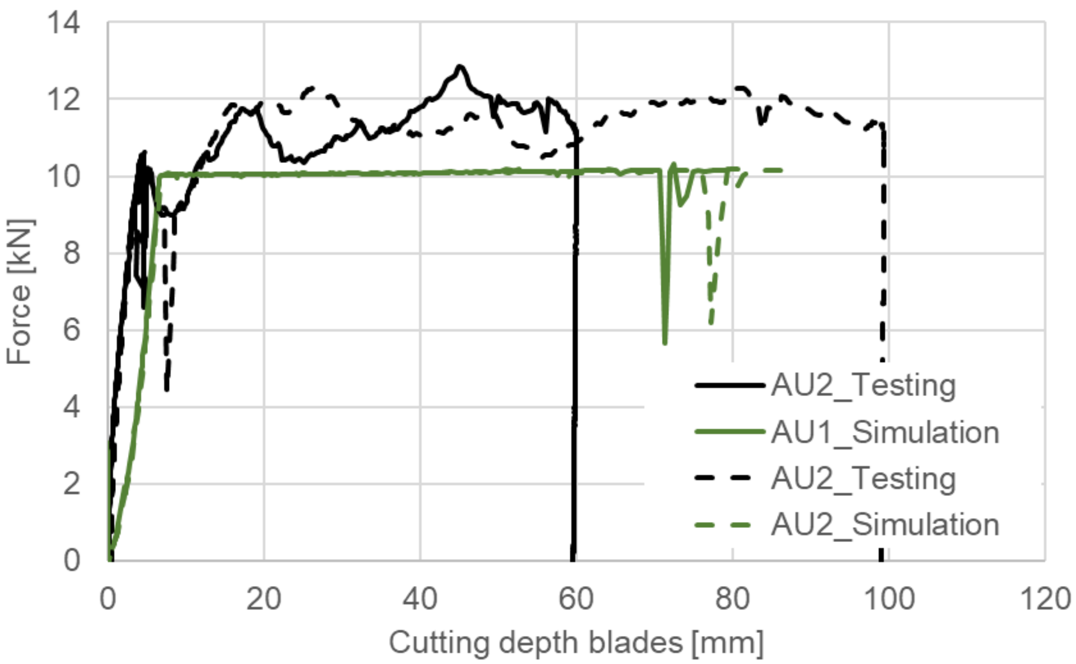
Simulation of veneer-based layered composites
Validation of simulation and material model – comparison

Testing | **Simulation**



Simulation of veneer-based layered composites
Validation of simulation and material model – results



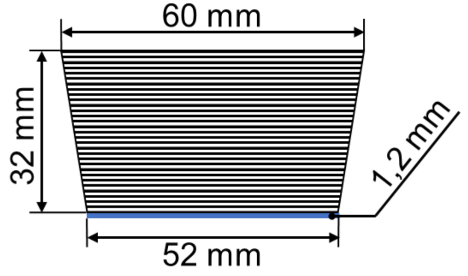


- qualitative course is similar
- absolute values in simulation tend to be smaller

- Sum of displacement is similar
- Kinematics in good approximation to testing

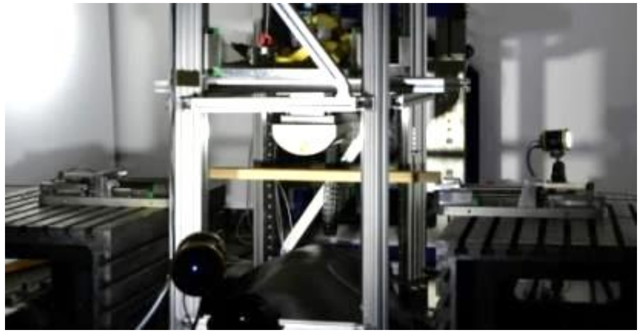
→ Validated simulation and material model

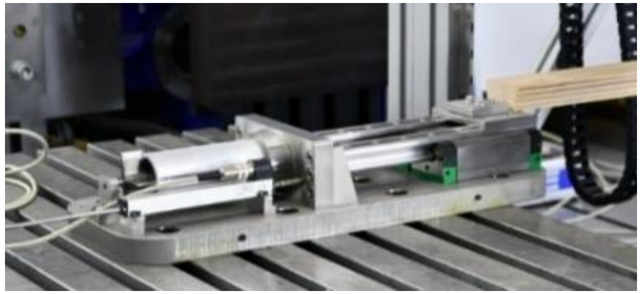
Simulation of veneer-based layered composites
Expansion of dynamic behavior – setup



- **Generic beam:**
  - Same geometry
  - Different orientation of layers

- **Testing:**
  - High-speed three-point bending flexural test
  - Test setup comparable to validation
  - Usage of drop tower in combination with AU
  - Force measurement at pole and at AU
  - Displacement measurement at pole and at AU

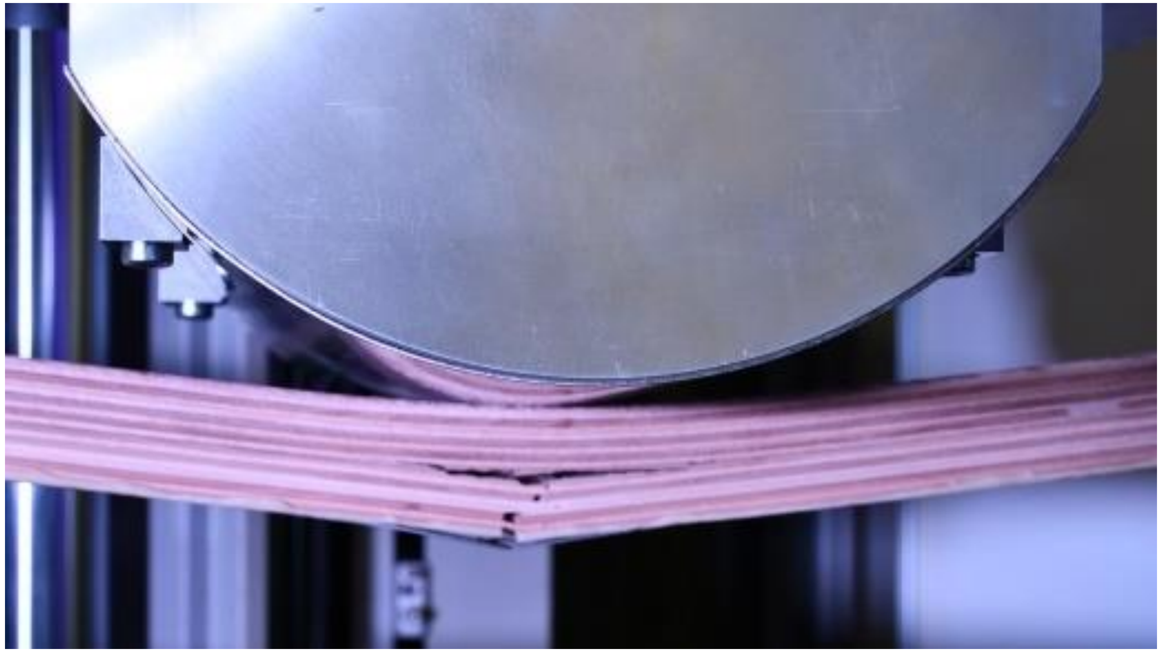




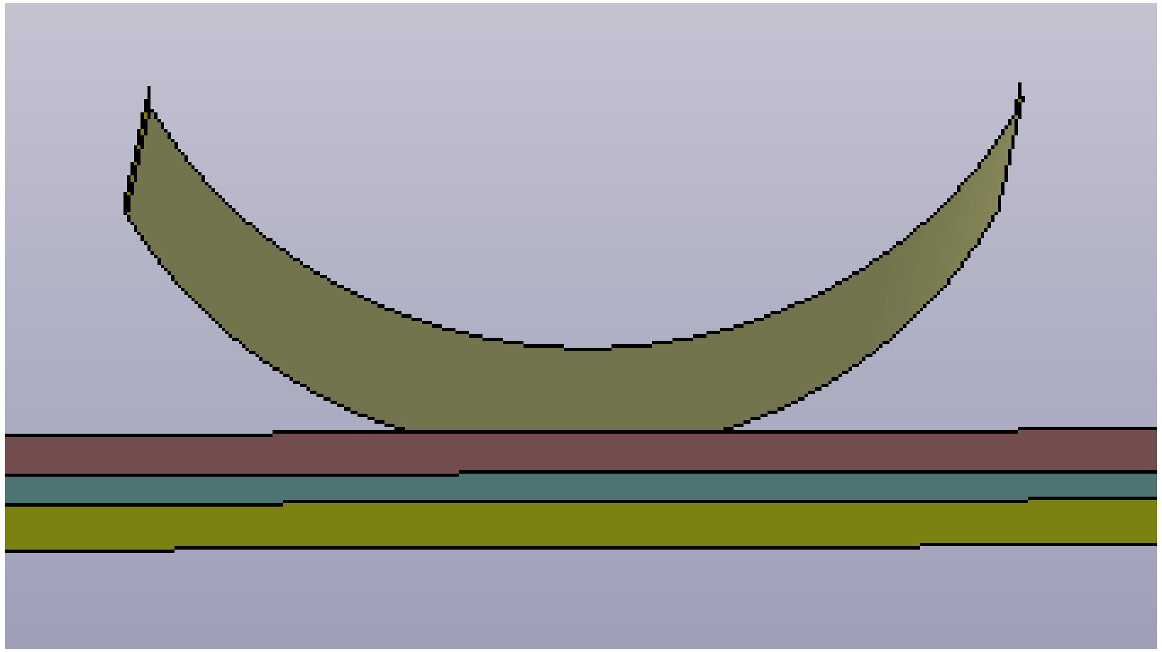
- **Simulation:**
  - 2 shell layers for wooden part & 1 shell layer for strip
  - Material model with dynamic behavior
  - **Aim: Expansion to dynamic material model**

Simulation of veneer-based layered composites
Expansion of dynamic behavior – comparison

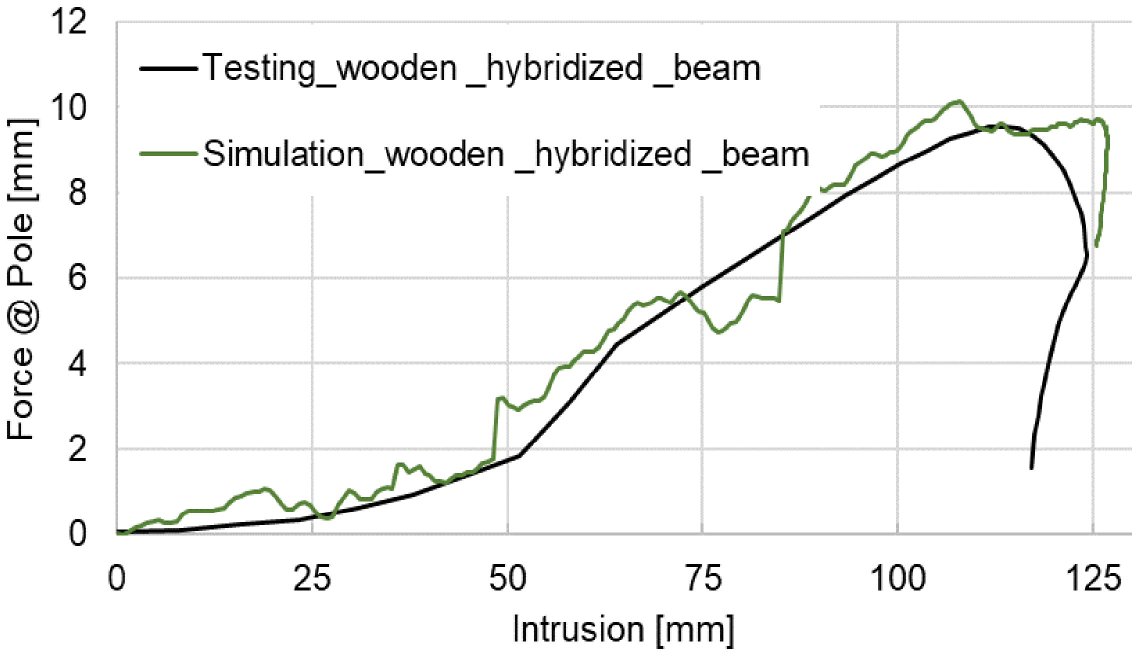
Testing

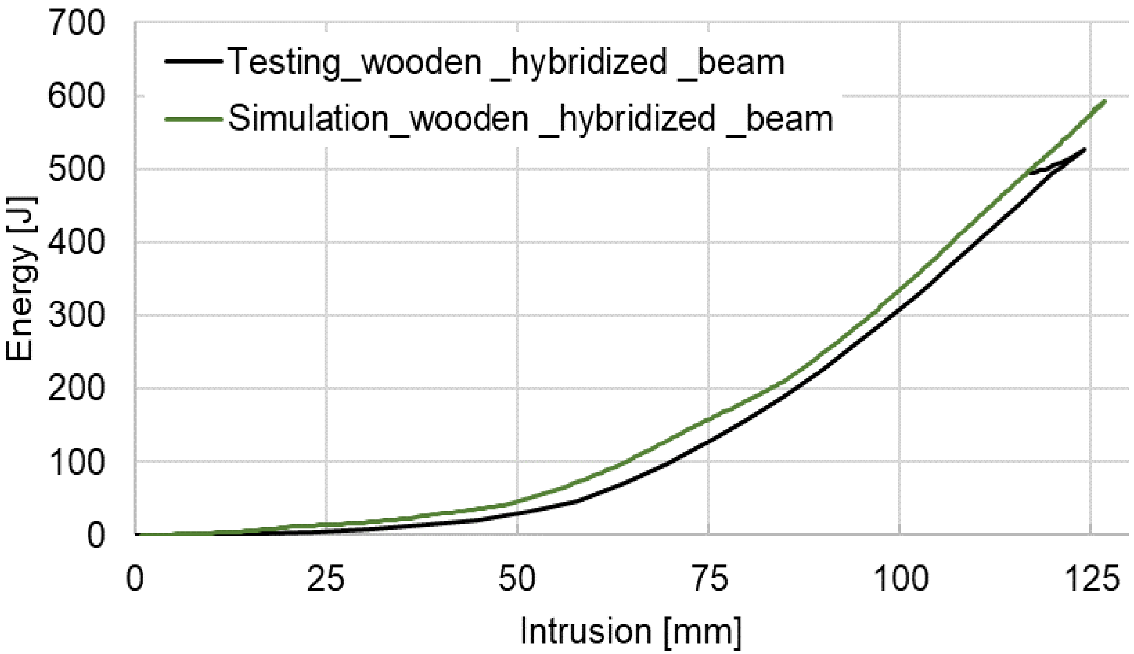


Simulation



Simulation of veneer-based layered composites
Expansion of dynamic behavior – results





- qualitative course is quite similar
- absolute values in simulation tend to be higher

- Higher absorbed energy in simulation (~15%)
- No spring back in simulation

→ Successful expansion of dynamic behavior

Summary and outlook

Summary

- Material model created for quasi-static and high-speed loads
- Intralaminar behavior modeled
- Modelling approach with layered shells validated

Outlook

- Refinement of dynamic parameters in order to better match absorbed energy
- Simulation of a specific assembly in a real use case, like Euro-NCAP Side Pole Impact
- Comparison of specific assembly with a reference impact beam to determine potential of veneer-based structure

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Further information about the project For(s)tschritt: holz-im-fahrzeug.de

Literature

[1] Ashby, M.F.: “Materials Selection in Mechanical Design“, 3rd edition, Elsevier, 2004

[2] Bergman, R., Alanya Rosenbaum, S.: “Cradle-to-gate life cycle assessment of laminated veneer lumber production in the United States”, Forest Products Journal, vol.67, November 2016

[3] Klein, B.: Lightweight-Construction. Wiesbaden, 2011

[4] LS-DYNA, Keyword user's manual, Volume II: material models, Livermore Software Technology Corporation (LSTC), 2013.