Talcum Particle Reinforced Thermoplastics - Part II Material Modeling and Simulation

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Thermoplastic polymers reinforced with mineral (talc) particles typically display an anisotropic mechanical behavior that results from the preceding manufacturing process (e.g. injection moulding) with a distinctive direction of melt flow [1]. Moreover, plastic dilatancy under tensile loading is observed which can be ascribed to particle-matrix debonding and subsequent void growth; see e.g. [2].
Based on the experimental study presented in [1], the present work deals with the development and implementation of a macroscopic constitutive model for talc particle reinforced polymers. Key incredients of the model are an anisotropic pressure-dependent yield criterion that contains the porosity due to void growth as a damage parameter, along with a rate and temperature dependent associated flow rule. The model well captures the experimentally observed anisotropy of the yield strength as well as the (likewise anisotropic) plastic dilatancy under tension. It has been implemented as a user-defined material model in LS-Dyna, and aspects of the numerical treatment will also be discussed in the presentation. Application to components subjected to crash loading serve to validate the constitutive model. Therefore, anisotropy directions and positions of weld lines as predicted from mould filling simulations [1] are accounted for via a mapping strategy.

References

[1] Kunkel, F., Becker, F. (2010). Talcum Particle Reinforced Thermoplastics - Part I Influence of Processing Conditions and Experimental Characterization. 9th German LS-DYNA User Forum, Bamberg.
[2] Hadal, R.S., Dasari, A., Rohrmann, J., Misra, R.D.K. (2004). Effect of Wollastonite and Talc on the Micromechanisms of Tensile Deformation in Polypropylene Composites. Mat. Sci. Eng. A 372, 296-315.

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Material Modeling and Simulation

Philipp Hempel, Thomas Seelig – Institut für Mechanik

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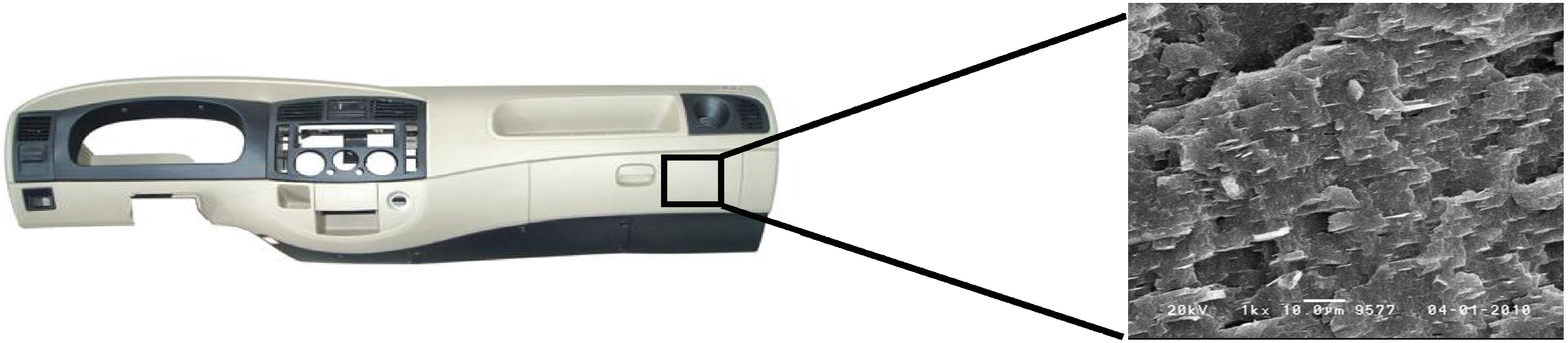
Outline

- Introduction
  - Motivation
  - Experimental findings
- Material model
  - Theoretical framework
  - Model response
- Validation

Motivation

- thermoplastic polymers (e.g. PP) reinforced with talc (mineral) particles used in many technical applications



- macroscopic material models needed for structural analyses, e.g. crash simulations

Experimental findings – Hostacom (PP/talc)

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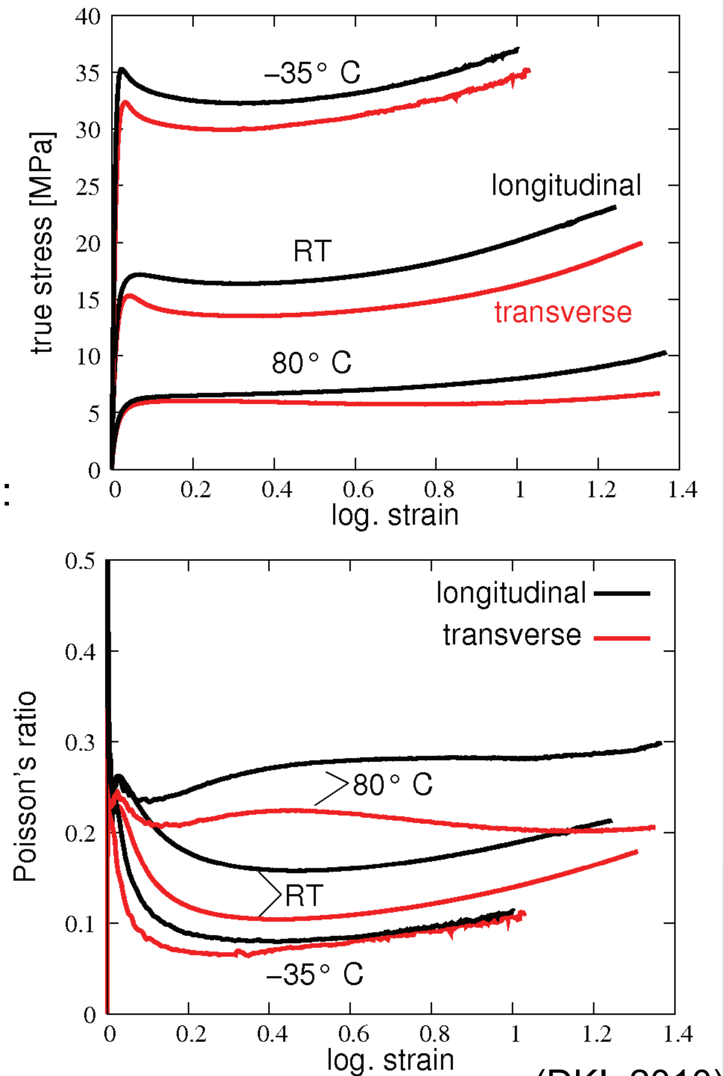
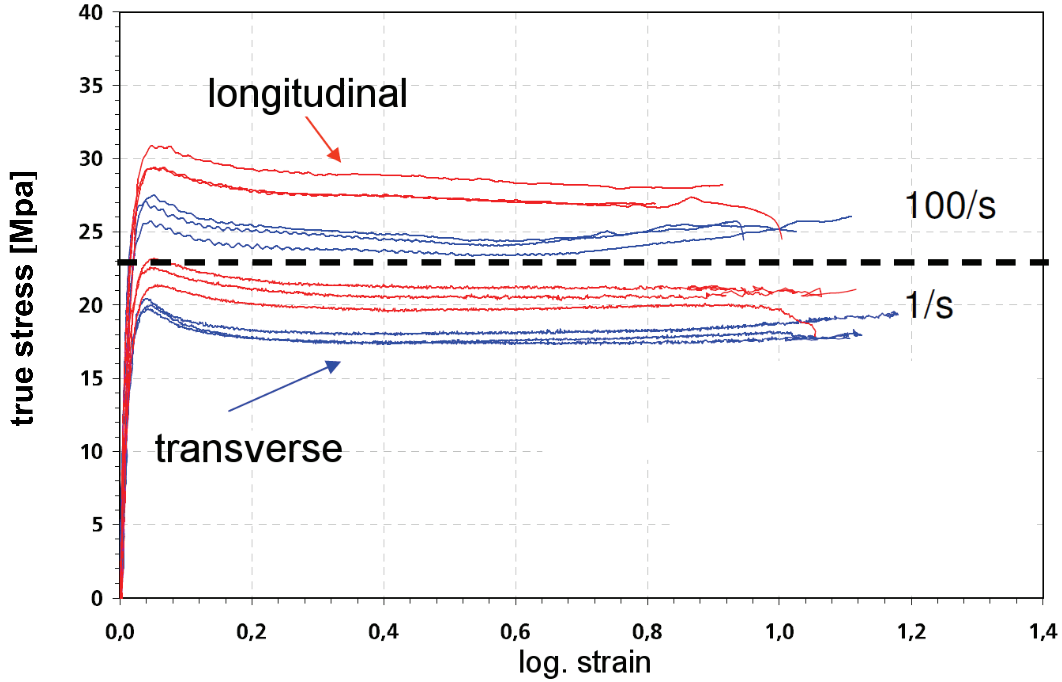
- **elastic behaviour** (small strains) **nearly isotropic**
- **plastic anisotropy** due to injection moulding:
  higher **yield stress in flow direction** („longitudinal")
  than perpendicular to flow direction („transverse")
- Poisson‘s ratio (= - transverse strain/ longitudinal strain):
  at uniaxial tension **drop** from (elastic) initial value
  => plastic dilatancy
  depends on direction, i.e. **anisotropy**
- temperature dependency of **stiffness**, **yield stress**,
  hardening and **plastic dilatancy**



(DKI, 2010)

Experimental findings – Hostacom (PP/talc)

- strain rate dependency of yield stress
- anisotropic behaviour at **different strain rates**



(IWM, 2010)

Material model - features

- **elastic isotropy**
- **plastic transverse isotropy** (anisotropy direction = flow direction „longitudinal“)
- **plastic dilatancy under tension**
- **plastic incompressibility under compression**
- **softening** and **rehardening**
- **strain rate** dependency
- **temperature** dependency of **stiffness**, **yield stress**, **hardening** and **plastic dilatancy**
- implemented in LS-Dyna for **solids** and **shells**

Material model – general structure

- elasticity (rate form) $\overset{\nabla}{\boldsymbol{\sigma}} = \mathsf{E} : (\boldsymbol{D} - \boldsymbol{D}^p)$ **E**: elasticity tensor

- flow rule $\boldsymbol{D}^p = \dot{\varepsilon}^p \boldsymbol{N}$ with $\boldsymbol{N}(\boldsymbol{\sigma}) = \dfrac{\dfrac{\partial \Phi}{\partial \boldsymbol{\sigma}}}{\sqrt{\dfrac{\partial \Phi}{\partial \boldsymbol{\sigma}} : \dfrac{\partial \Phi}{\partial \boldsymbol{\sigma}}}}$

- flow potential $\Phi(\boldsymbol{\sigma}, \varepsilon^p, f, \text{mat. param's})$

- plastic strain rate $\dot{\varepsilon}^p = \dot{\varepsilon}_0 \langle \Phi \rangle^{1/r}$, $\langle x \rangle = \begin{Bmatrix} x & , & x \geq 0 \\ 0 & , & x < 0 \end{Bmatrix}$

- porosity $\dot{f} = (1 - f)\ \mathrm{tr}\boldsymbol{D}^p$

Material model – flow potential

$$\Phi(\boldsymbol{\sigma}) = \sqrt{\boldsymbol{\sigma} : \mathbf{A} : \boldsymbol{\sigma}} - g(T)(1-f)$$

A: forth order tensor

$$[\mathbf{A}] = \begin{bmatrix} a_{11} & a_{12} & a_{12} & 0 & 0 & 0 \\ a_{12} & a_{22} & a_{23} & 0 & 0 & 0 \\ a_{12} & a_{23} & a_{22} & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(a_{22}-a_{23}) \end{bmatrix}$$

transverse isotropy:

5 independent parameters

- a_{11}, a_{12}, a_{22} obtainable from tensile tests (flow stress, plastic Poisson‘s ratio)
- assumption due to lack of data: $a_{23} = a_{12}\,,\ a_{44} = 2(a_{22} - a_{12})$ (v. Mises like)

Material model – hardening and temperature

- **hardening:** $a_{11} = \dfrac{a_{11_0}}{1 + h_1(T)\,\varepsilon_p^{n_1}}$ $\quad a_{22} = \dfrac{a_{22_0}}{1 + h_2(T)\,\varepsilon_p^{n_2}}$

- **material parameters (11):** $(E\,,\nu\,,a_{11_0}\,,a_{12_0}\,,a_{22_0}\,,h_1\,,h_2\,,n_1\,,n_2\,,\dot{\varepsilon}_0\,,r)$

- **temperature dependency :**

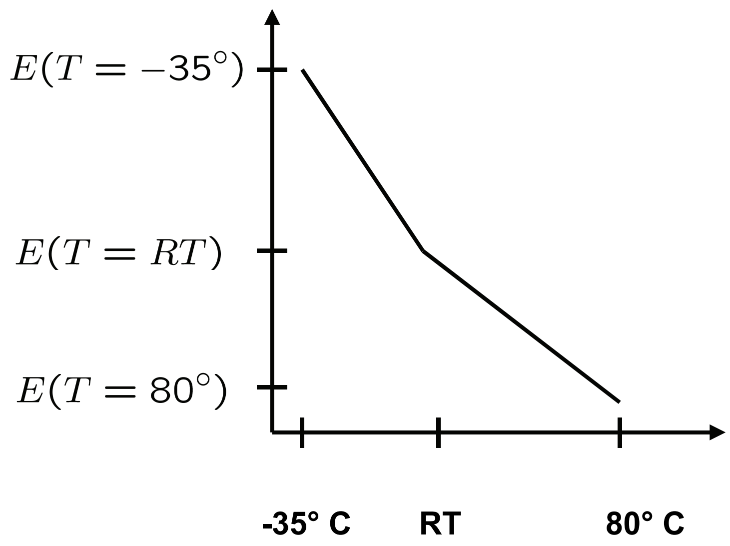
  bi-linear fit (interpolation) between 3 testing temperatures (-35° C, RT, 80° C) :

  - stiffness $E(T)$

  - yield stress $g(T)$

  - hardening $h_1(T)\,,\ h_2(T)$

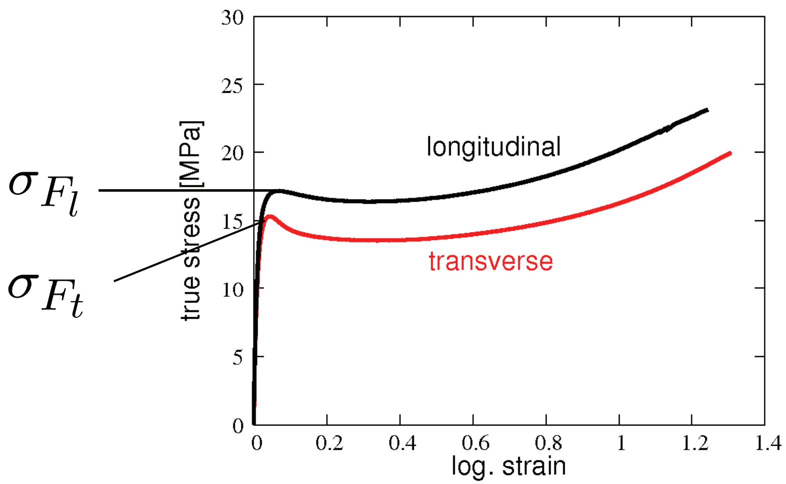
  - plastic dilatancy $a_{12}(T)$

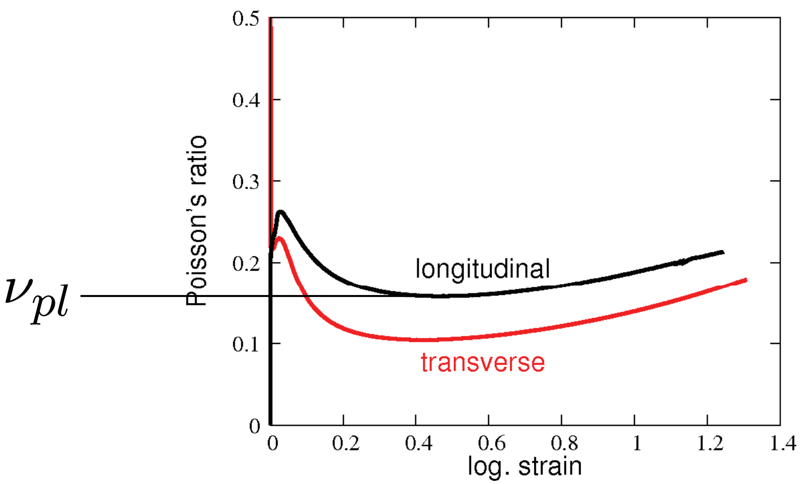


Material model – parameter identification

- yield stresses and plastic Poisson's ratio identifiable from uniaxial tensile tests
- parameters by evaluation of yield criterion and flow rule for uniaxial tension:

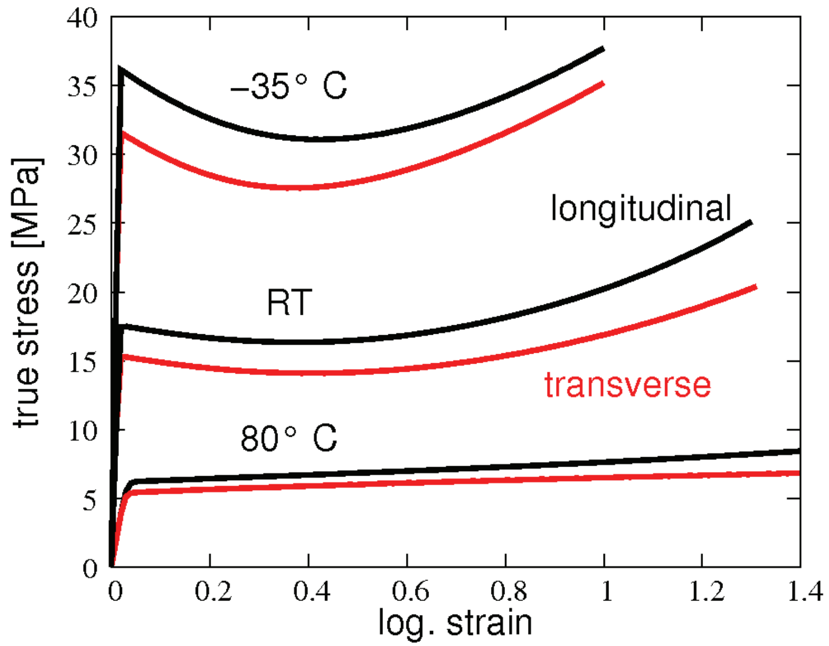
$$a_{11_0} = \frac{4}{(\sigma_{F_l})^2} \qquad a_{22_0} = \frac{4}{(\sigma_{F_t})^2} \qquad a_{12_0} = -\nu_{pl} a_{11_0}$$

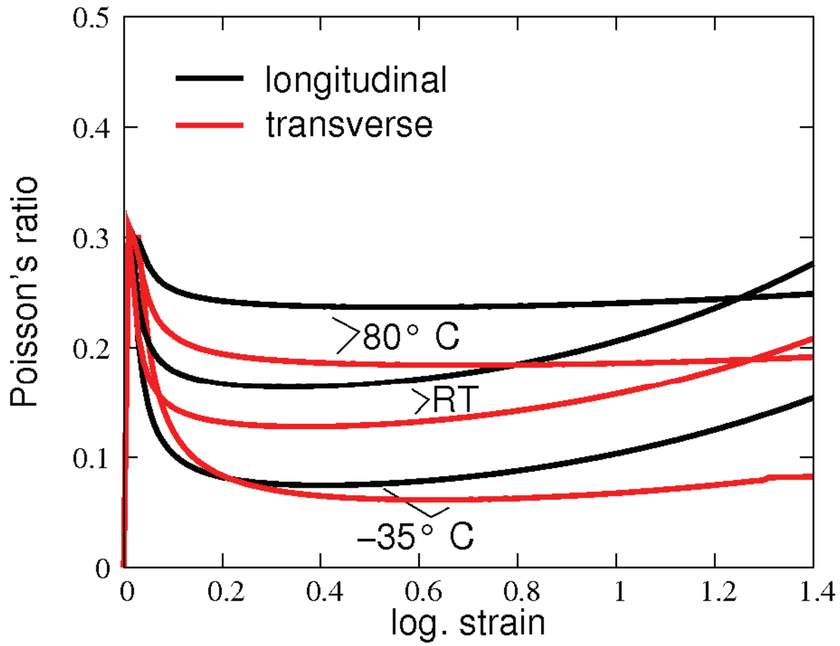




Model response

- **uniaxial tension**



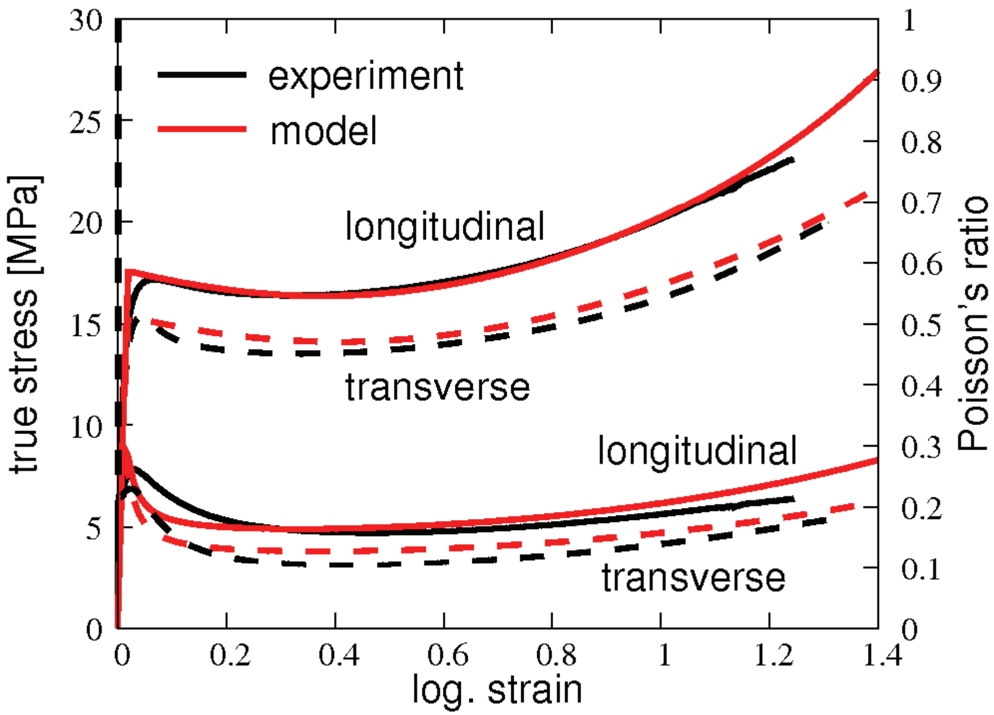


- plastic anisotropy
- temperature dependency of
  - stiffness
  - flow stress
  - hardening

- plastic dilatancy
  (direction- and temperature dependent)

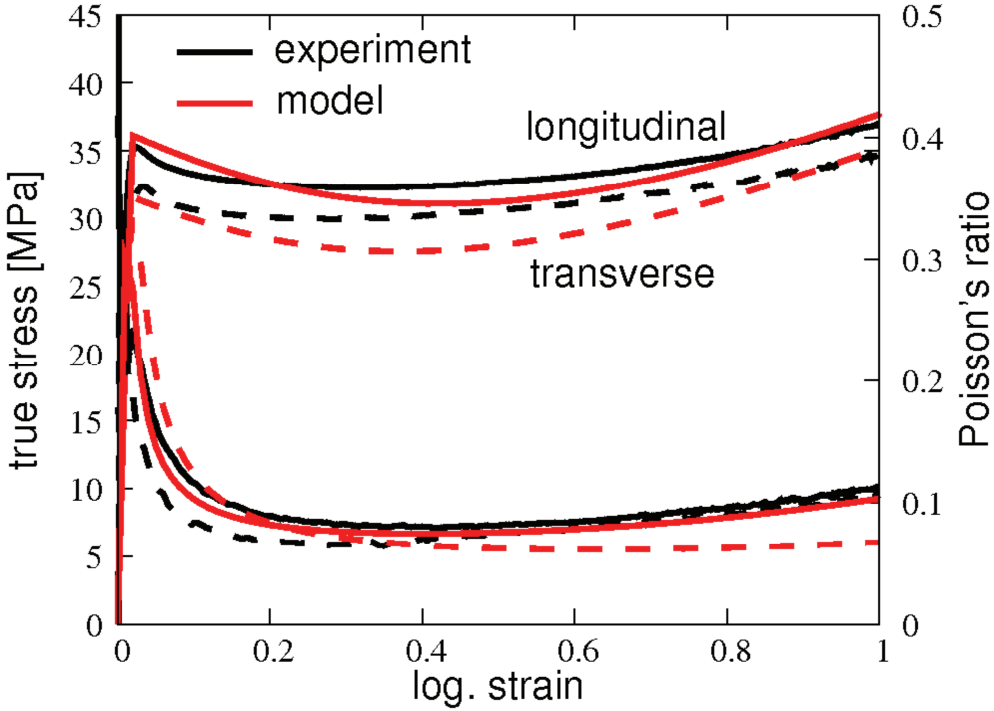
Comparison model – experiment

- **uniaxial tension, room temperature**



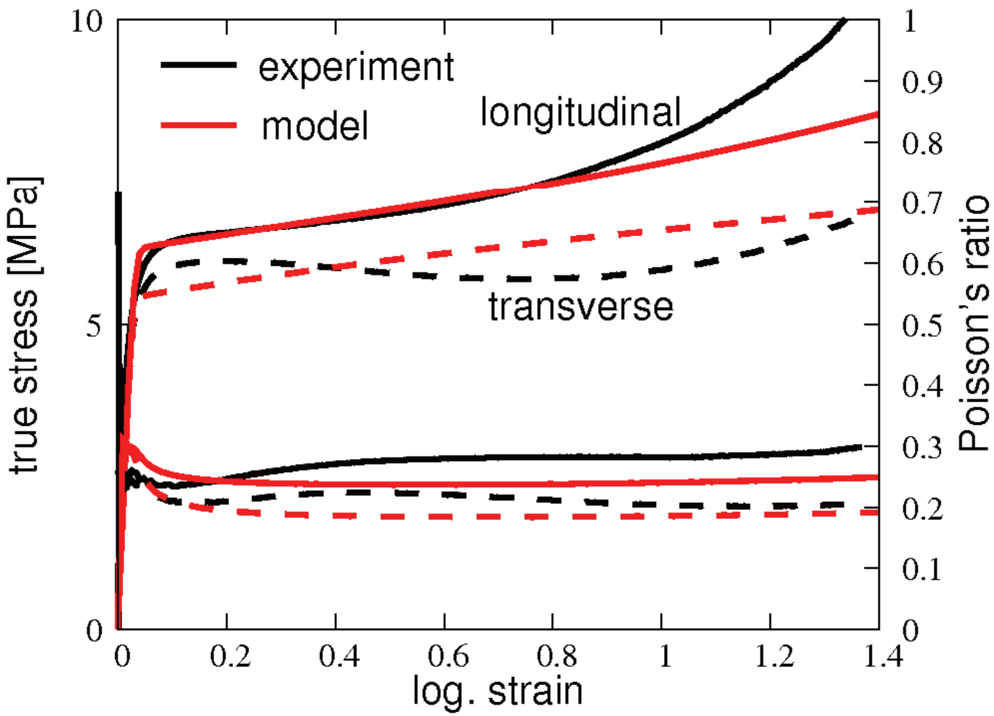
Comparison model – experiment

- **uniaxial tension, -35° C**



Comparison model – experiment

- **uniaxial tension, 80° C**



Comparison model – experiment

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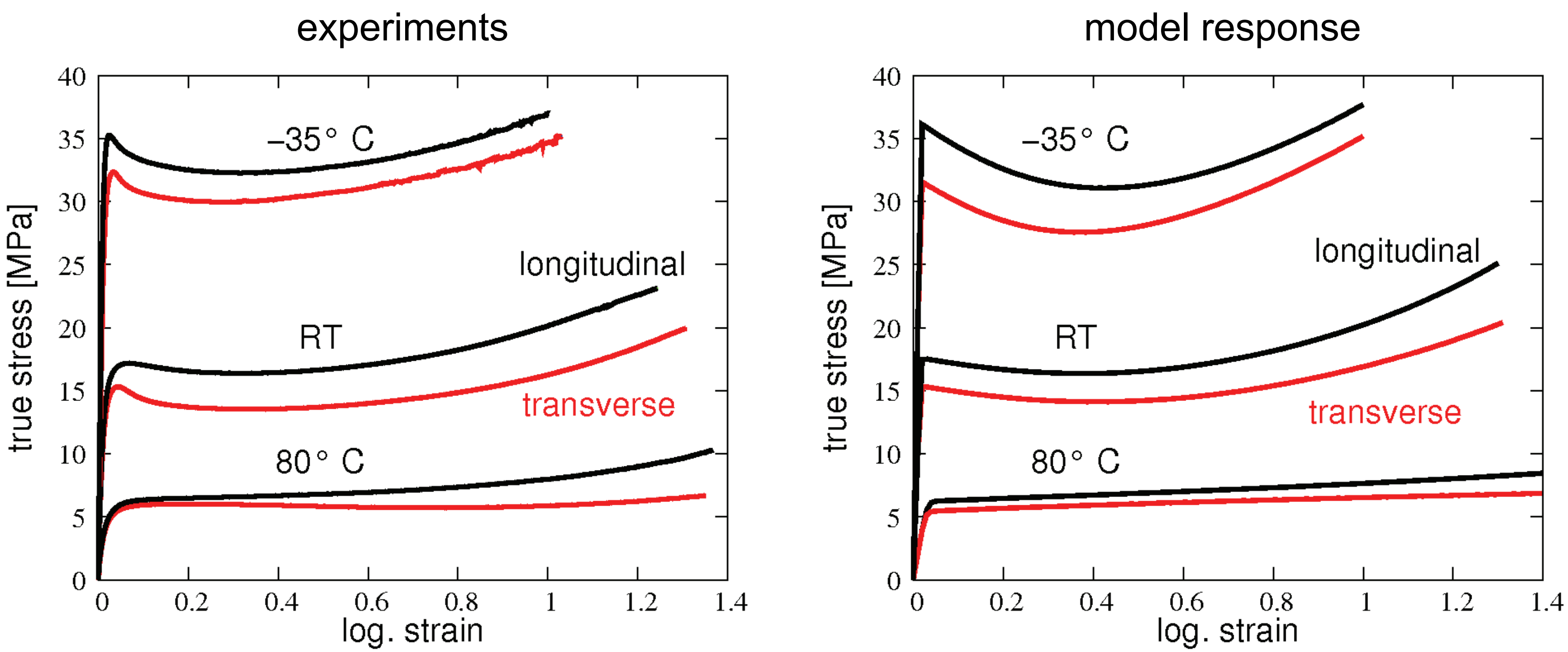
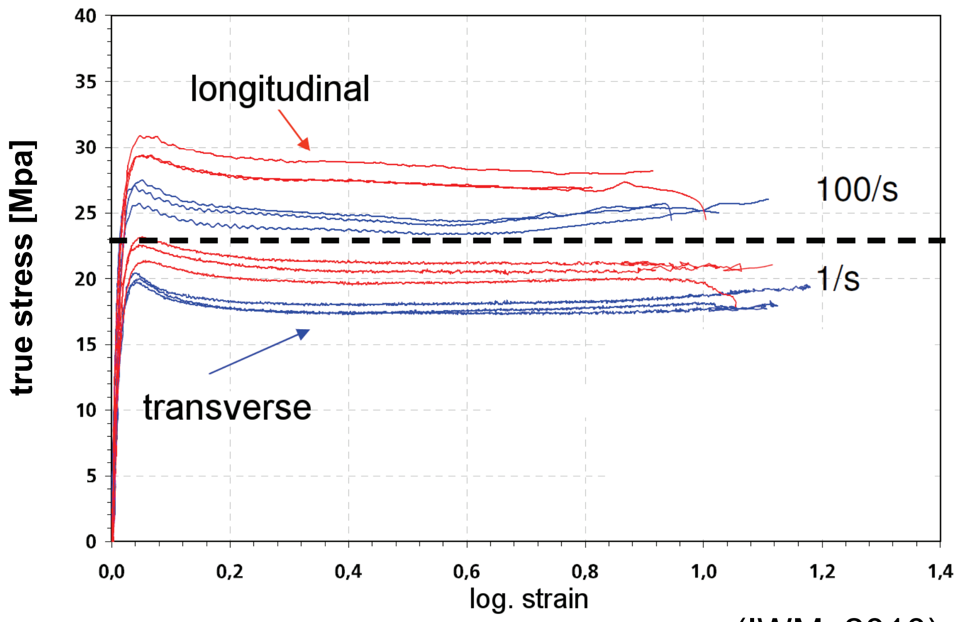
- **uniaxial tension, all temperatures**



Comparison model – experiment

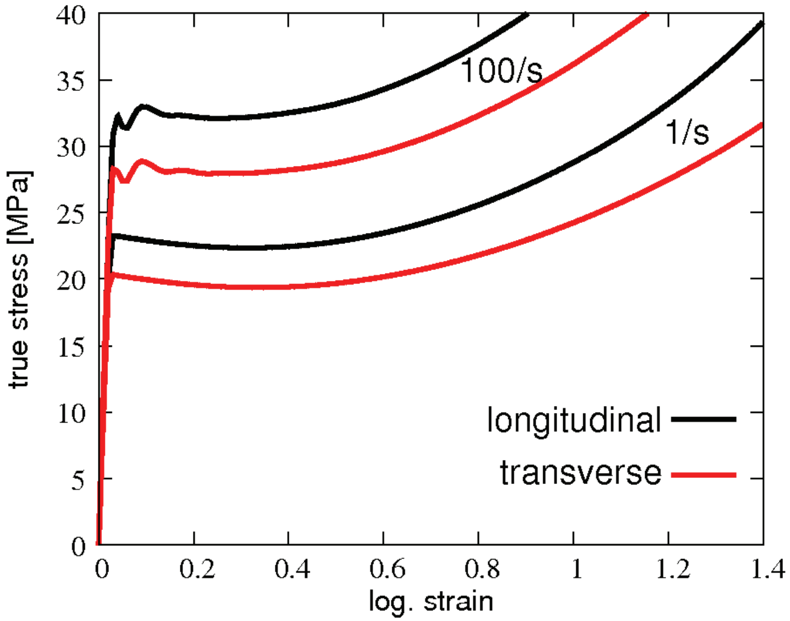
- **strain rate dependency, room temperature**

experiments



(IWM, 2010)

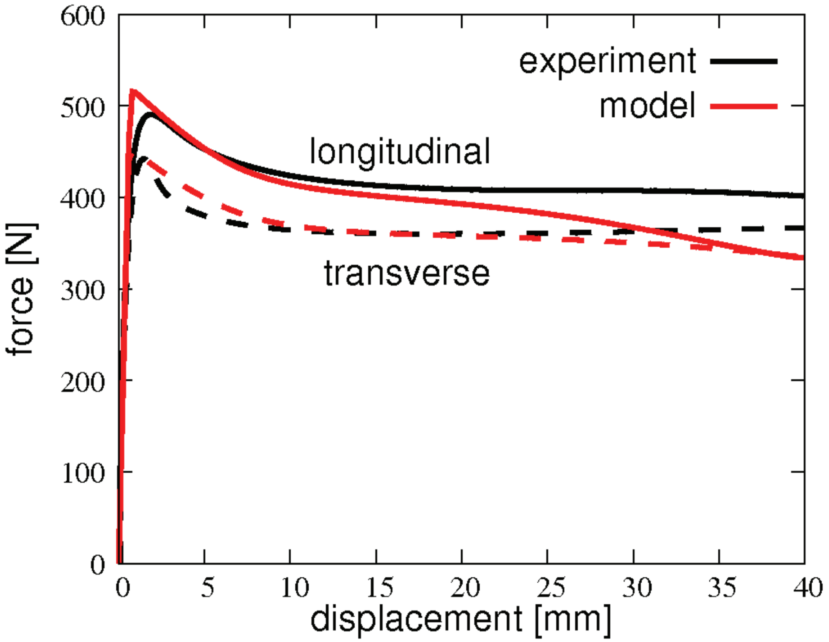
model response



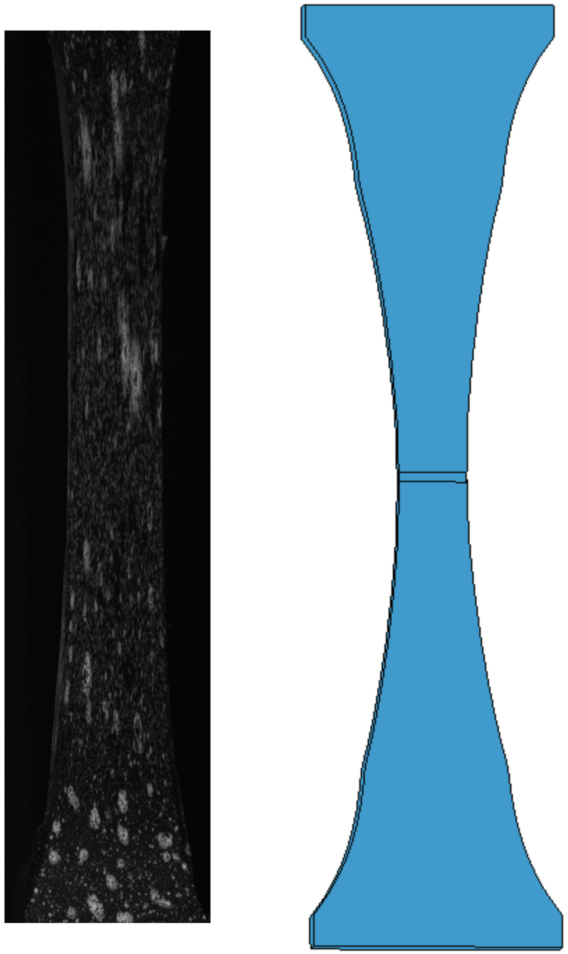
Validation

- **Tensile test simulation**

  room temperature



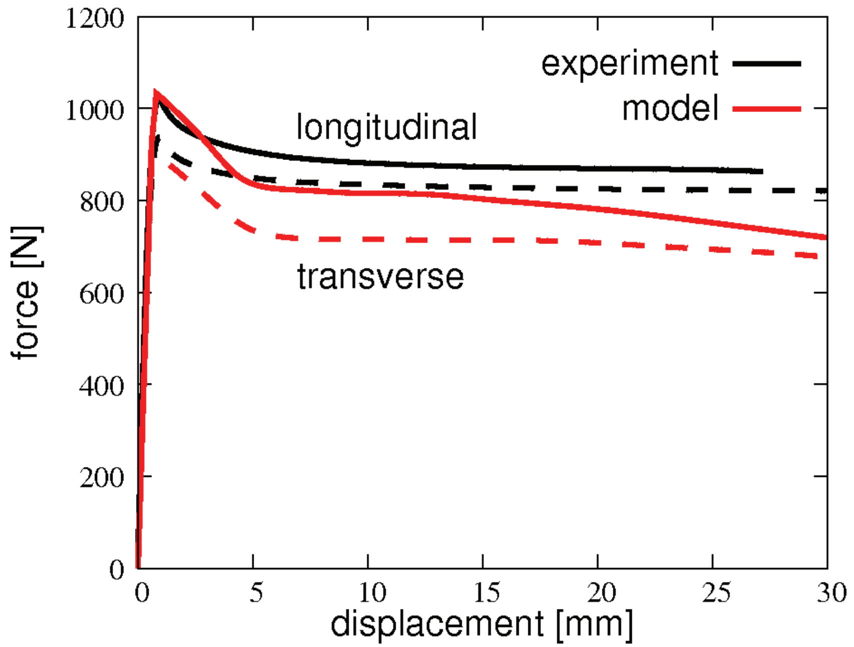
deformed specimen



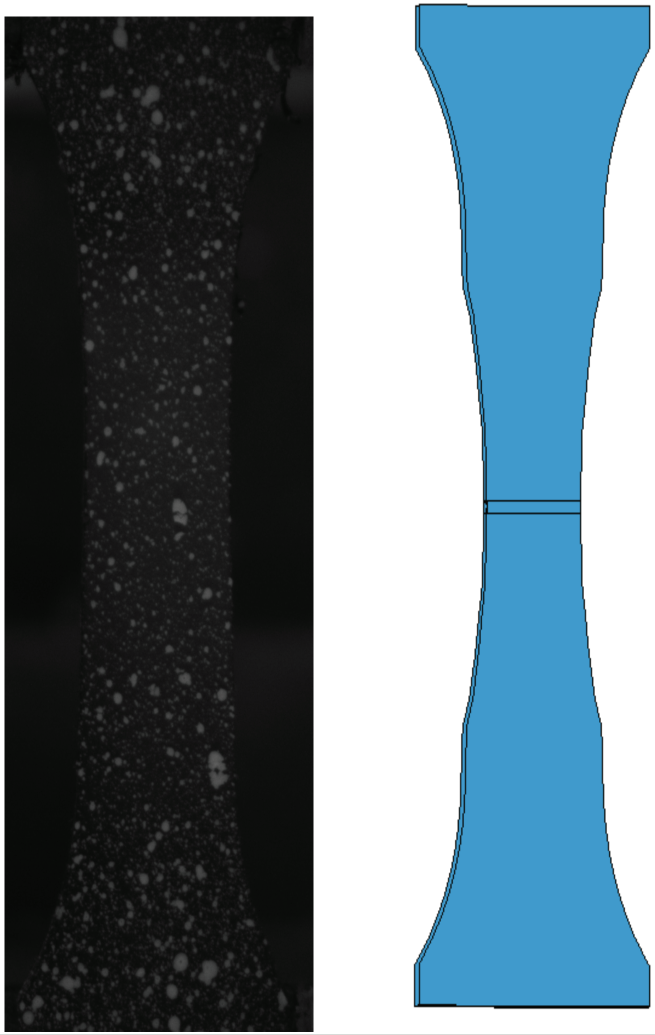
Validation

- **Tensile test simulation**

  temperature: -35° C



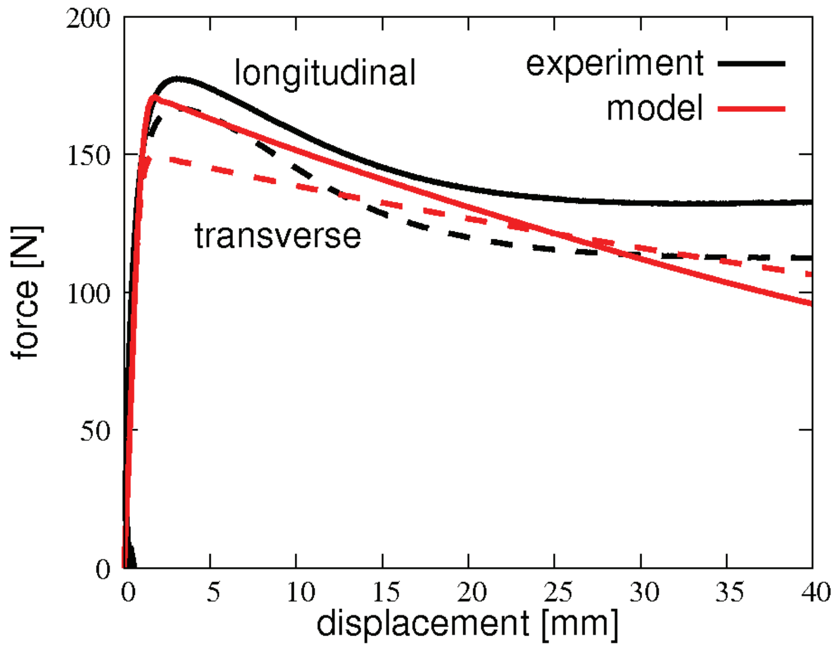
deformed specimen



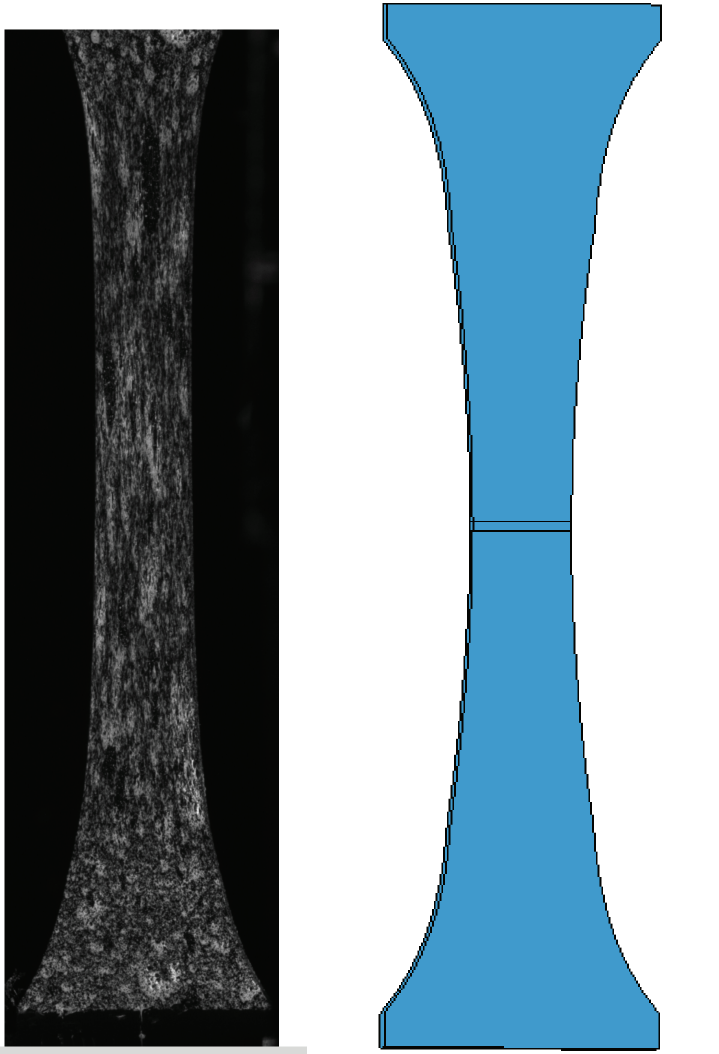
Validation

- **Tensile test simulation**

  temperature: 80° C

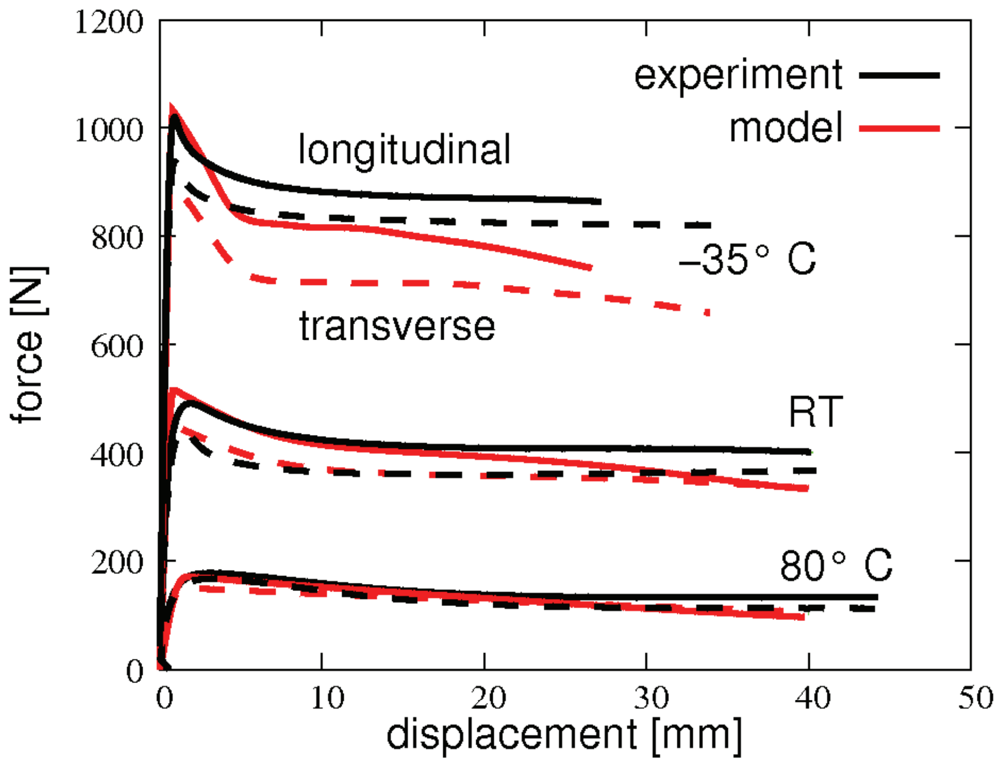


deformed specimen



Validation

- **Tensile test simulation all temperatures**



=> overestimation of necking in longitudinal direction

Conclusions

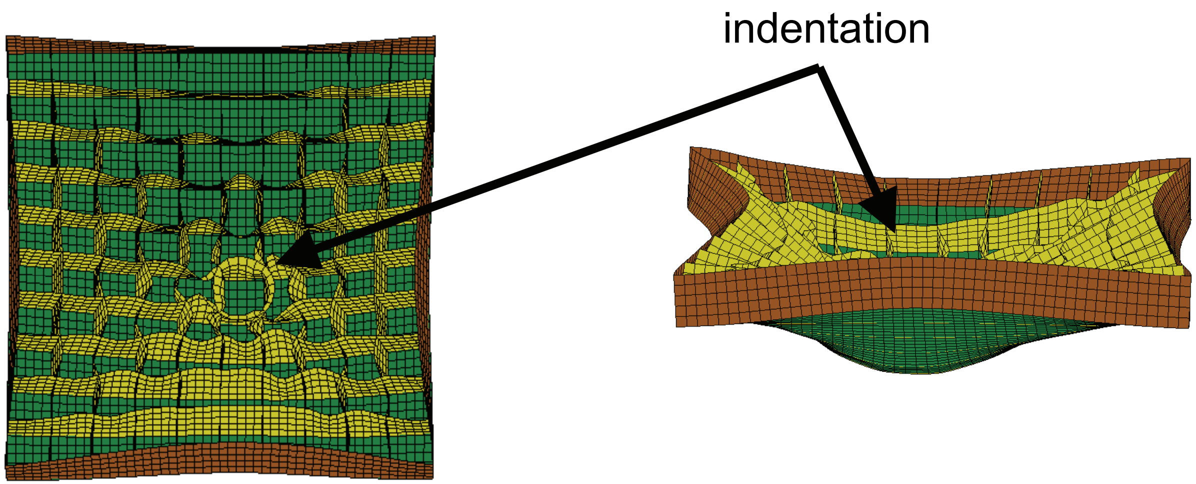
- material model shows qualitative and quantitative agreement of anisotropy, temperature and strain rate dependency, plastic dilatancy
- material parameters easy to fit
- temperature dependency tabulated
- implemented as a user defined material model in LS-Dyna for solids and shells
- model fine tuning required:
  - necking of tensile specimen
  - fit for compression test data

Outlook

- failure criteria for bulk material and weld lines

- mapping of flow direction and weld line locations
  from mould filling simulation to FE model => „process chain“

- crash-simulation of component to validate the model



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Thank you for your attention

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