Approach to model the material behavior of a wooden layered composite in LS-Dyna

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Motivation

- Ecological aspects
  - public interest
  - new environmental policies

    → vehicles with reduced carbon footprint

- Possible options for green technology vehicles:
  - Usage of renewable fuels
  - Usage of renewable energy during manufacturing
  - **Usage of renewable materials**

    → Biomaterials → Wood

Wood as construction material
Advantages

- renewable
- cheap
- simple machining
- easily accessible resource
- carbon neutral
- recyclable
- combined with a sustainable and local cultivation

→ low carbon footprint as well as environmental impact

- Comparison with classical materials: [Se97], [DIN01], [On01], [On02]

characteristic	unit	Wood (0°)	Mild Steel	Aluminum	CFRP (0°)
density	[kg/m^3]	480-870	~7850	~2750	~1580
Young's modulus	[GPa]	8-17	~210	~70	~182
specific strength	[kNm/kg]	120-250	40-100	110-200	~785
specific stiffness	[MNm/kg]	16-32	25-27	24-26	~114

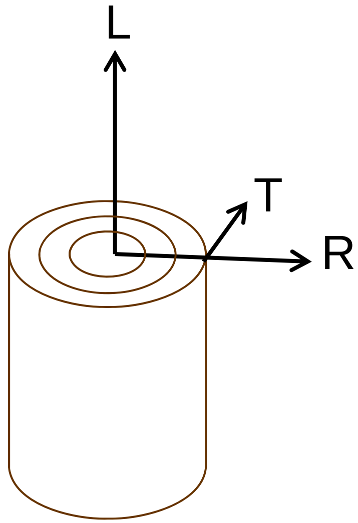
Wood as construction material
General aspects

- huge variety of species
- fibrous and porous
- hygroscopic
- imperfections
- good insulator due to air in the cellular structure
- good damping behavior (noise and vibration)

- 3 main components [Gr98]

	Cellulose	Lignin	Hemicellulose
ratio of dry substance	38-51 %	18-30 %	27-40%
central task	tension / bending	compression	coupling
Type	oriented fibers	polymer matrix	short fibers

Wood as construction material
Structural aspects



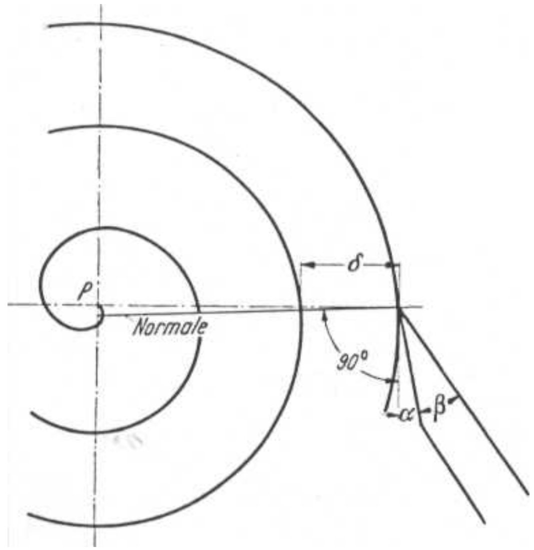
- orthotropic in longitudinal, radial and tangential direction
  - elastic modulus
  - yield stress and fracture mode
  - thermal expansion
  - swelling

- high dependency of mechanical properties on
  - density
  - wood moisture
  - Temperature

- wide scatter of characteristic values between trees of same species

- varying characteristic values depending on location

Wood as construction material
WLC instead of native wood



[Ko36]

- Manufacturing of a wooden layer composite:
  - stewing of a trunk
  - cutting of the trunk
  - drying of the veneer layer
  - applying glue
  - pressing of multiple layers to a composite
- Advantages:
  - optical presorting of layers [DIN02] → fewer imperfections
  - density based presorting of layers → less scatter
  - multiple layers → less impact of imperfections

    → less scatter and better reproducibility
  - engineered wooden layered composite

    → locking of swelling and thermal expansion in R- and T-direction

    → customization to requirements

    → optimal usage of mechanical properties

Material model
Comparison of WLC to CFRP

similarities

- similar setup of an CFRP composite with UD-layers and a WLC
- fiber-matrix-system
- similar behavior:
  - tension/compression anisotropy
  - brittle in tension
  - similar failure modes

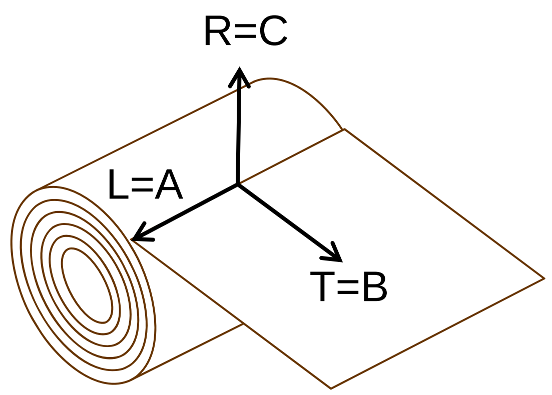
differences

- UD-layer made of endless fiber, wood fibers partly cut during manufacturing of veneer layer
- anisotropy of T- and R-direction
- dependency of mechanical properties on density, humidity and temperature of fiber and matrix

Material model
Requirements and desired properties

- Requirements:
  - LS-Dyna as solver
- Property with priority 1:
  - orthotropic
  - tension handled differently than compression
  - failure
- Property with priority 2:
  - strain rate effects
  - plasticity
  - post-failure simulation
- Properties not to be modelled :
  - creep
  - temperature effects
  - humidity effects

} effects modelled by changing the parameters of the material model



L-, T-, R-directions of a wooden layer in LS-Dyna

Material model
General approach

- full characterization of the veneer layer through testing:
  - mechanical properties as a function of :
    - wood specimen
    - orientation
    - thickness
    - strain-rate
  - literature values only available for native wood
    →testing: tension, compression, shear

- insert testing data in simulation:
  - macroscopic approach
  - 1 layered T-Shell-Composite Element through thickness (5 for bending due to locking)
  - 1 integration point per layer
  - failure after first integration point fails
  - orthotropic material card with priority 1 and 2 properties

Material model
General approach

- Comparison of existing material models in LS-Dyna:
  → no material model fulfills all priorities
    → modification of the most promising ones and comparison with each other (results, cost-efficiency, stability) and testing data
    → sensitivity analysis to get the driving parameters

- alternative approach:
  - combined shell model
  - shell layers tied by cohesive elements
  - orthotropic material card with priority 1 and 2 properties

Summary

- WLC has a huge potential
- scatter of characteristic values despite the use of WLC
  - → probabilistic approach
    - → quantile e.g. 10%/90%
- behaviour of a veneer layer comparable to UD-CFRP-layer
- testing data of veneer layers necessary
- material model must be developed

Thank you for your attention!

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Sources

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  - [Gr08]: Grimsel, M.: Mechanisches Verhalten von Holz. Dissertation, 1998
  - [Ko36]: Kollmann, F.: Technologie des Holzes und der Werkstoffe, VDI, 1936
  - [Ni93]: Niemz, P.: Physik des Holzes und der Holzwerkstoffe, DRW-Verlag, 1993
  - [Se97]: Sell, J.: Eigenschaften und Kenngrößen von Holzarten, Lignum, 1997

- Standards:
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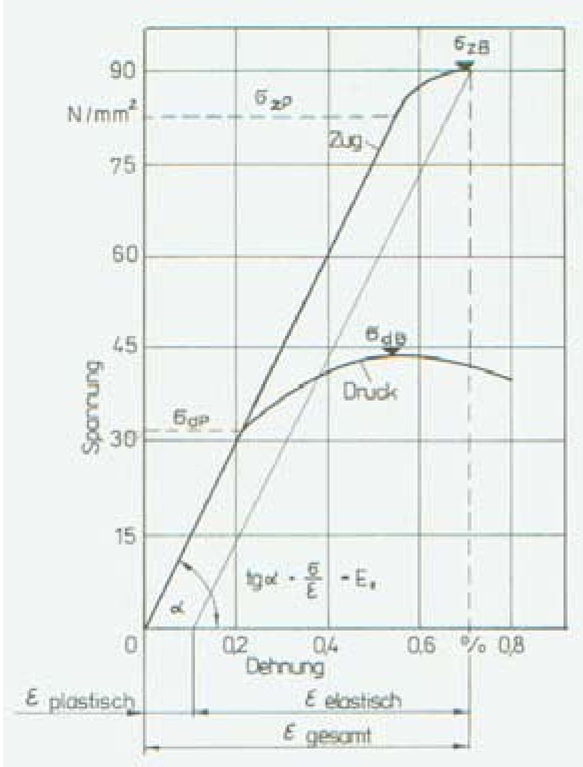
  - [Din02]: DIN 4074-5:2008-12, Sortierung von Holz nach der Tragfähigkeit - Teil 5: Laubschnittholz
- Online:
  - [On01]: Aluminum alloy 6061-T6, asm.matweb.com/search/specificMaterial.asp
  - [On02]: CFRP Hexel IM8, www.hexcel.com/user_area/content_media/raw/IM8_ HexTow_ DataSheet.pdf

Open questions for the discussion



[Ni93]

- transversal isotropic instead of orthotropic [GR08]?
  - $E_T : E_R : E_L \approx 1{,}0 : 2{,}0 : 12{,}0$
  - $G_{RT} : G_{TL} : G_{LR} \approx 1{,}0 : 2{,}3 : 3{,}5$

- brittle fracture in tension, ductile in compression

→ Which failure criterion is best suited?
  - Tresca
  - Hashin
  - Liu-Huang-Stout
  - Stress based & strain based

- failure in c-direction due to delamination inside a wooden layer and thickness of glue almost zero due to pressing

  → Is there a necessity to model the glue or is it negligible?

Transversal isotropic vs. orthotropic

- Transversal isotropic in B- and C-direction:
  - no coupling between tension and shear and vice versa
  - Inverse of stiffness matrix $S = \begin{bmatrix} \frac{1}{E_A} & \frac{-\nu_{AB}}{E_A} & \frac{-\nu_{AB}}{E_A} & & 0 & \\ \frac{-\nu_{AB}}{E_A} & \frac{1}{E_B} & \frac{-\nu_{BC}}{E_B} & & & \\ \frac{-\nu_{AB}}{E_A} & \frac{-\nu_{BC}}{E_B} & \frac{1}{E_B} & & & \\ & & & \frac{2(1+\nu_{BC})}{E_B} & 0 & 0 \\ & 0 & & 0 & \frac{1}{G_{AB}} & 0 \\ & & & 0 & 0 & \frac{1}{G_{AB}} \end{bmatrix}$
  - 5 independent material constants instead of 9