WoodC.A.R. - Wood-based materials for functional vehicle structures

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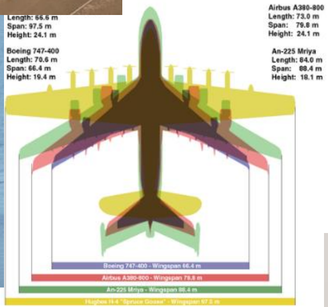
FFG - COMET K-Project
Wood - Computer Aided Research

More than 70 years of high-performance industrial applications



De Havilland Mosquito bomber, Cessna AT10, H-4 Hercules named the Spruce Goose, Giant Plane Comparison

Wooden bicycle frame

2016 Toyota Setsuna EV Concept

Train bogie

Project consortium

Scientific Partners

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Business Partners

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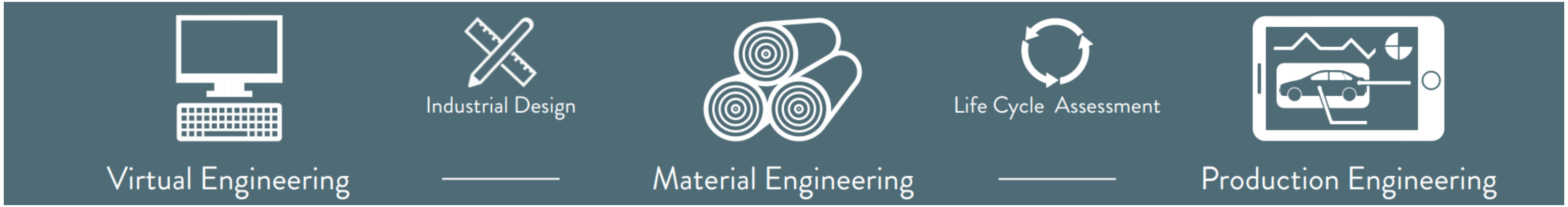
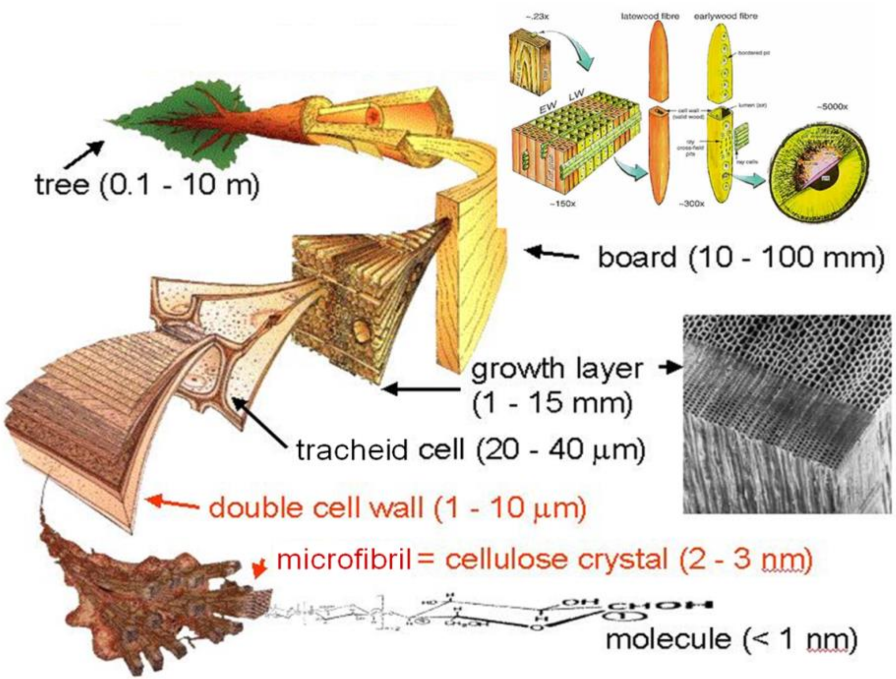
Vision

The vision of the K-Project WoodC.A.R. (**Wood** – **C**omputer **A**ided **R**esearch) is to introduce **E**ngineered **W**ood **P**roducts (EWP), **E**ngineered **W**ood **C**omponents (EWC) and wood-based materials to the mobility sector, which follows the demand for improvement of environmental and economic sustainable materials in this branch. Key for the application of EWPs and EWCs in the engineering and the development process are reliable **C**omputer **A**ided **E**ngineering (CAE) models of wooden materials exposed to dynamic and static loads. Additionally, new production technologies for shaping, joining and bonding are required. Simulation tools as well as new technologies will open new markets within and beyond the mobility sector.

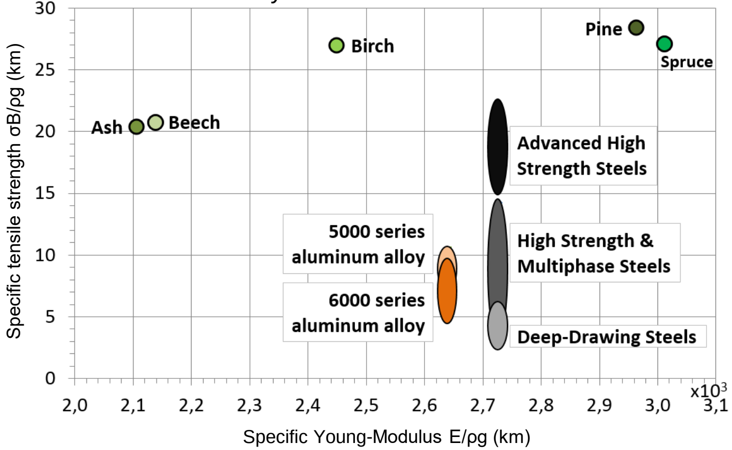


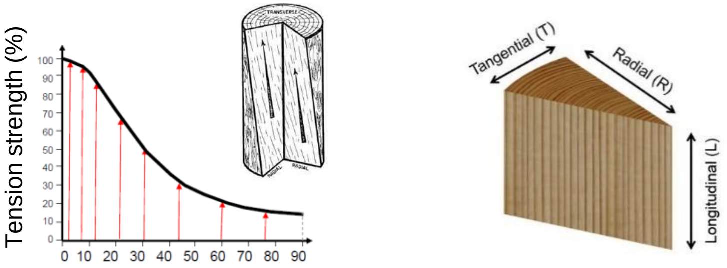
Wood – chemistry, structure & mechanical properties



Source: The hierarchical structure of cellulose in wood. From an artwork by Mark Harrington, Copyright University of Canterbury, 1996.

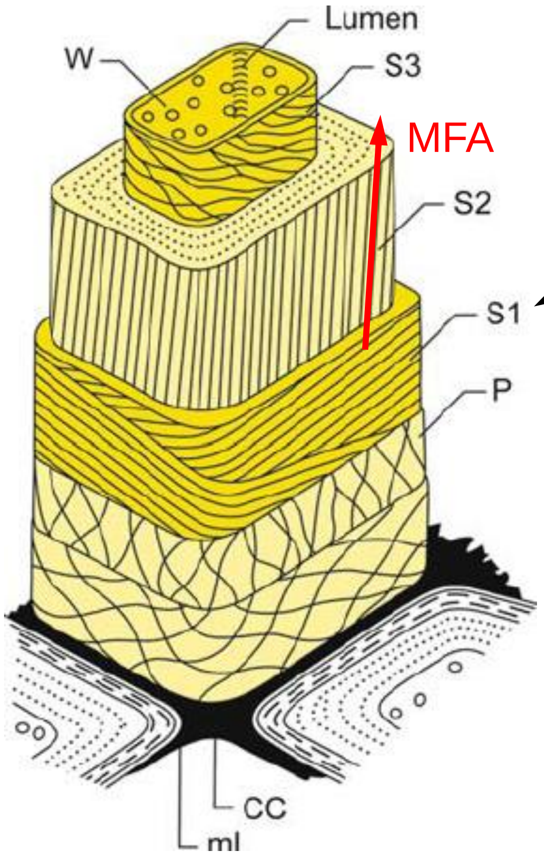
Dealing with wood properties demands considering all hierarchical levels of wood structure

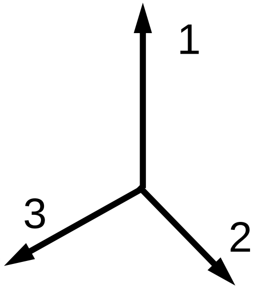




Load distribution throughout the angle

Effects of wood cell wall and chemical composition on mechanical properties





Fibre reinforced laminate: calculation of the wood cell wall elastic properties (E and G)
S2: 80% of cell wall
Orientation of cellulose micro fibrils in S2 = MFA

Roles of mixture

θ = MFA

$E_1 = V_c * E_{1c} + V_m * E_{1m}$

$E_2 = E_{2c} * E_{2m} / (V_c * E_m + V_m * E_{2c})$

$G_{12} = G_{12c} * G_m / (V_c * G_m + V_m * G_{12c})$

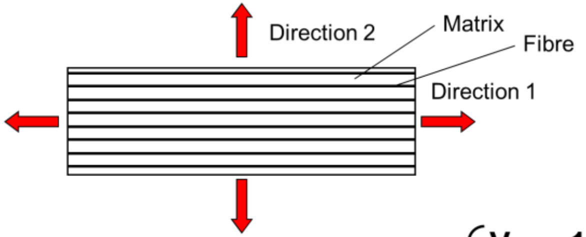
	C (GPa)	HC (GPa)	L (GPa)
E_1	167.5	7.0	2.0
E_2	30.5	3.5	2.0
G_{12}	3.0	1.8	0.8

E_1 = Young's Modulus in longitudinal direction
E_2 = Young's Modulus in transverse direction
ν_{12} = Poisson's ratio in longitudinal direction
ν_{21} = Poisson's ratio in transverse direction
m = matrix material (lignin + hemicellulose)
c = fibre material (cellulose)

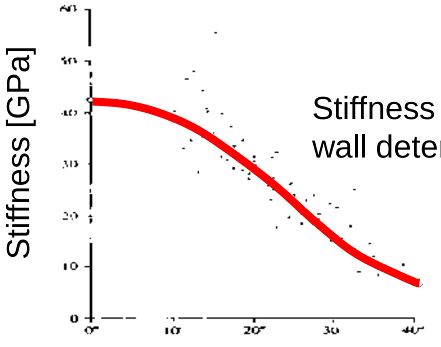
Source: Sjostrom E (1993) Wood chemistry. Fundamentals and applications, 2nd edn, Ch 1. Academic, San Diego, pp 1–20

Material properties influenced by the orientation of MFA

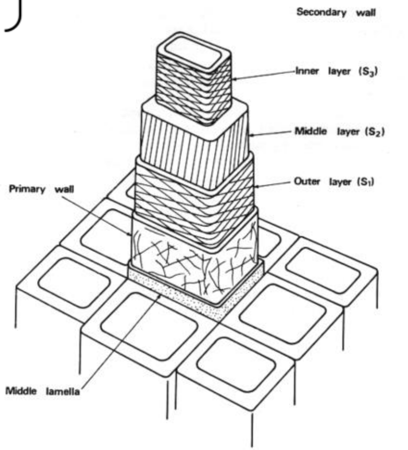
Fiber-reinforced composites consisting of matrix (m) and fibre (f) materials

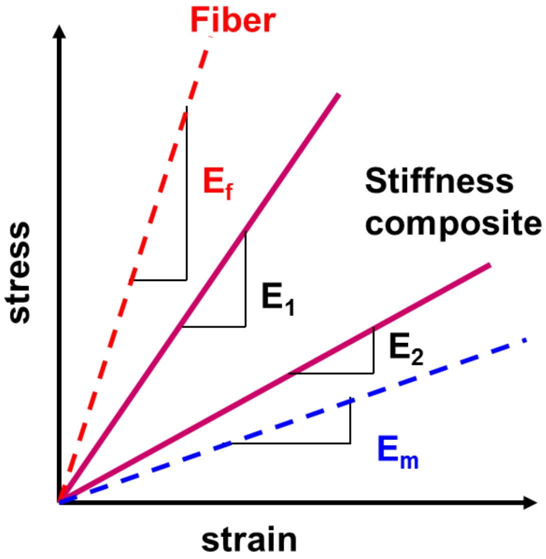


$$E_1 = E_f\,V_f + E_m\,(1 - V_f) \qquad E_2 = \left(\frac{V_f}{E_f} + \frac{1 - V_f}{E_m}\right)^{-1}$$

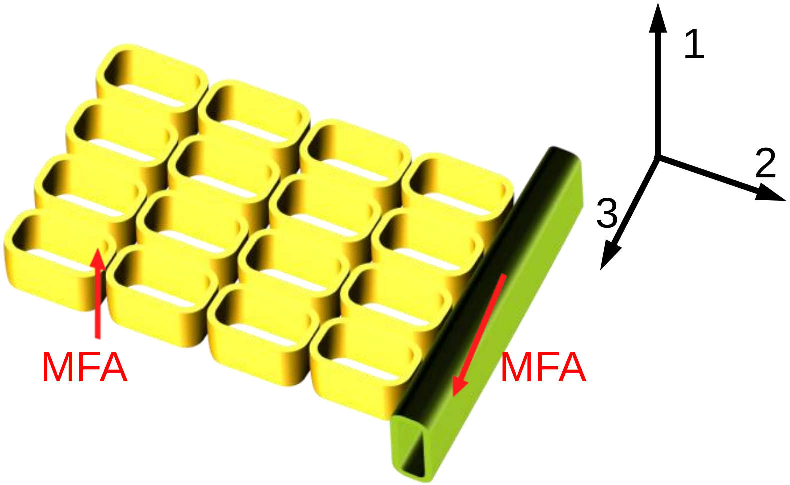


Stiffness of the cell wall determined by MFA

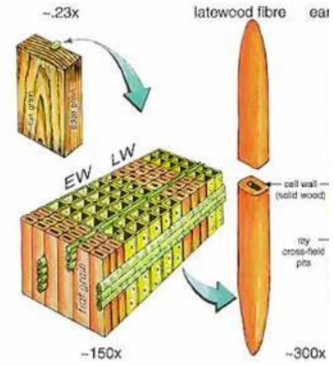


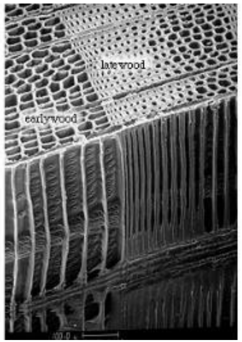


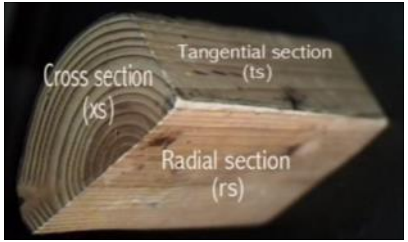
Effects of wood anatomy on mechanical properties



In comparison to the cell wall, solid wood is not a fibre composite but could be understood as a composite sandwich structure.

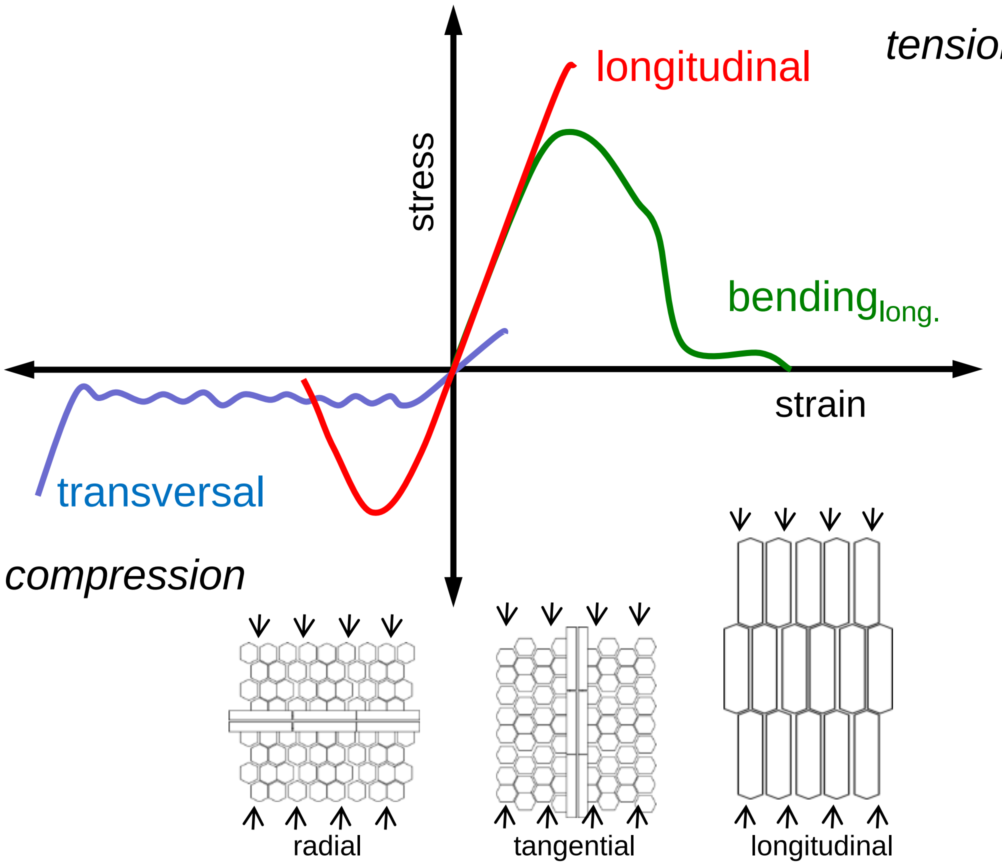






Physical and mechanical differences between tangential (2) and radial (3) direction based on MFA, geometry of cells and rays

Elastic and plastic deformation and fracture behaviour of wood



Tension:

- ➢ Brittle failure in longitudinal and
- ➢ transversal direction

Compression:

- ➢ Ductile behaviour in longitudinal
- ➢ Reduction in force to almost 0?
- ➢ Highly plastic deformation in transversal direction

Bending:

- ➢ Longitudinal: ductile behaviour until tensile strength is reached, than stepwise brittle failure
- ➢ Transversal: brittle failure due to low tensile strength perpendicular to grain

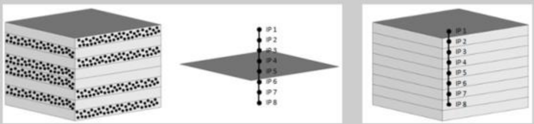
Shearing:

- ➢ Abrupt failure in all directions

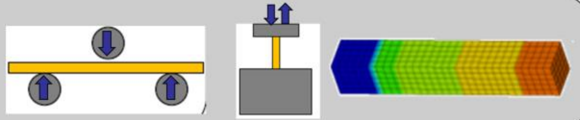
Method development "Wood crash simulation"

- Material characterization

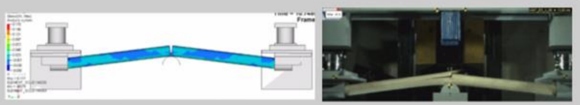
- Select appropriate modeling method
  - material cards
  - FE-model for wood



- Validation material simulation



- Validation component simulation



Material characterization and Modeling

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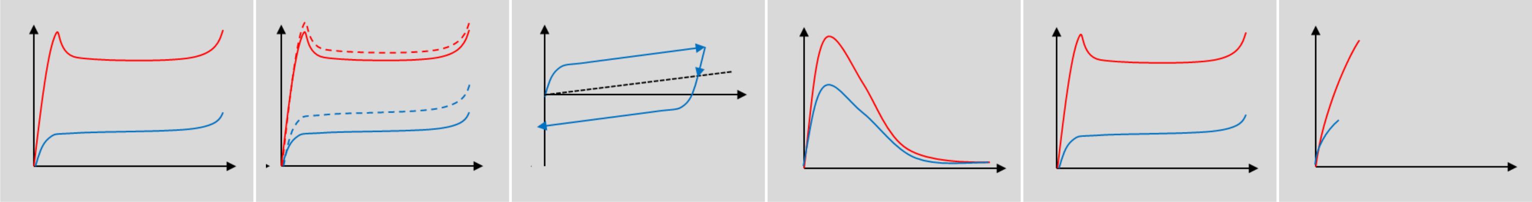
Solid wood	Plywood
	

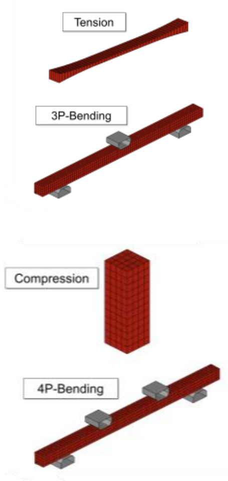
SOLID	SHELL	TSHELL

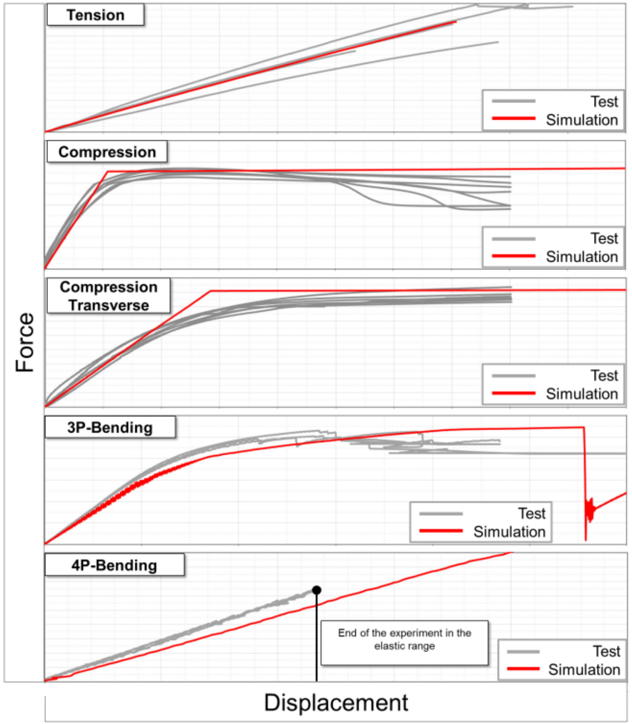
Softening or kinking / pushing	Strain rates dependency	Nonlinearity	Softening shear	Densification (compression)	Failure



*MAT_ENHANCED_COMPOSITE _DAMAGE (*MAT_054)	*MAT_LAMINATED_COMPOSIT E_FABRIC (*MAT_058)	*MAT_WOOD (*MAT_143)	*MAT_LAMINATED_FRACTURE _DAIMLER_CAMANHO (*MAT_262)	*MAT_LAMINATED_FRACTURE _DAIMLER_PINHO (*MAT_261)

Validation Material Simulation

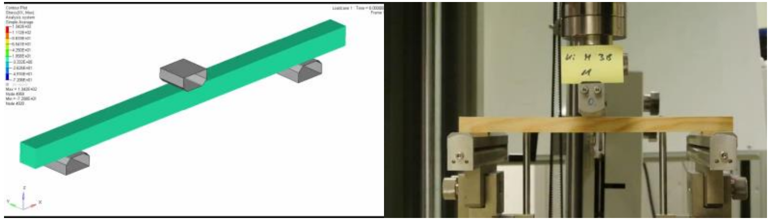




Tension:
- ➢ Quite good results in elastic region
- ➢ ToDo: Failure behaviour

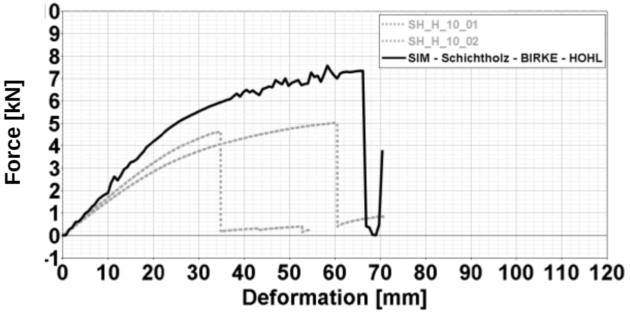
Compression:
- ➢ Good results in simulation
- ➢ No failure on compression simulation

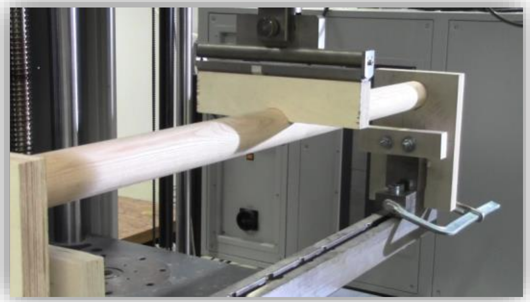
Bending:
- ➢ 3P-Bending: ductile behaviour until tensile strength is reached, than stepwise failure on the tension side
- ➢ 4P-Bending: no shear failure

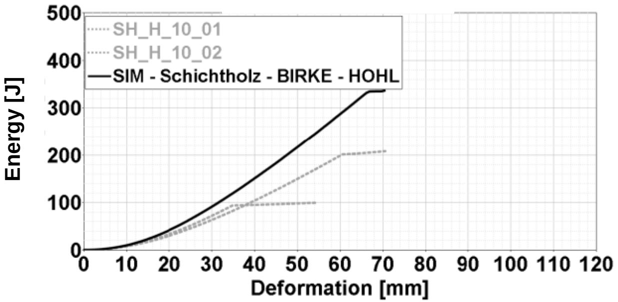


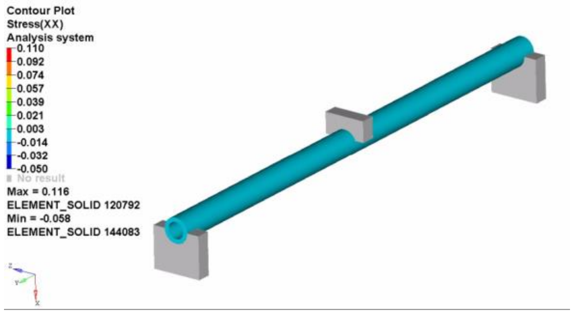
Validation Component Simulation

Static



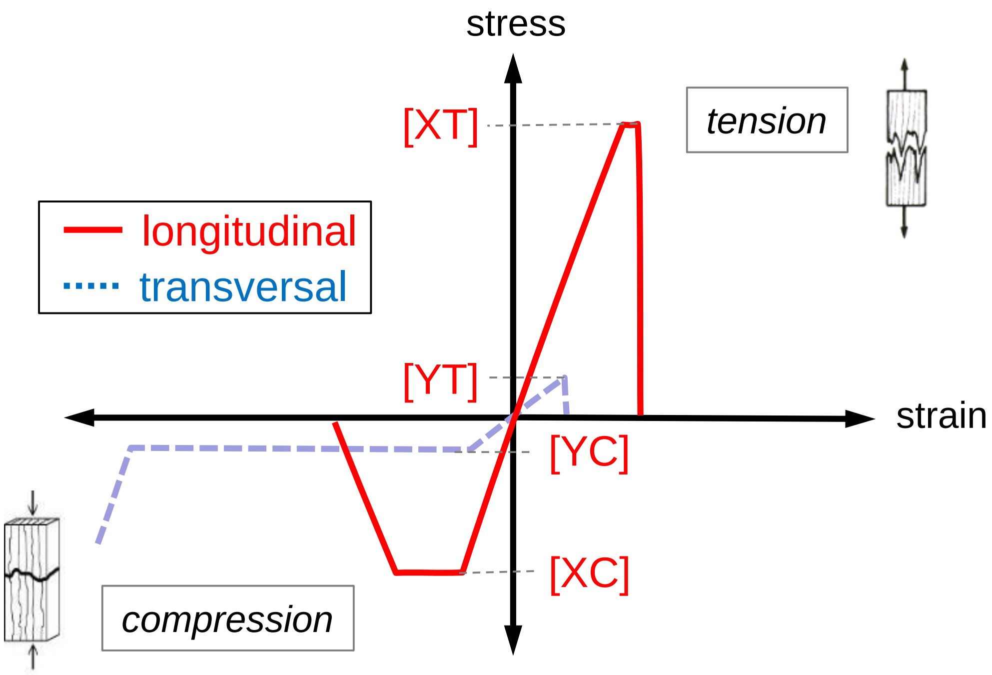






- No consideration of the adhesive
- The laminated wood composite is significantly overestimated in terms of energy absorption up to the component failure in the simulation, since the lower adhesive rigidity compared to wood is not taken into account
- Due to the very simplified material modeling, the progressive damage after crack initiation in solid wood can not be reproduced

Material card – MAT xx - wood



Conclusio

- FE material simulation of wood and wood composites for complex structures under crash loading can be performed with standard material cards
- Further significant improvements can be achieved by additional adjustments to the material model with respect to the failure and damage model as well as strain rate effects
- Functional structural components, in terms of basic function to the initial failure can be designed and evaluated in an early vehicle development phase
- Joining technology plays a major role and must be considered especially in plywood and wood composites

Photo: Mattro

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www.woodcar.eu

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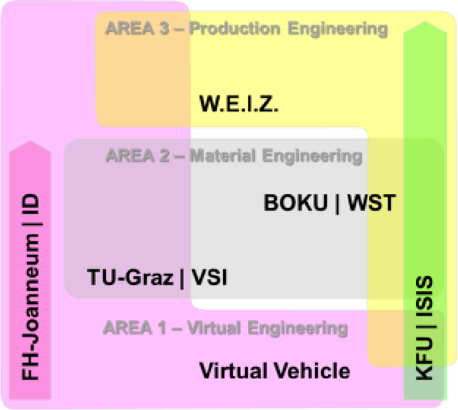

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