Innovative usage and application-oriented simulation of veneer based hybrid materials in vehicle structures

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DLR – Overview

In brief:

- 33 sites
- 55 institutes and facilities
- Approx. 10,000 employees
- Offices in Brussels, Paris, Tokyo and Washington

Research Areas

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

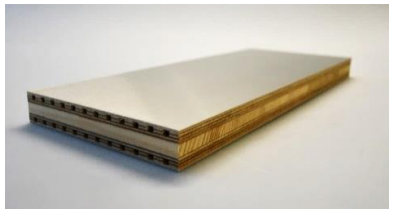
In addition

- Space Administration
- Project Management Agency

Engineered woods
Previous work done at DLR

Basic research of engineered woods for vehicle structures


Application potential of engineered woods for DLR's Next Generation Car (NGC) concepts e.g. studies of hybridized eng. wood in vehicle floor




2009 — **2017** — **2018** — **since 2020**

Research project For(s)tschritt:
- Veneer-based multi-material-system for road and rail vehicles

Main focuses of DLR:
- Conception, Construction, Simulation, Optimization, Testing and Validation




Expansion of application areas of molded wood



Outline

- Introduction
- Concepts for the usage of wood in vehicle structures
- Modelling of veneer-based layered composites
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- Recycling
- Summary and outlook

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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	Ashby Performance Index Bending stiffness	Ashby Performance Index Bending 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

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
- Conception, Construction, Simulation, Optimization, Testing and Validation
- Demonstrators
  (Front Door, Train Door, Train Side Panel)

Goal

- Qualification of wood for the usage in vehicle structures

For(s)tschritt

VOLKSWAGEN AKTIENGESELLSCHAFT · Bode · ALSTOM · SALZGITTER MANNESMANN FORSCHUNG · RohTech-DST · SWZ SIEBENWURST WERKZEUGBAU · UNIKASSEL VERSITÄT · Fraunhofer WKI · DLR Institut für Fahrzeugkonzepte · TÜVRheinland®

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

Introduction
Project “For(s)tschritt”

For(s)tschritt

Considered Components

Door (Train)

Side Panel (Train)

Side Impact Beam (Car)

Different components and requirements lead to different concepts and solutions

Introduction
Project “For(s)tschritt”

For(s)tschritt

Final prototype components

Door (Train)

Module of Side Panel (Train)

Side Impact Beam (Car) **[5]**

Different solutions for each component but all based on “building blocks”

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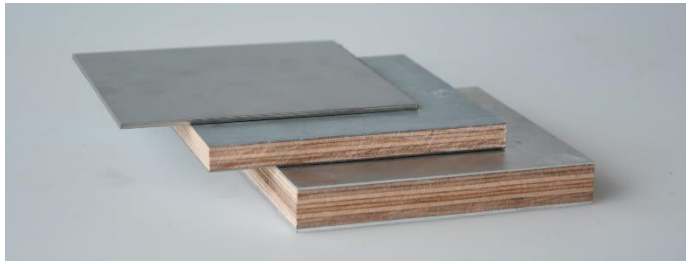
Concepts for the usage of wood in vehicle structures

Example of “Building Blocks”

- Structured sandwich core

- Reinforcement of thin metal sheets

- Homogeneous sandwich core

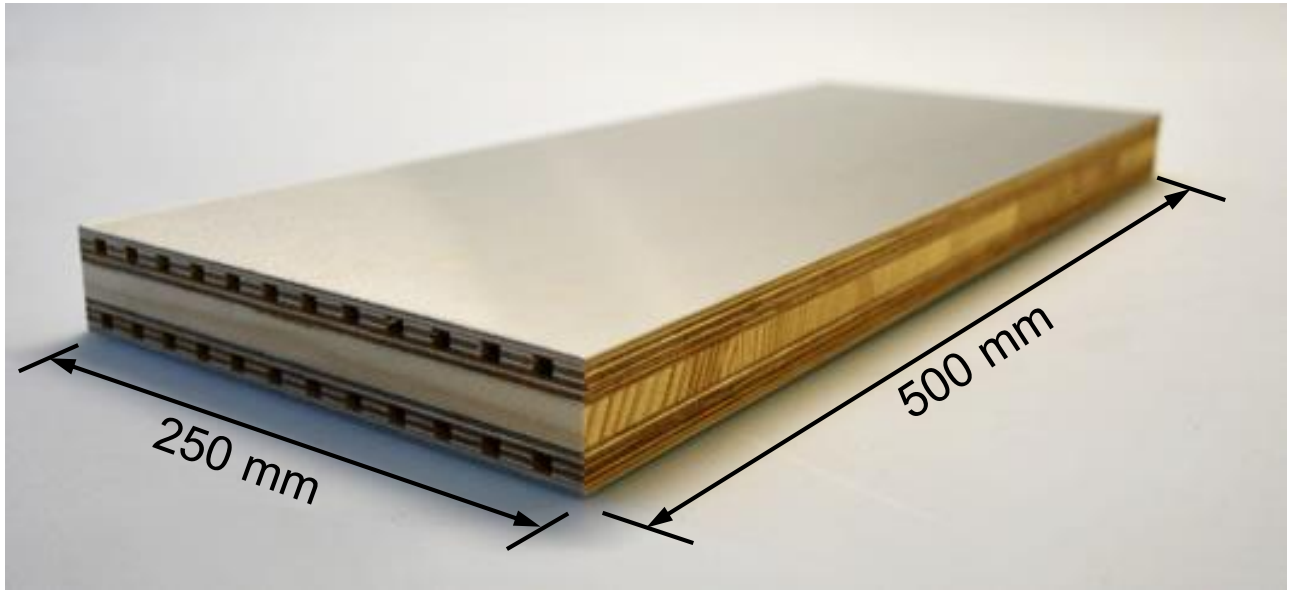


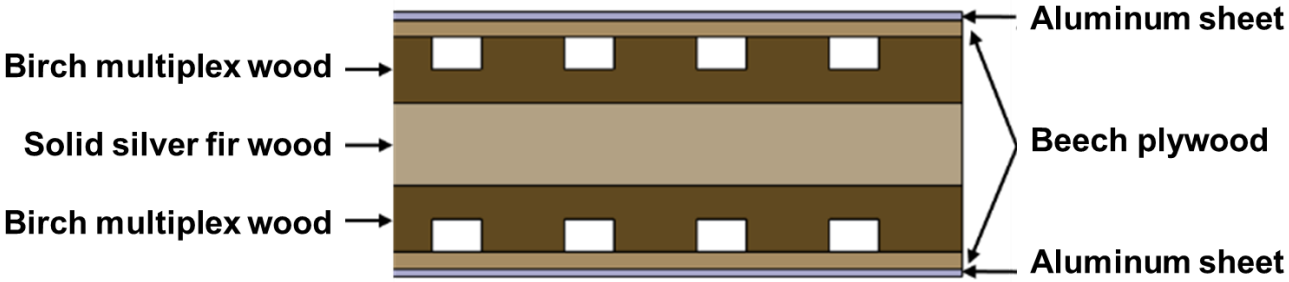
- Wooden parts with local reinforcement e.g. door impact beam

Concepts for the usage of wood in vehicle structures
NGC – Generic Vehicle Floor

Metal-Wood & Wood-Wood Hybridization:

- Aluminum sheets each 0.6 mm to protect the wood from environment and for “class A” surface
- Beech plywood for reinforcement of thin aluminum sheets
- Birch multiplex plywood for stability with grooves for lightweighting and space for controlled crushing
- Solid silver fir wood for energy absorption through crushing





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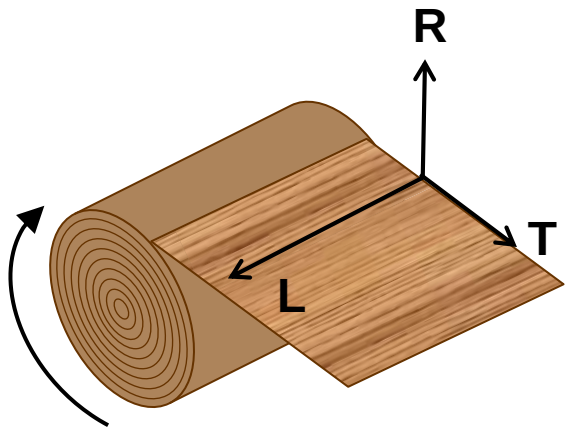
Modelling of veneer-based layered composites
Properties of veneer-based components

Veneer:

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



Longitudinal (*L*), Tangential (*T*) and Radial direction of veneer

Veneer-based layered composites (e.g. plywood):

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

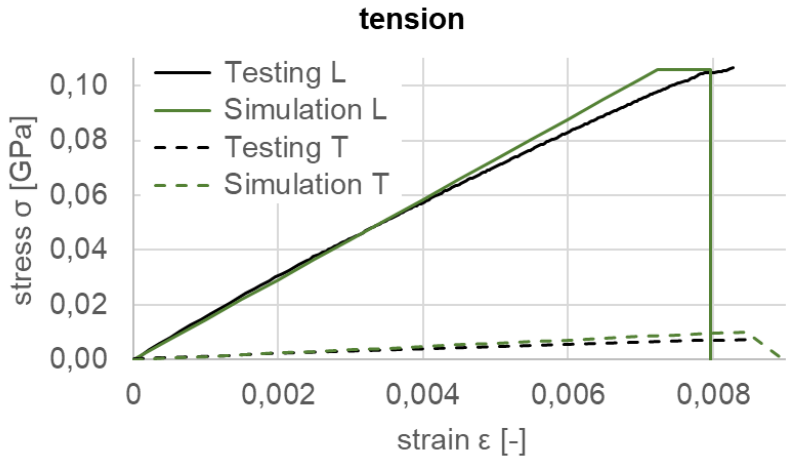
Modelling of veneer-based layered composites
Calibration of Material Model

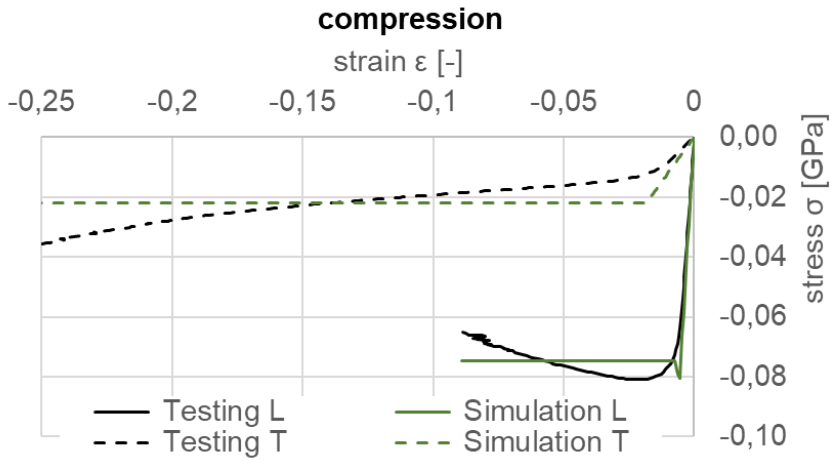
- LS-Dyna as FEM-Solver

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

- Comparison with data from testing shows:
  - UTS and failure strain in tension *L* met quite well
  - UTS in tension *T* met quite well
  - UCS and failure strain in compression *L* met quite well
  - UCS and failure strain in compression *T* met quite well

  - But: failure strain in tension *T* and compression *T* has to be the same in material card
    → Reduced stress after reaching UTS in tension *T*
    → Trade-off in compression to get energy correct

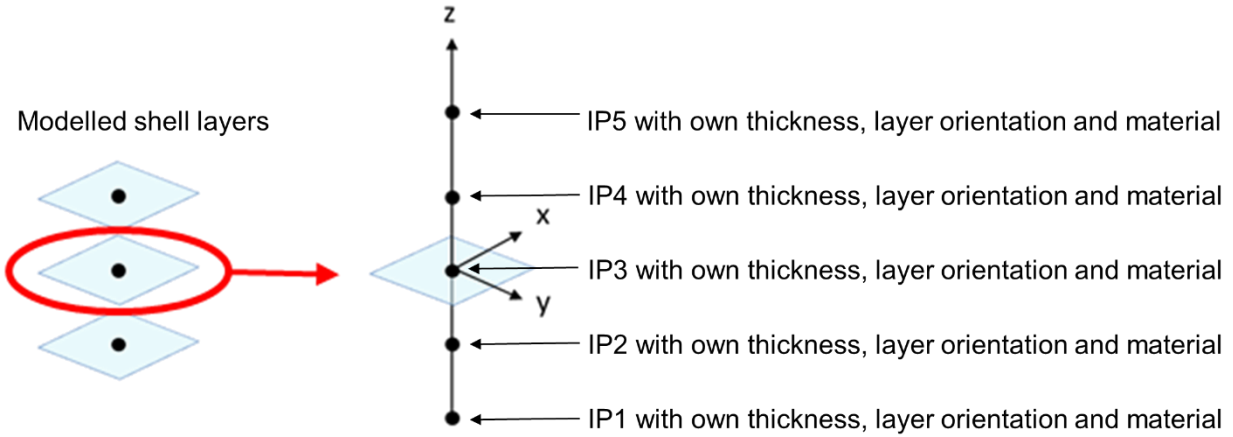




Modelling of veneer-based layered composites

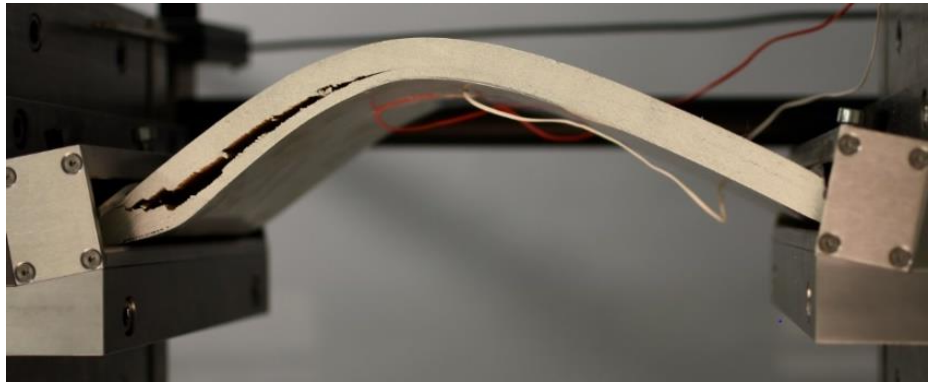
Layered Composites

- Each shell layer represents a sub-laminate
- Characteristics from true layers stored in numerical integration points (IP)



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

→ Component has to be discretized with multiple shell layers



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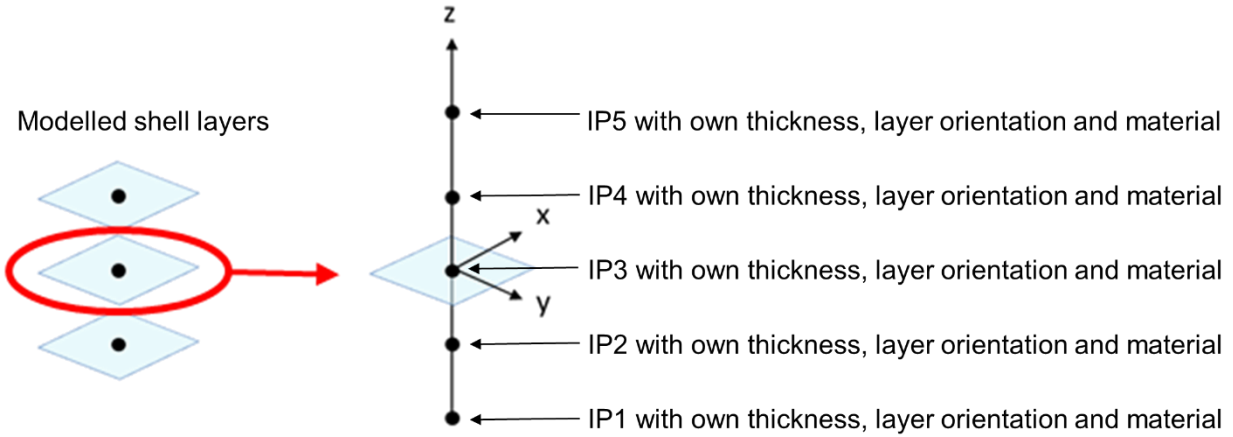
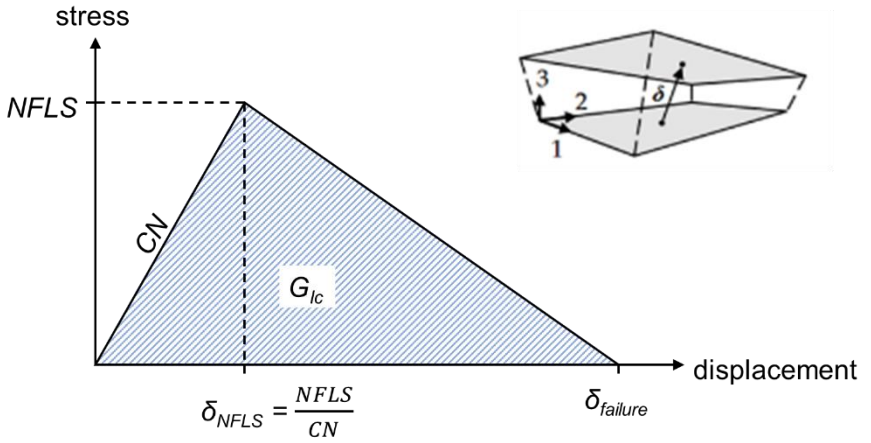


Modelling of Delamination:

- Usage of 2 different Tiebreak Contacts each based on a bilinear traction-separation law
  - one for wood-wood-delamination
  - one for metal-wood-delamination



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Simulation of NGC - Generic Vehicle Floor

Model Set-up

- 5 layers of shell-elements:
  - 2 for aluminum sheets
  - 2 for beech plywood
  - 1 for birch multiplex woods and solid silver fir wood

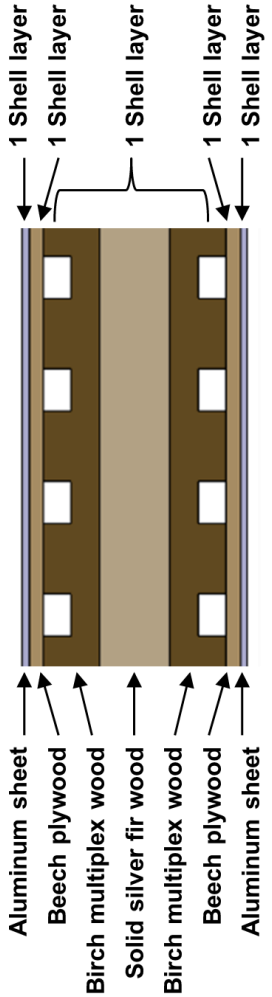
  → metal-wood delamination possible

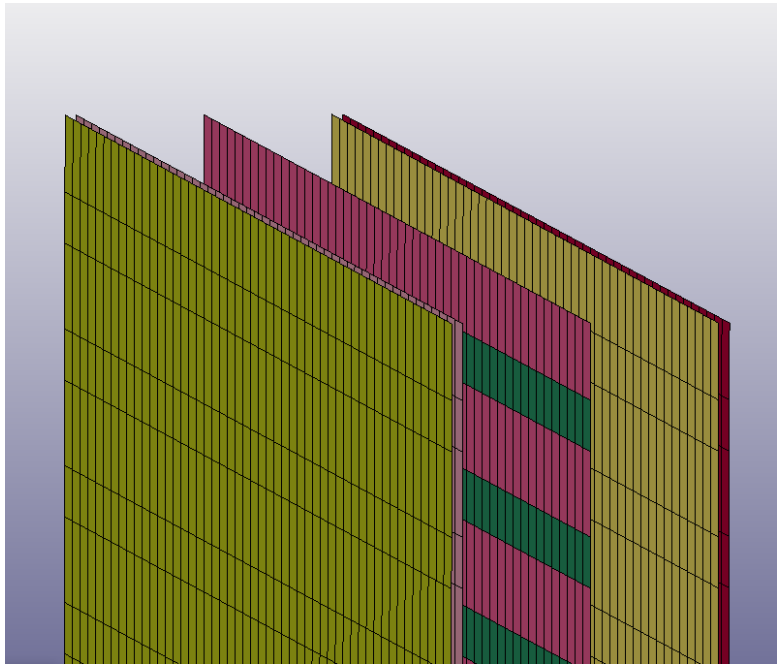
  → wood-wood delamination possible

- Quasi-static impact test with Pole (d = 254 mm; v = 10 mm/min)

- Birch veneer: Characteristics (Young's Modulus, Strengths, etc.) from literature

- Solid silver fir wood: Characteristics from literature but reduced to 80 % due to accumulation of imperfections in solid wood compared to specimen

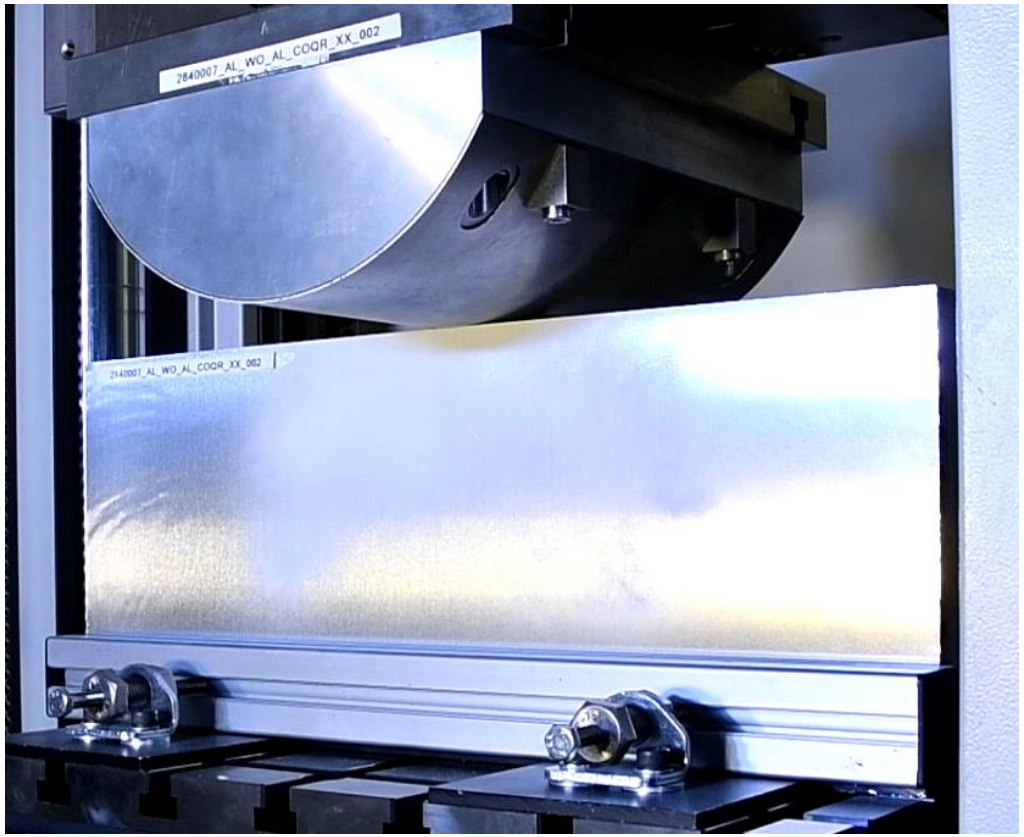




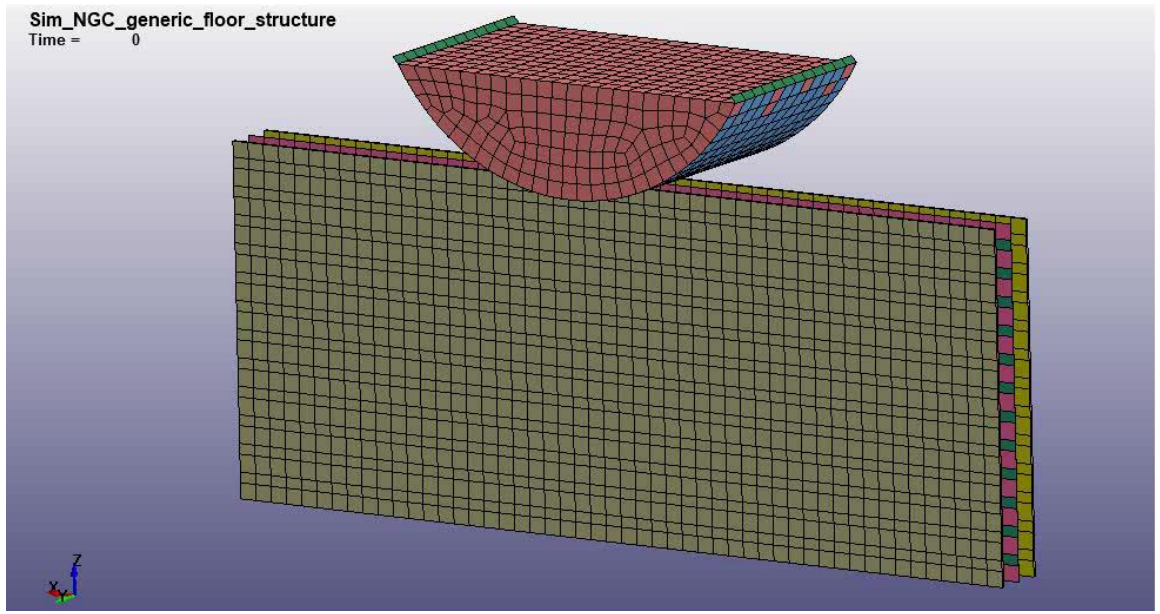
Simulation of NGC - Generic Vehicle Floor

Testing and Simulation

Testing



Simulation

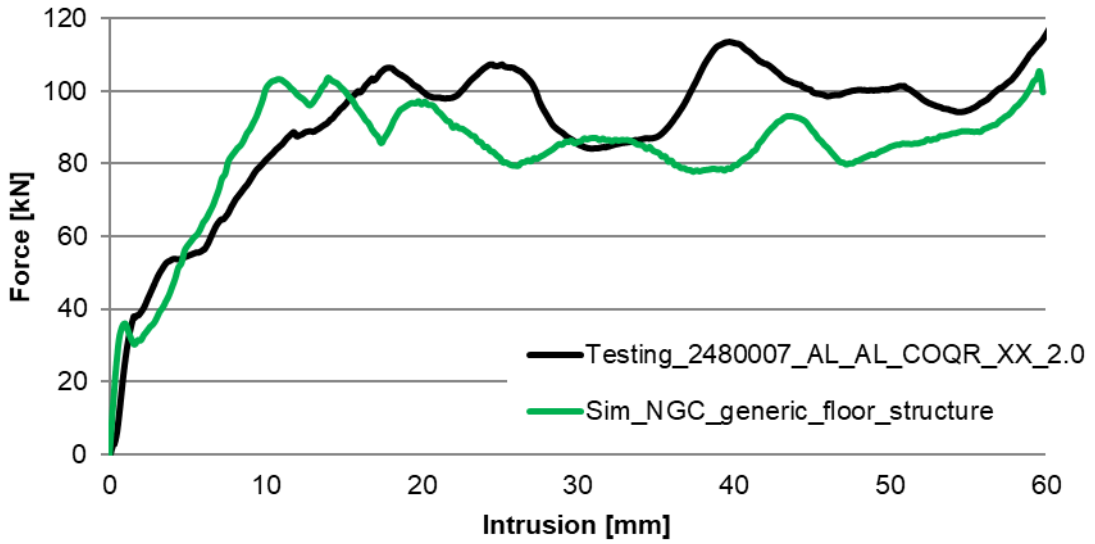


- Qualitative evaluation: good matching of general behavior of all components

Simulation of NGC - Generic Vehicle Floor

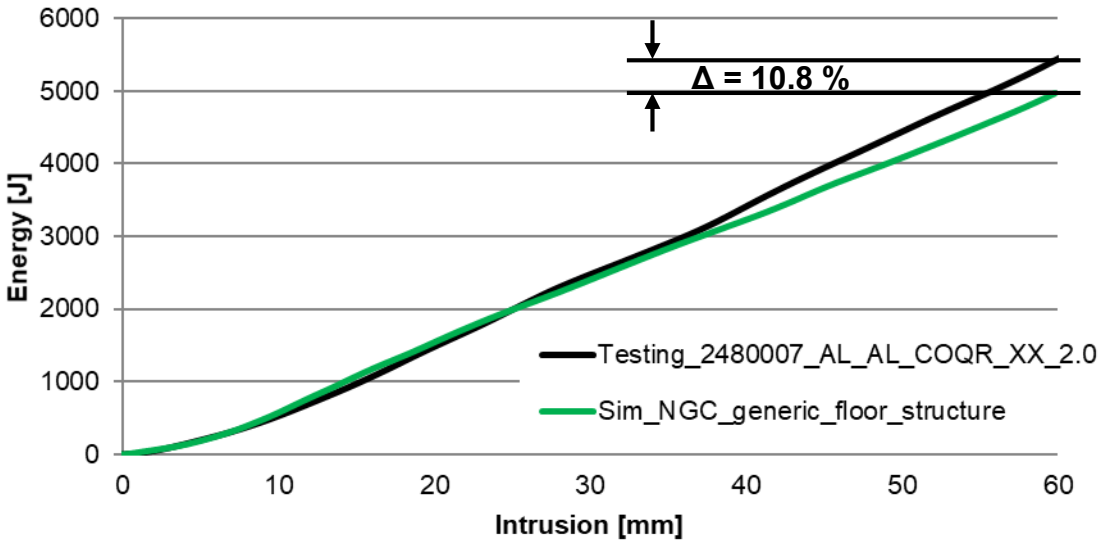
Comparison of results

Comparison of Force-Displacement-curves



- Qualitative: good matching of curves
- Quantitative: medium of force level to low

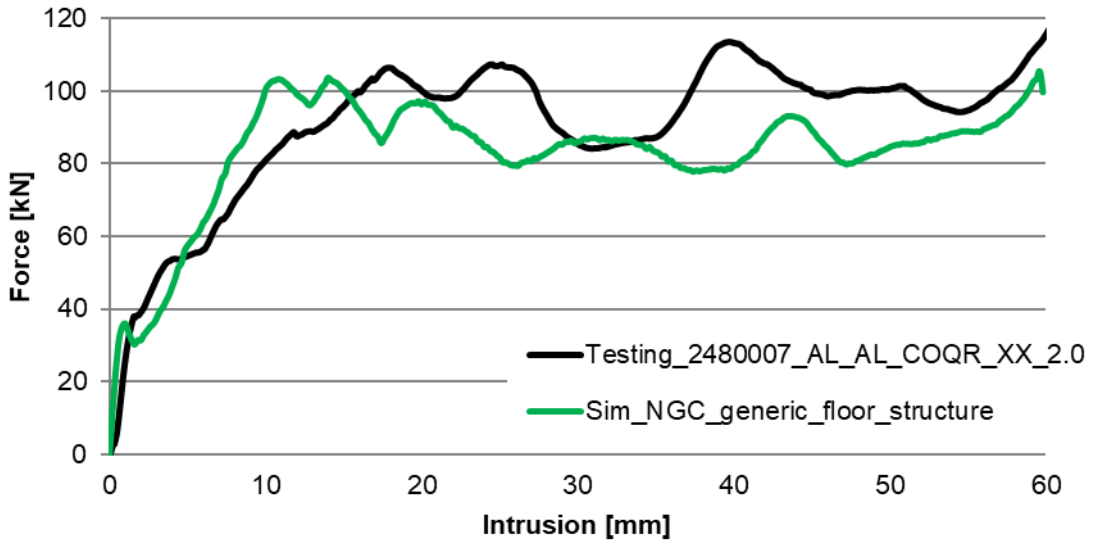
Comparison of Energy-Displacement-curves



- Qualitative: good matching of curves
- Quantitative: discrepancy in force-level leads to 10.8 % difference in absorbed energy

Simulation of NGC - Generic Vehicle Floor
Comparison of results

Comparison of Force-Displacement-curves



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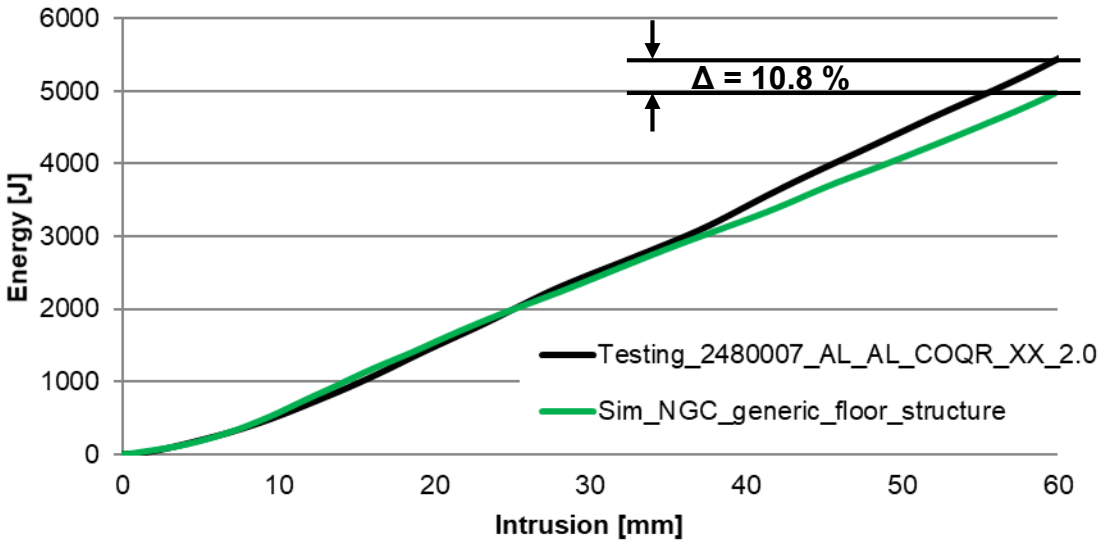

→ Correlation between simulation and testing at around 90 % without fitting of parameters

→ Refinement / Fitting of literature values needed for better results

→ **Methodology of simulating veneer-based engineered woods works quite well**

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Recycling
Possible approach

- Complete separation of wood and metal in hammer mill:
  - Time needed is only around 15 sec

- Recycling of metal components:
  → Reduction of the CO_2-impact of metal components

- Possible usage of wood components:
  - Usage of strands
    → ask us about the new project
  - Usage of chips for particle boards

  → Restart of product life time for wood

- Thermal utilization of wood as worst case/last step:
  → stored quantity of CO_2 is released

HYEND-WOOD
hybridized engineered wood

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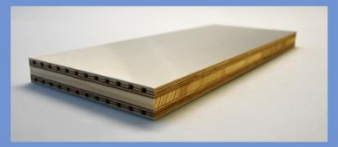
Summary and outlook

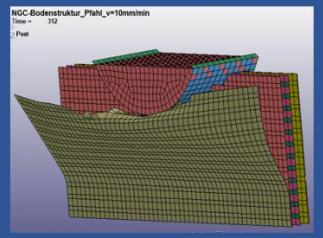
Summary

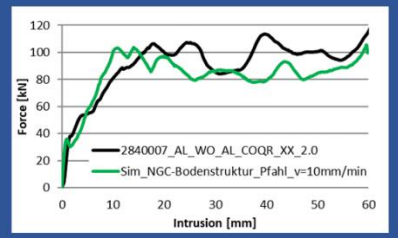
Building kit

Generic structure



Simulation, Testing and Validation





Recycling

Outlook

- Simulation of specific assemblies in a real high speed use case, like Euro-NCAP Side Pole Impact
- Comparison of those specific assemblies with a real reference data to determine potential of wood-based structures
- Deeper dive into recycling
- Deeper dive into LCA
- Look into production technologies for a quantity of greater 100,000 pieces a year

Thank you for your kind attention!

Your contact persons at the DLR Institute of Vehicle Concepts
Research Area Material and Process Applications for Road and Rail Vehicles

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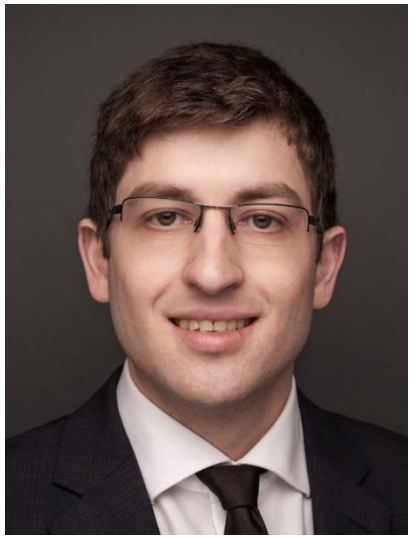

Simulation of engineered wood

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Literature

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

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

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

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

[5] T. Große et. al.: *Collaborative project: Structural assemblies based on sustainable wood-based material systems to reduce mass and environmental impact in road and rail vehicle construction - final report for the research project For(s)tschritt*, **2020,** Volkswagen AG,Wolfsburg.

[6] D. Kaese, G. Piazza, E. Beeh, et al., *Potential for Use of Veneer-Based Multi-Material Systems in Vehicle Structures*, **2019**, Key Eng. Mater., 809, 633-638.

[7] D.H. Roubins, J.N. Reddy, *Modelling of Thick Composites using a Layerwise Laminate Theory*, **1993**, International Journal for Numerical Methods in Engineering, vol. 36, 655-677.

[8] P. Niemz, W. Sonderegger, *Holzphysik - Physik des Holzes und der Holzwerkstoffe*, **2017**, Leipzig, Carl-Hanser-Verlag, 57-68.

Summary and outlook

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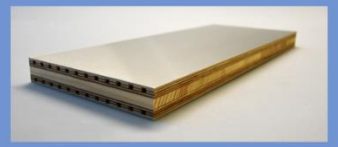

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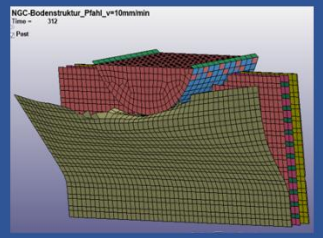

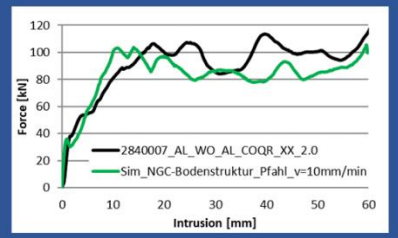

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