TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

Faculty of Mechanical Science and Engineering
Chair of Computational and Experimental Solid Mechanics

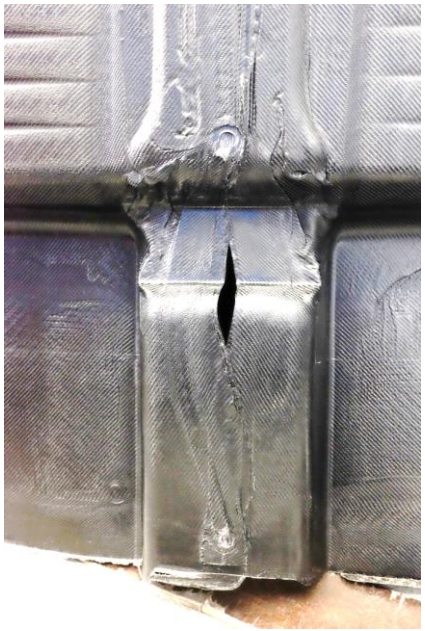
Jean-Paul Ziegs

Numerical Modeling of Single-Step Thermoforming of a Hybrid Metal/FRP Lightweight Structure

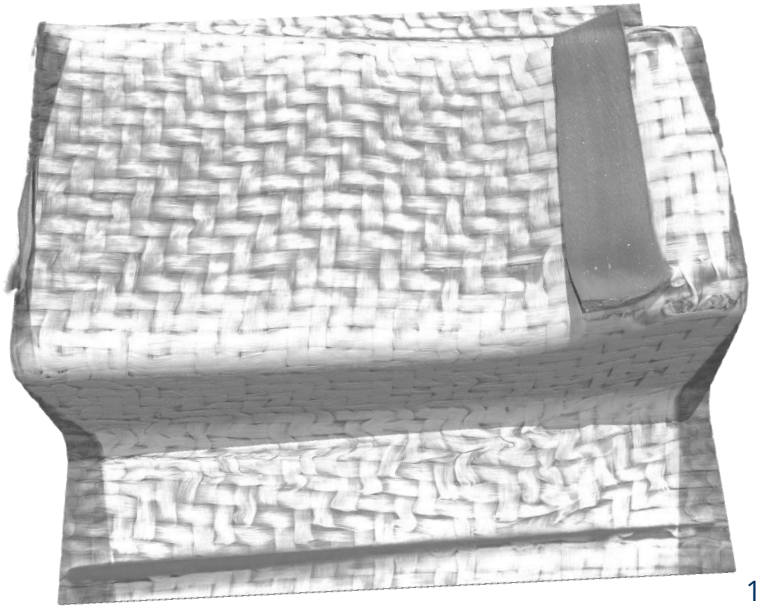
15th German LS-DYNA Forum 2018 // Bamberg // 15.-17.10.2018

FKM

- Manufacturing process of hybrid workpieces characterized by “trial and error”



1)



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1) TU Dresden, ILK

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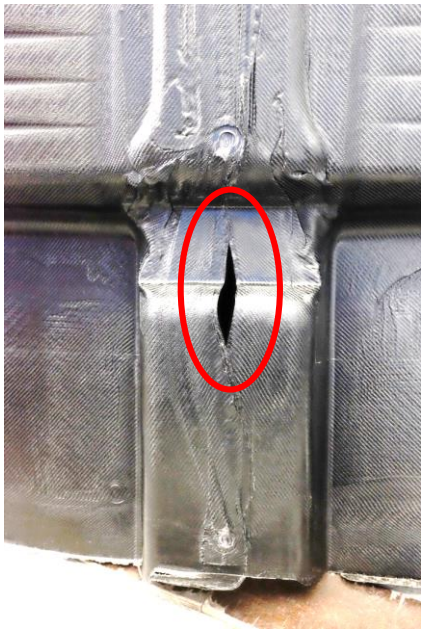

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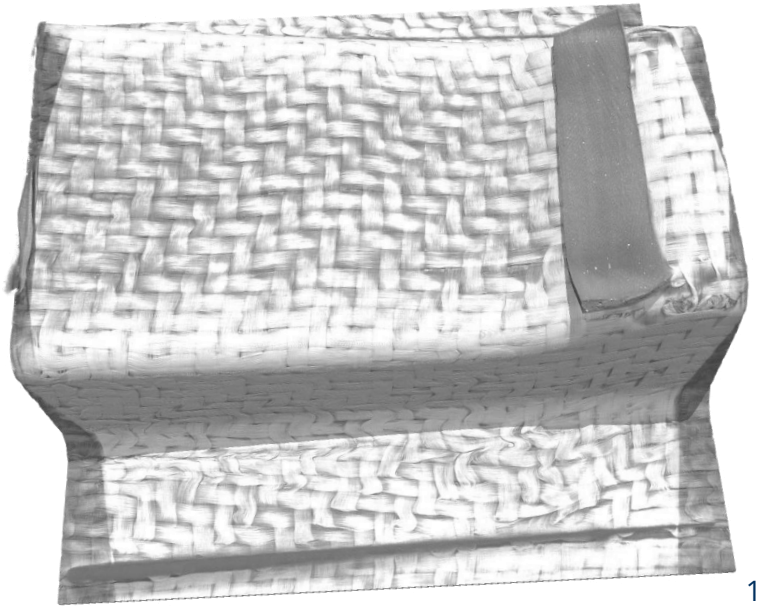

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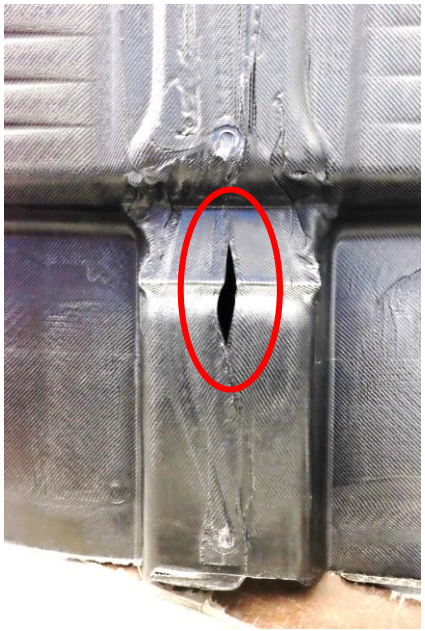

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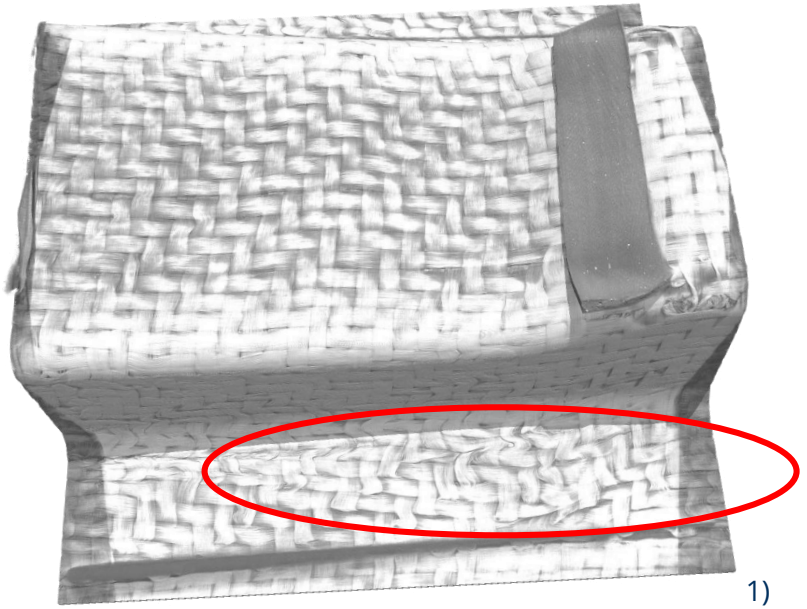

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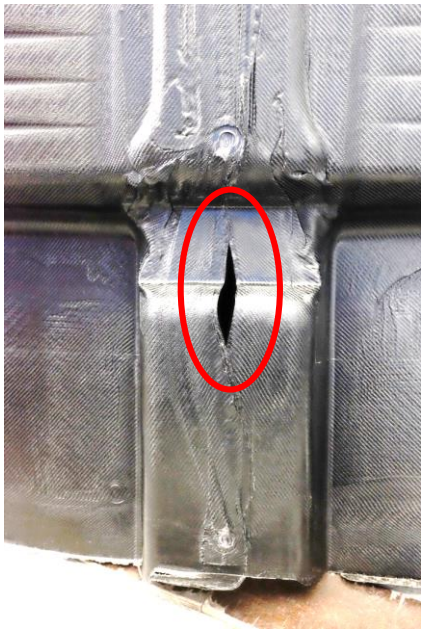

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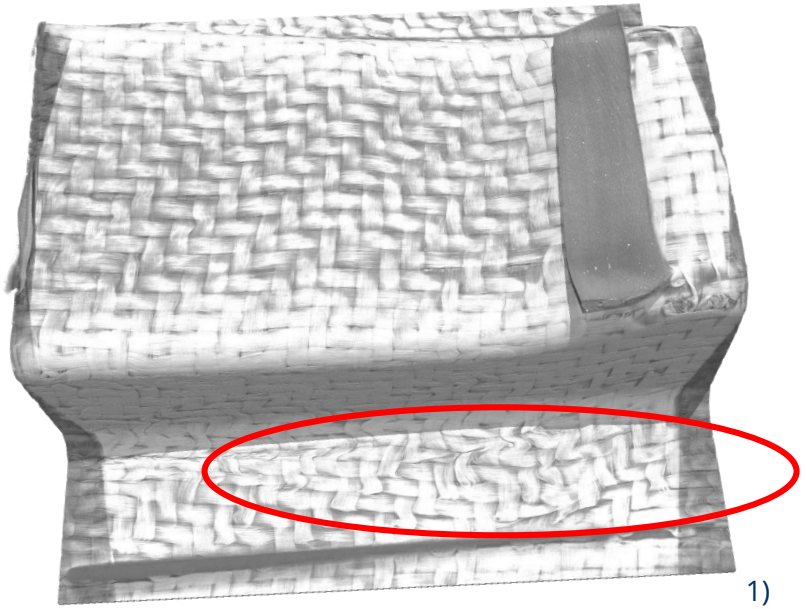

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➢ Simulation of manufacturing processes to optimize process parameters

1) TU Dresden, ILK

Introduction and motivation

Process chain

Material modeling and parametrization

Process simulation and results

Summary

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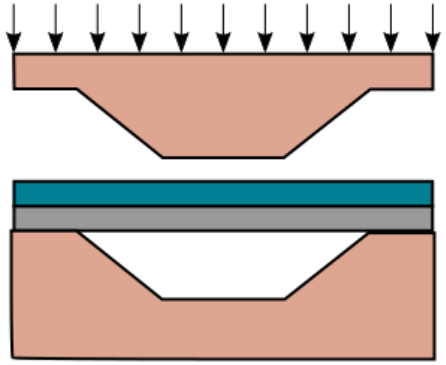
Manufacturing process



2)

2) TU Dresden, IF

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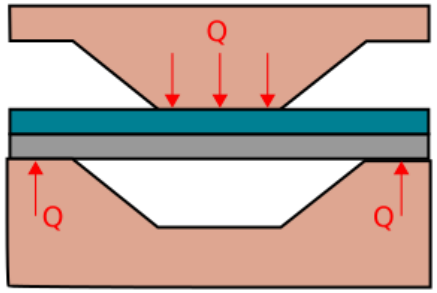


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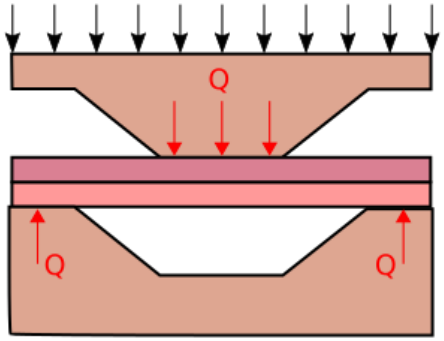

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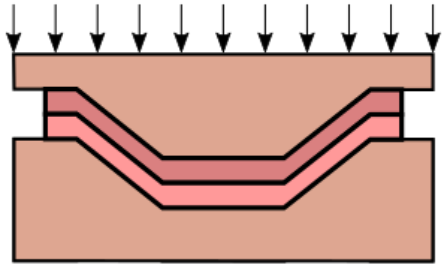

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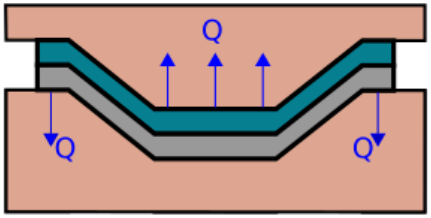


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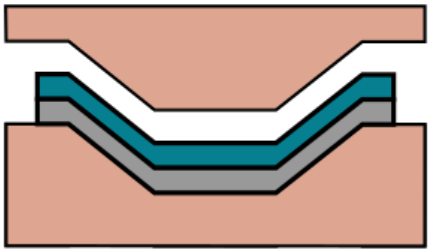

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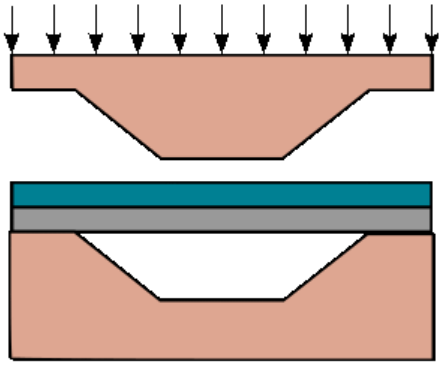

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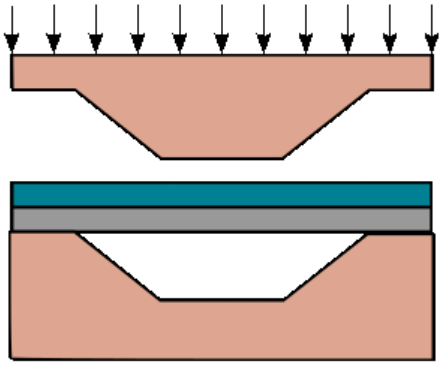

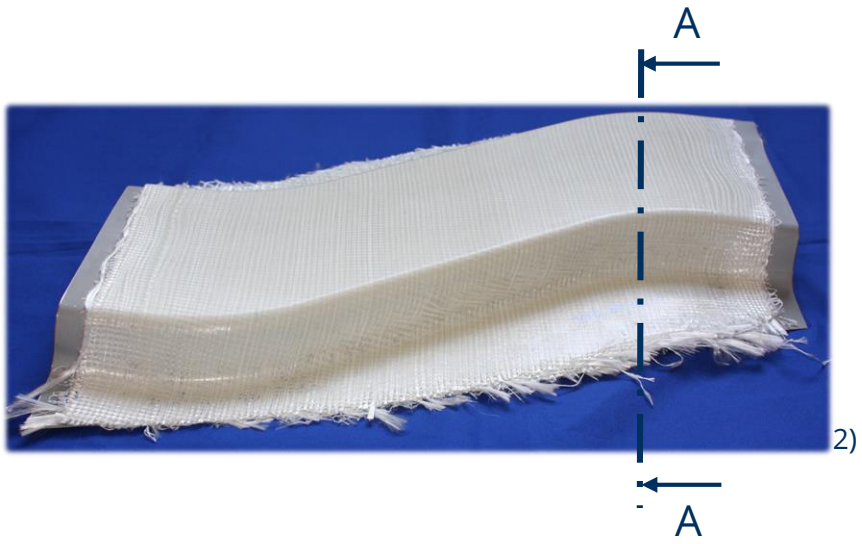

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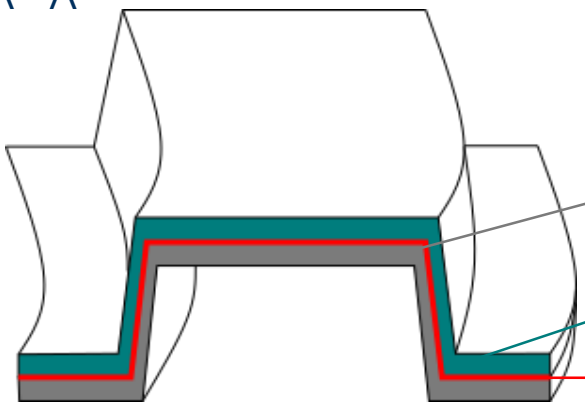


Material modeling to predict behavior of:

Metal

Fiber-reinforced plastic

Interface

2) TU Dresden, IF

Material modeling and parametrization

➢ Metal (*MAT122-Hill_3R)

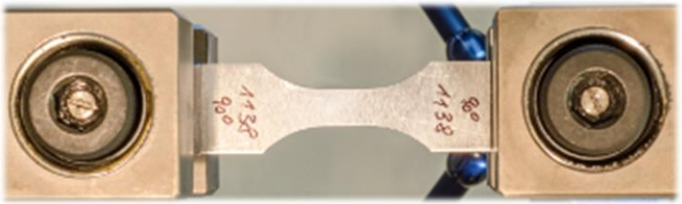
Metal sheet: DC05


3)

Constitutive law:

- Anisotropic elastic-plastic
- HILL48–yield criterion
- Temperature independent

Uniaxial tension tests for parameter identification



3) ThyssenKrupp-Company presentation, February 2013

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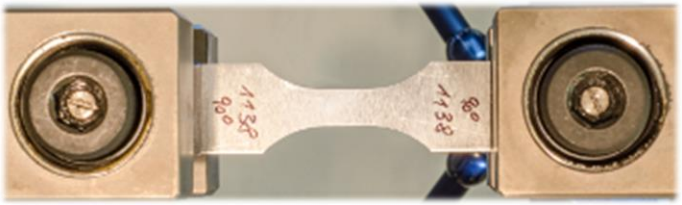
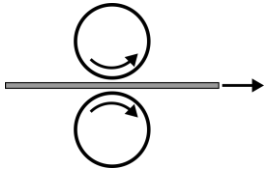
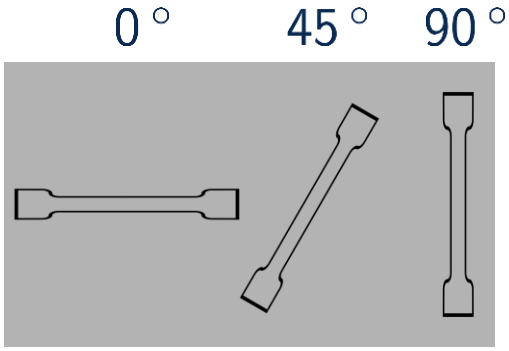
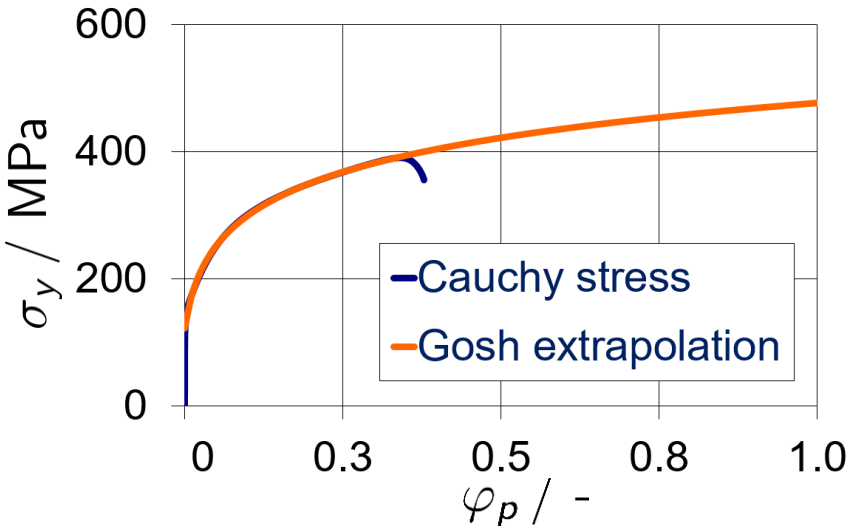


Rolling direction





Parameter	E	ν	R_{00}	R_{45}	R_{90}
Value	207 GPa	0.28	1.88	1.4	2.23



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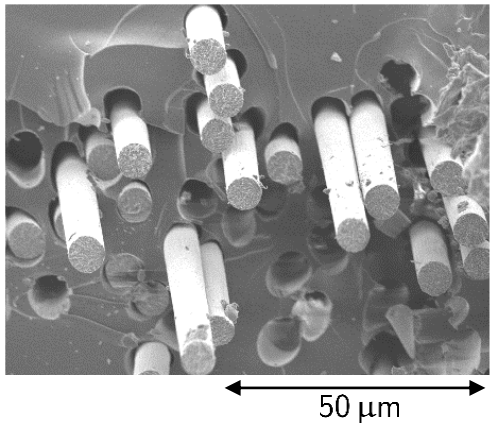
Material modeling and parametrization

➢ FRP (*MAT249-Reinforced_Thermoplastic)

FRP material: CF-PA6.6



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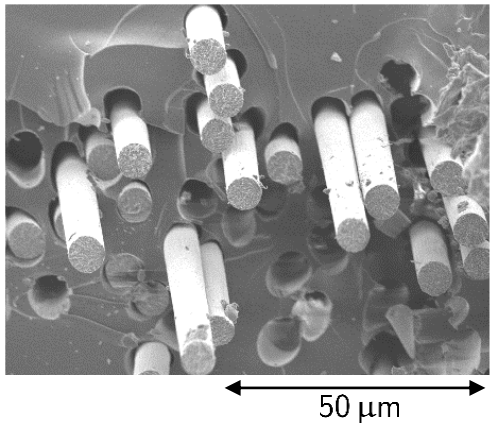

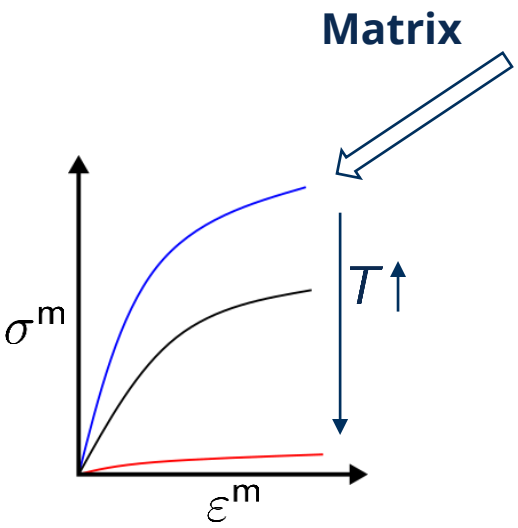

- Thermo-elastic-plastic
- V. MISES-yield criterion
- Vanishing stiffness and yield stress at melting temperature

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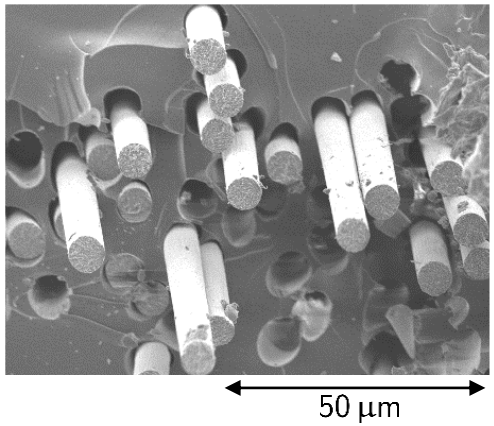
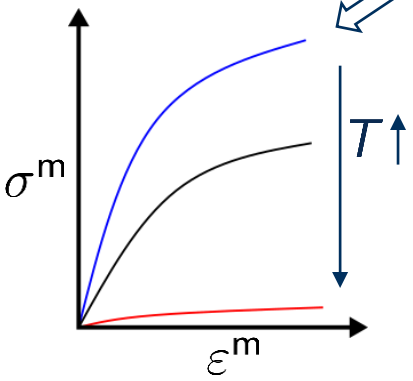


Matrix



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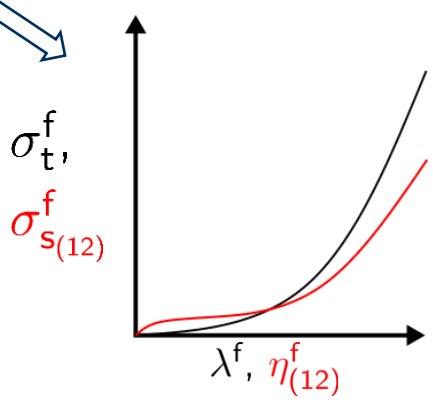
Fiber



- Effective behavior
- Anisotropic, non-linear elastic
- Different treatments for tension/compression and shear response

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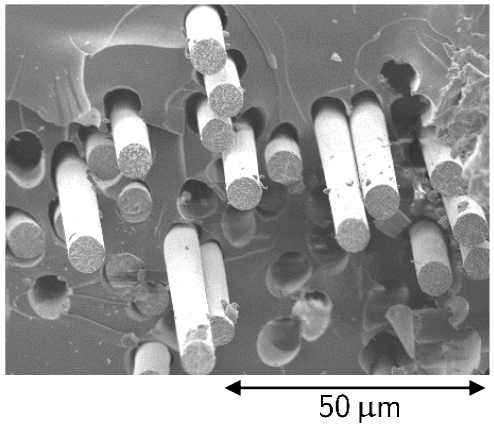

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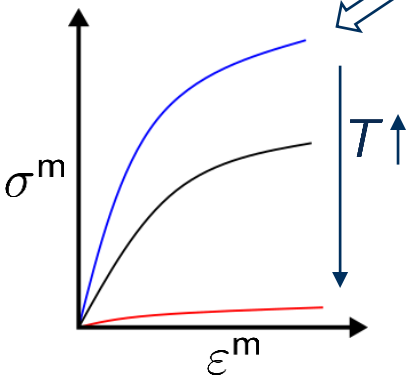
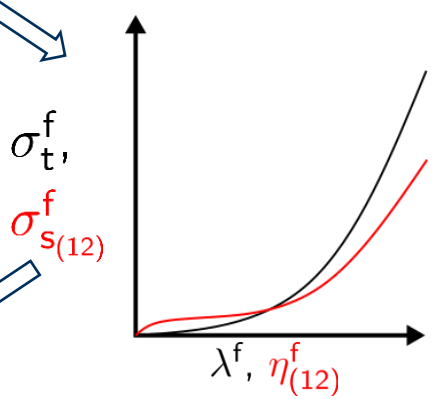
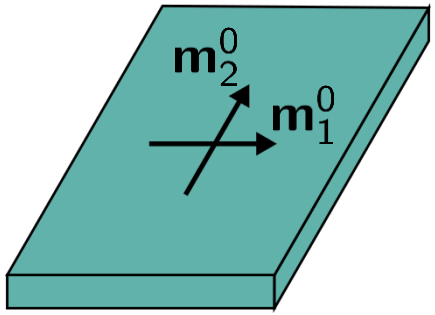


Fiber



$$\boldsymbol{\sigma} = \boldsymbol{\sigma}^m + \boldsymbol{\sigma}^f$$



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Material modeling and parametrization

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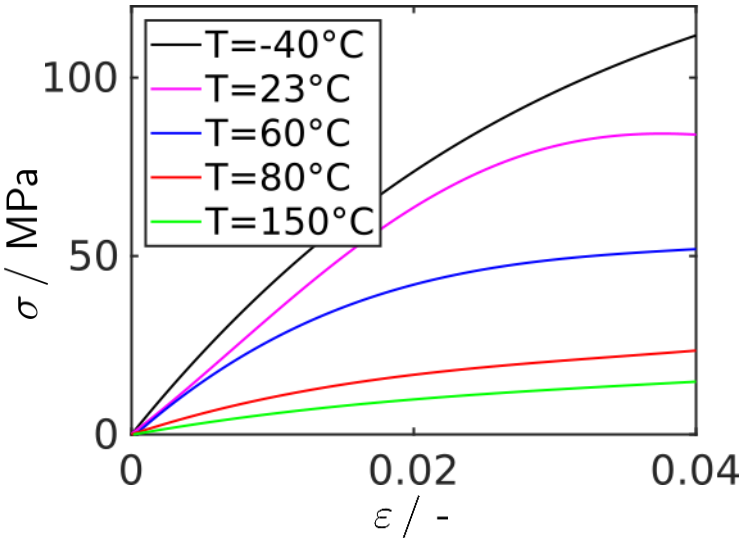
Temperature dependent material behavior of polyamide 6.6 (PA6.6)

Stress-strain curves ($-40\,°C < T < 150\,°C$) of PA 6.6 from database: *"Campusplastics"*



- Determination of stiffnesses and initial yield stresses by EHRENSTEIN[4)]
- Empirical extrapolation approach[5)] for flow rules at higher temperatures

4) Ehrenstein 2001

5) Behrens et al. 2015

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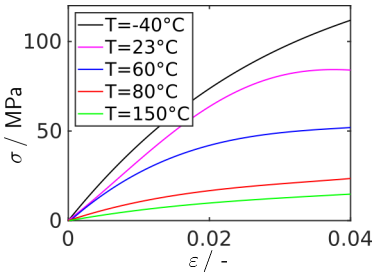

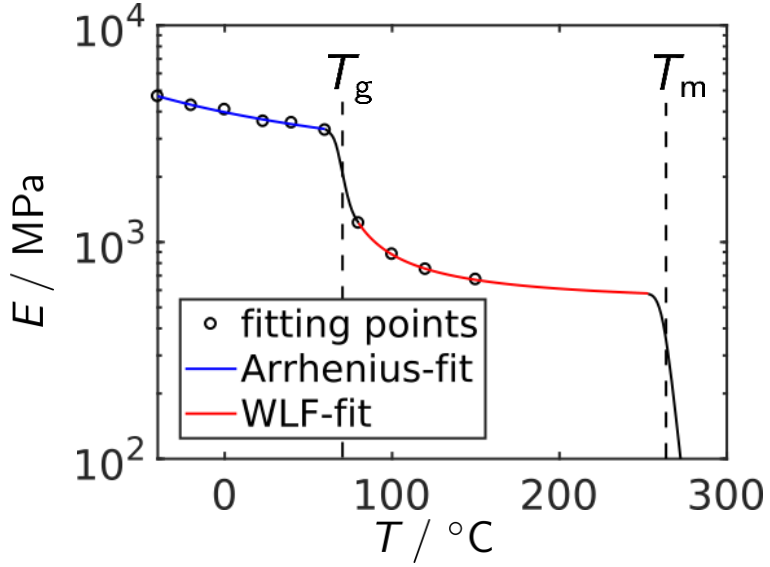

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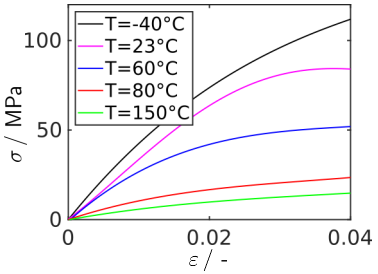

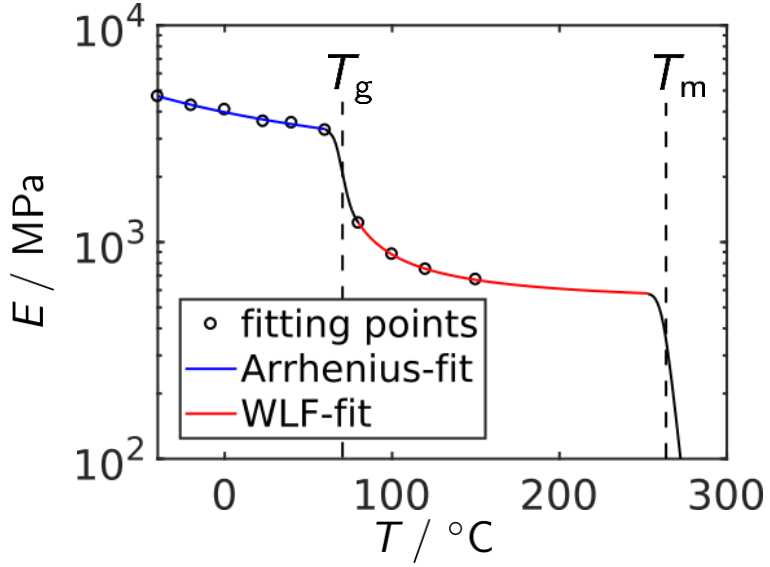

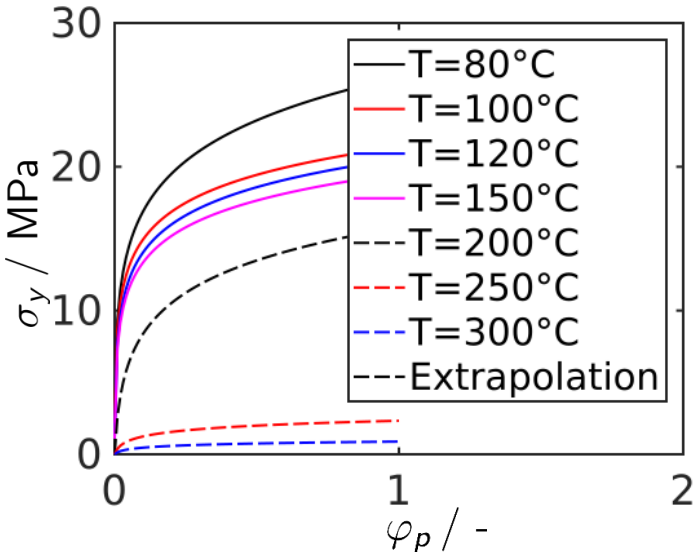

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Textile material:
biaxial reinforced
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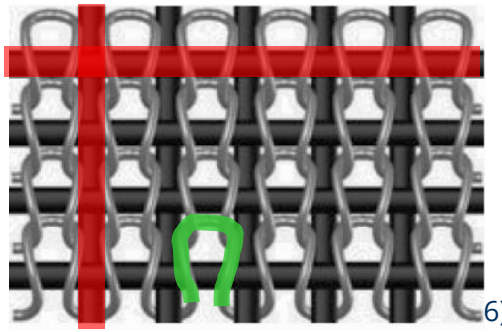
6)

Reinforcement yarns:
carbon fiber (CF) &
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6) TU Dresden, ITM

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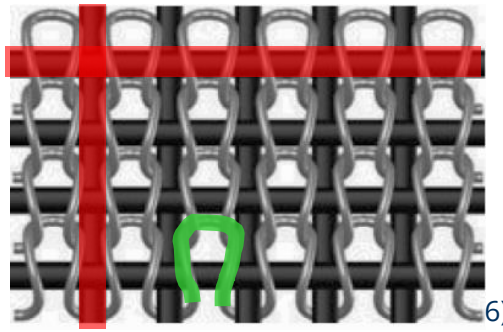

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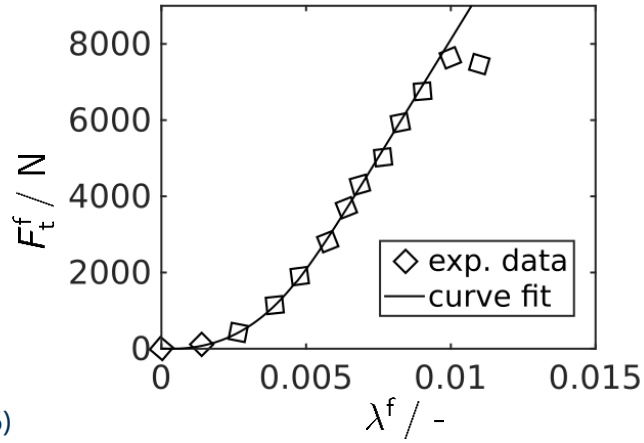

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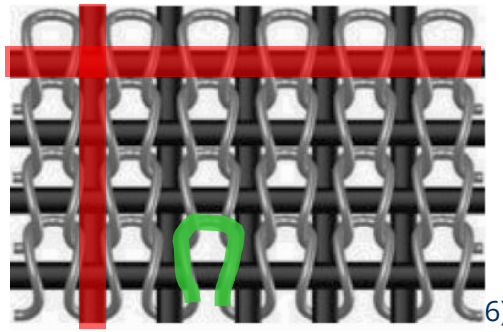

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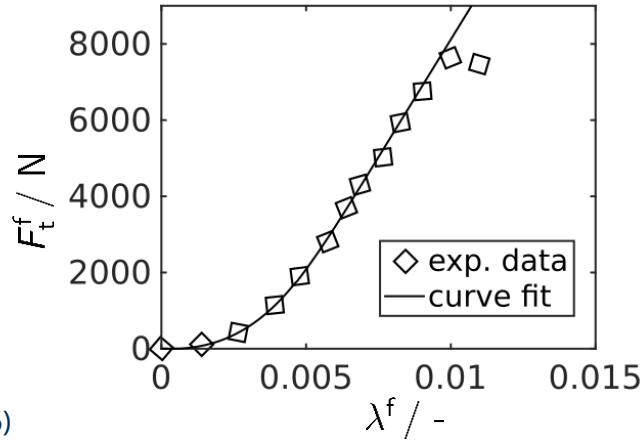

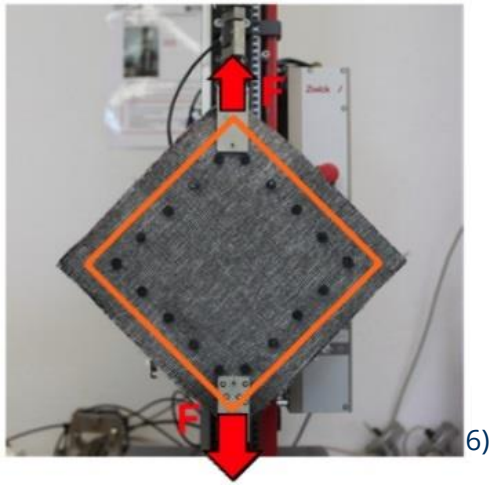

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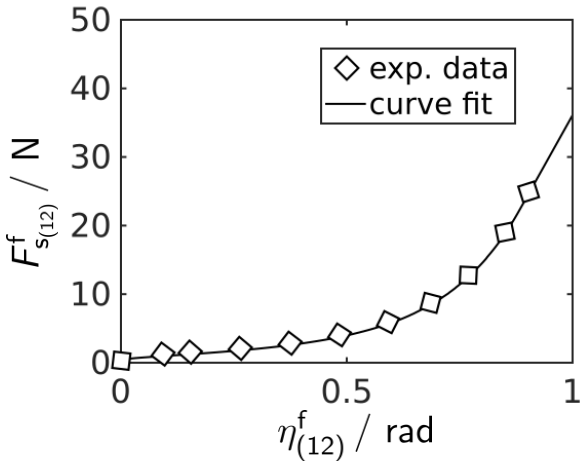

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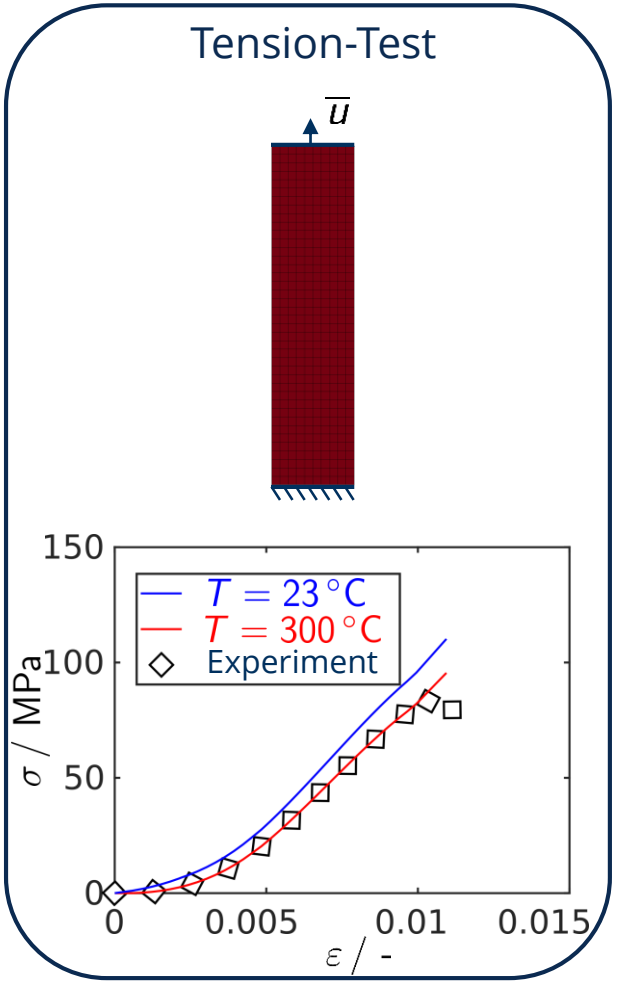

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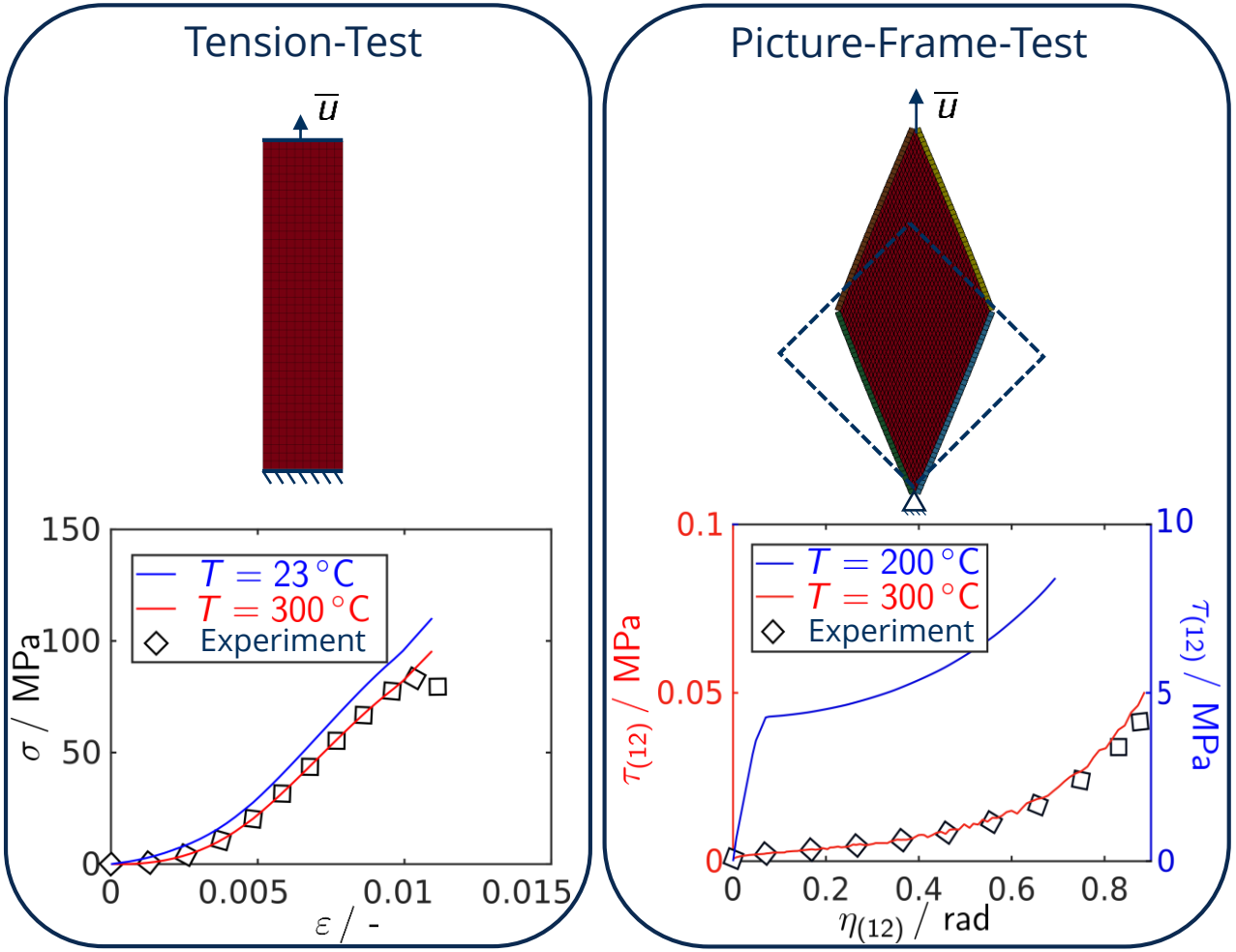
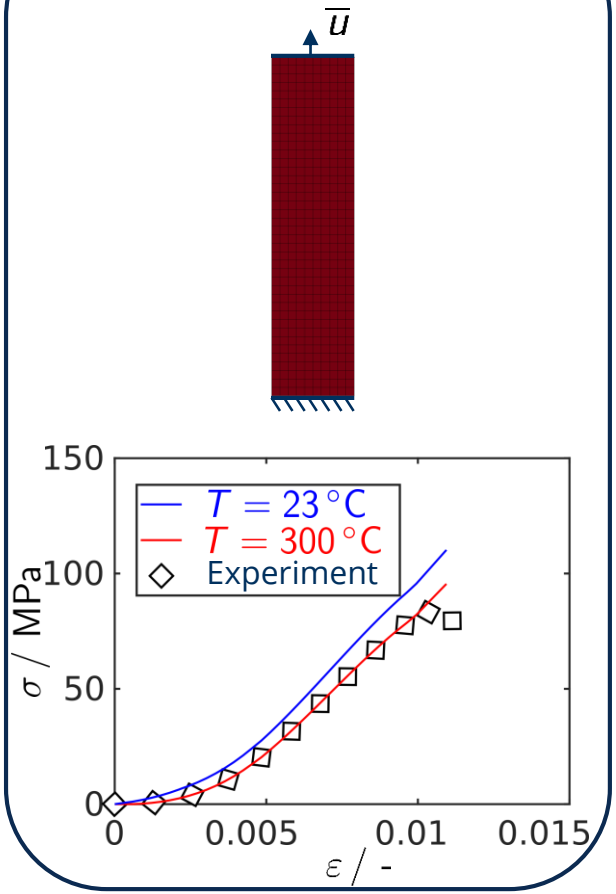


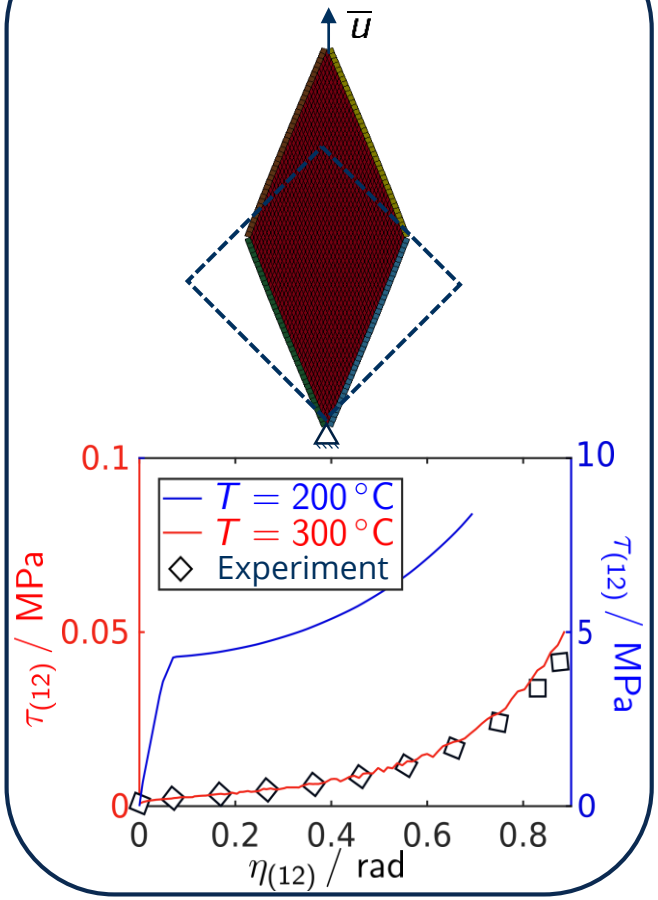
Material modeling and parametrization

➢ FRP (*MAT249-Reinforced_Thermoplastic)

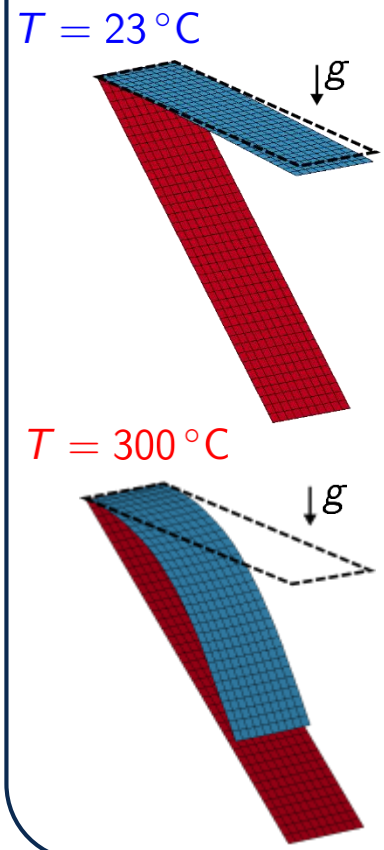
Tension-Test



Picture-Frame-Test



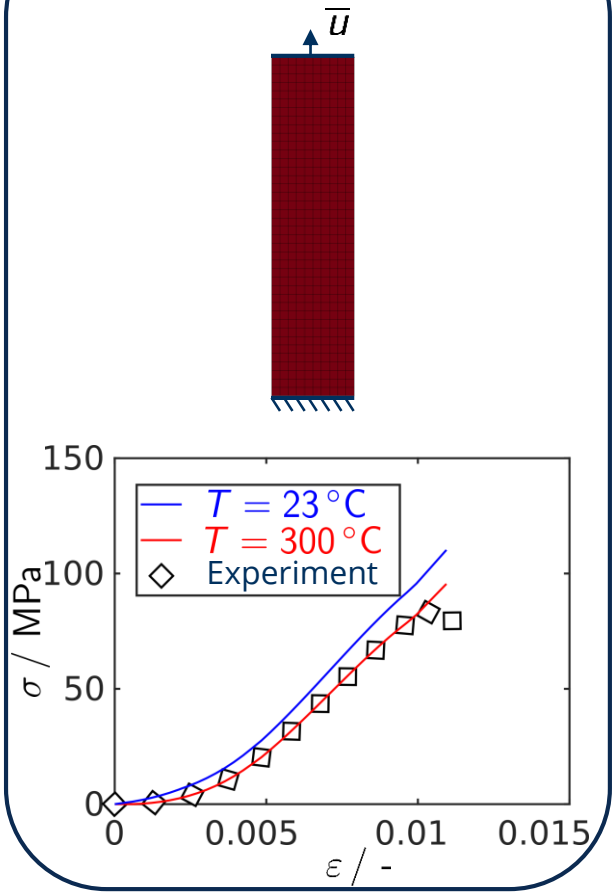
Cantilever-Test



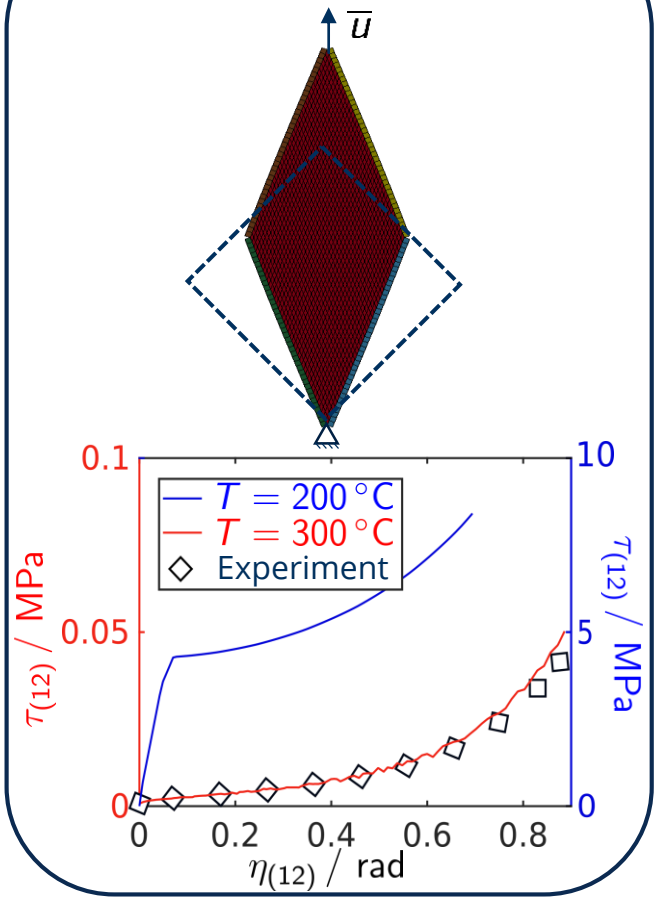
Material modeling and parametrization

➢ FRP (*MAT249-Reinforced_Thermoplastic)

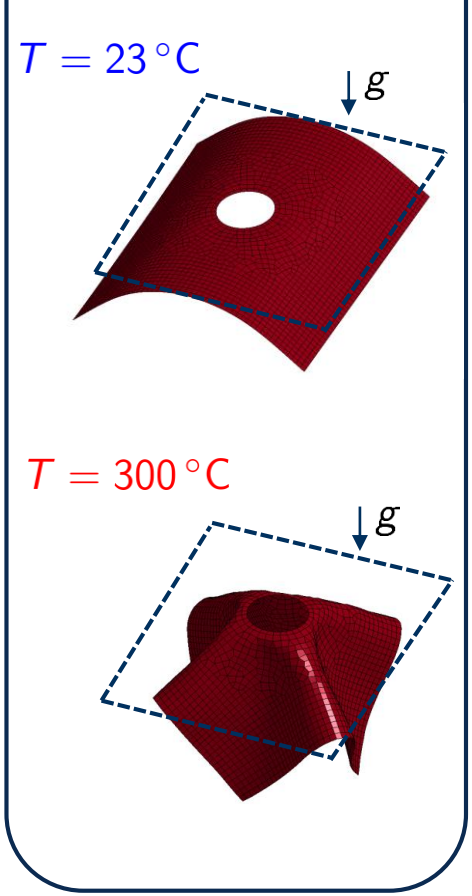
Tension-Test



Picture-Frame-Test



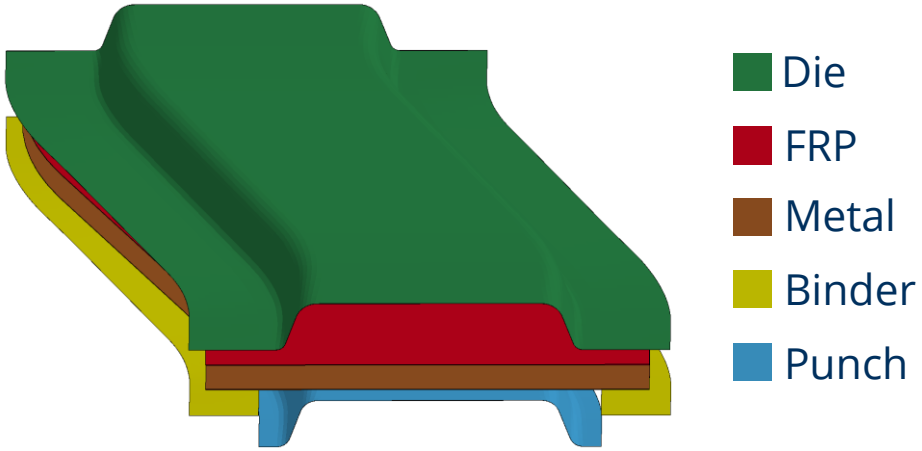
Multiaxial bending



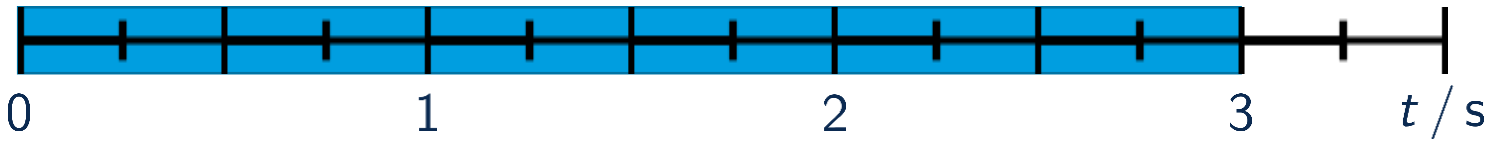
Process simulation and results

➢ Process modeling

Parameter	Value
T_0^{FRP}	$300\,^{\circ}\mathrm{C}$
T_0^{Metal}	$220\,^{\circ}\mathrm{C}$
T^{Tool}	$150\,^{\circ}\mathrm{C}$ (const.)
t_{Process}	$3\,\mathrm{s}$
n_{Elements}	$\approx 2 \cdot 40000$
h_{Elements}	$\approx 2\,\mathrm{mm}$
Δt_{mech}	$\approx 1 \cdot 10^{-6}\,\mathrm{s}$
$\Delta t_{\mathrm{therm}}$	$\approx 1 \cdot 10^{-4}\,\mathrm{s}$



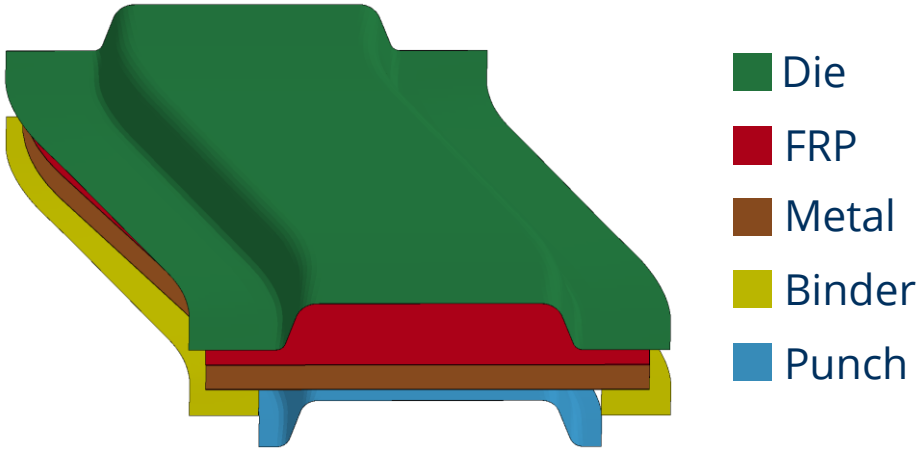
Step 1: Heating **Step 2: Forming** **Step 3: Cooling**



Process simulation and results

➢ Process modeling

Parameter	Value
T_0^{FRP}	300 °C
T_0^{Metal}	220 °C
T^{Tool}	150 °C (const.)
t_{Process}	3 s
n_{Elements}	$\approx 2 \cdot 40000$
h_{Elements}	≈ 2 mm
Δt_{mech}	$\approx 1 \cdot 10^{-6}$ s
Δt_{therm}	$\approx 1 \cdot 10^{-4}$ s



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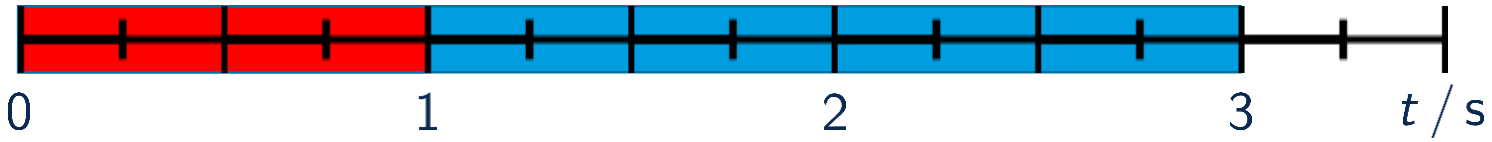

Process simulation and results

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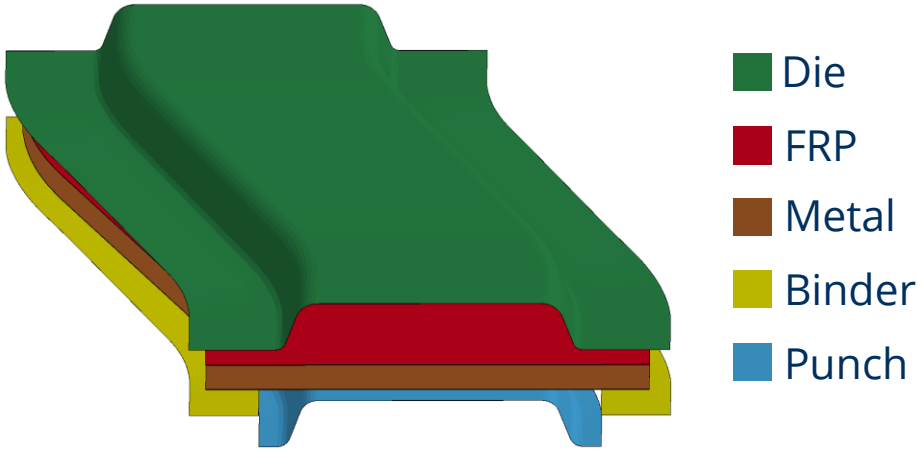
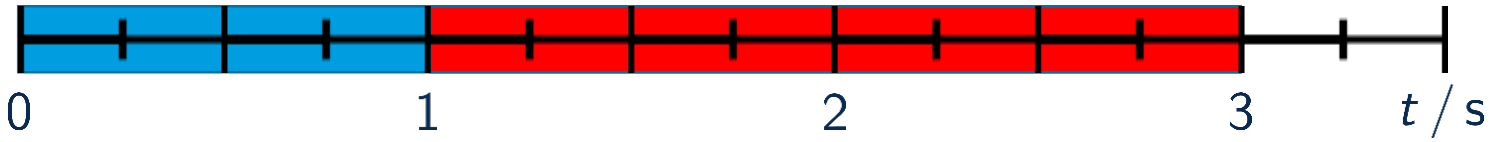


Step 1: Heating **Step 2: Forming** **Step 3: Cooling**



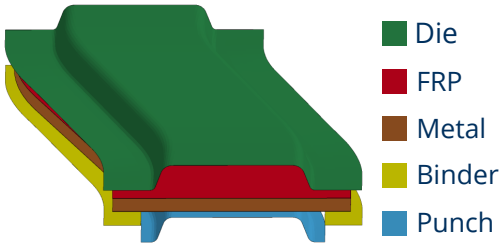
Process simulation and results

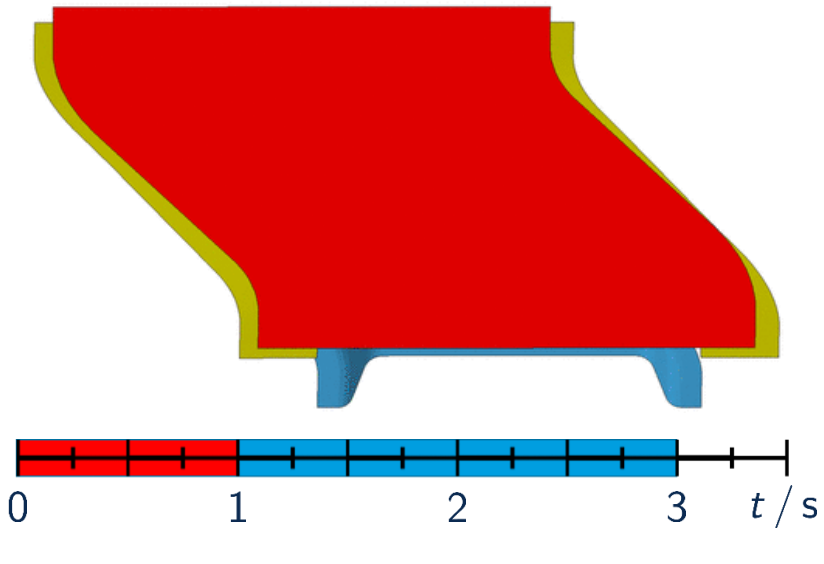
➢ Process modeling and results

Parameter	Value
t_{Forming}	1 s
v_{Punch}	50 mm/s
F_{Binder}	10 kN
t_{Holding}	2 s

Parameter	Value
$\mu,\ \mu_0$	0.15
h_{cont}	1000 W/m^{2}K
L_{min}	1 mm

Parameter	Value
$c_{\text{p}}^{\text{FRP}}$	1.7 J/gK
k^{FRP}	0.23 W/mK
$\alpha_{\text{th}}^{\text{FRP}}$	$0.3 \cdot 10^{-6}$ K^{-1}
$c_{\text{p}}^{\text{DC05}}$	460 J/gK
k^{DC05}	50 W/mK
$\alpha_{\text{th}}^{\text{DC05}}$	$1 \cdot 10^{-6}$ K^{-1}

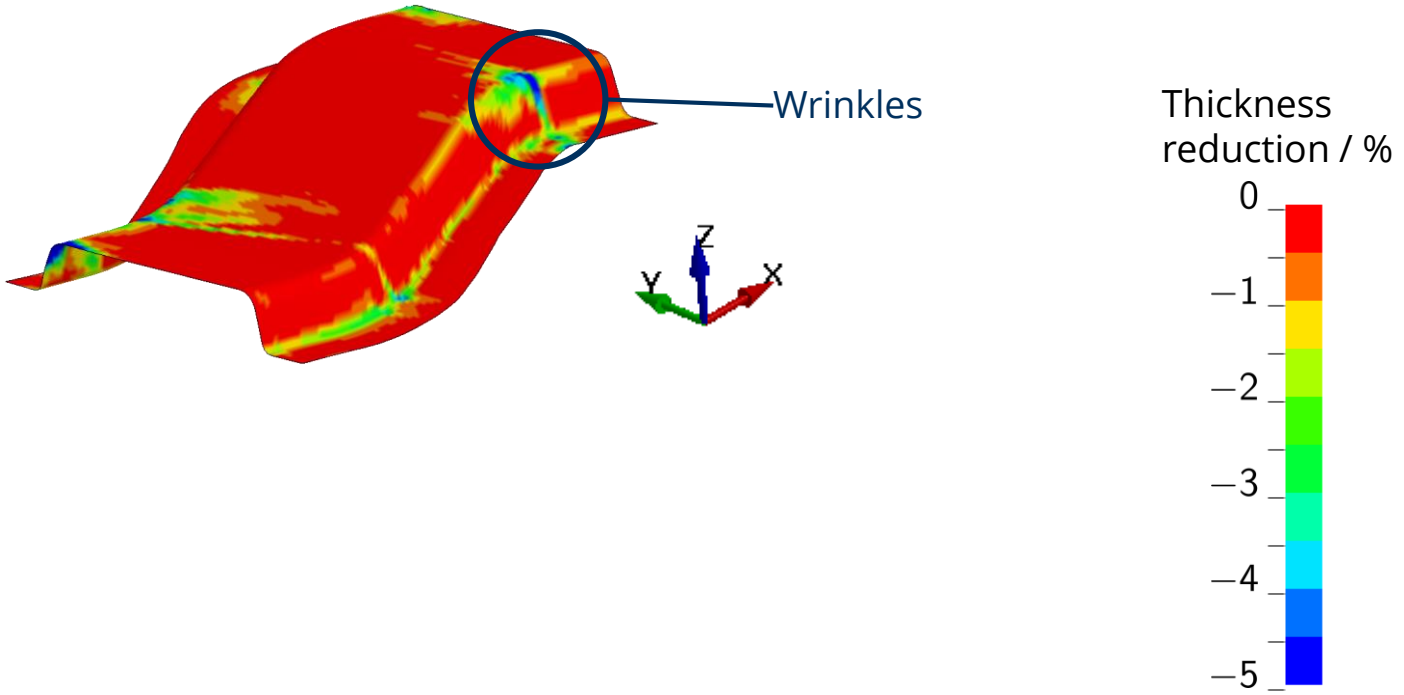




Process simulation and results

➢ Results

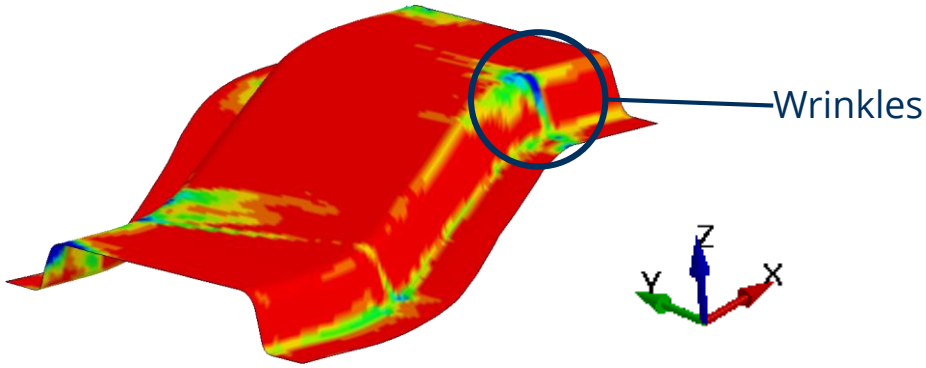
Formation of wrinkles due to missing tensile forces in x-direction



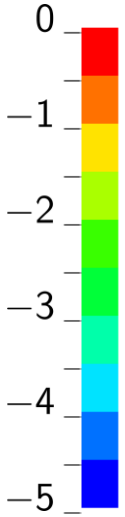
Process simulation and results

➢ Results

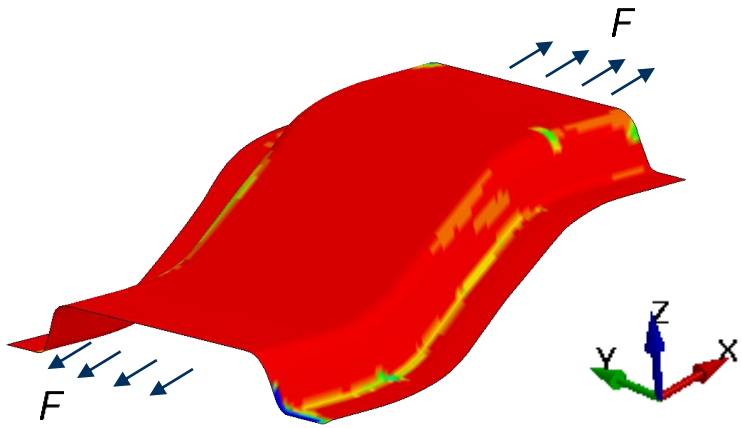
Formation of wrinkles due to missing tensile forces in x-direction



Thickness reduction / %

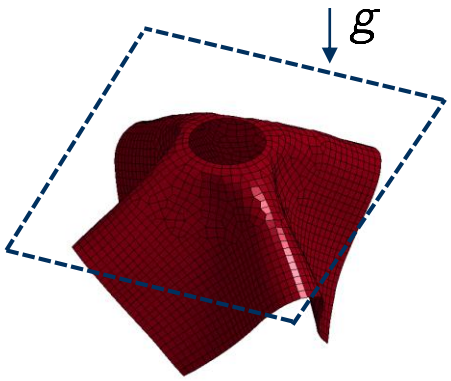


Application of additional loads in x-direction reduces defects



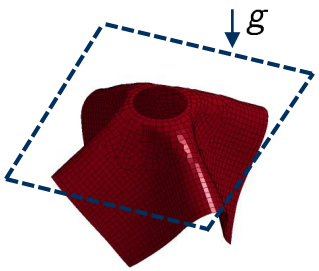
Summary

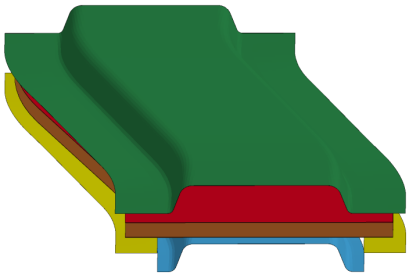
- ✓ Formulation for temperature dependent forming behavior of pre-consolidated fiber-reinforced thermoplastics

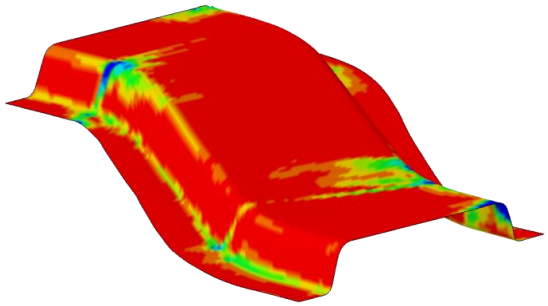


Summary

- ✓ Formulation for temperature dependent forming behavior of pre-consolidated fiber-reinforced thermoplastics
- ✓ Numerical modeling of thermoforming process

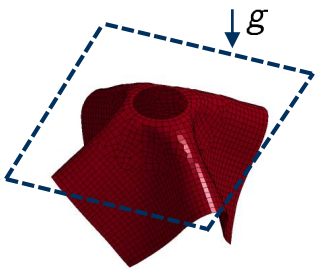


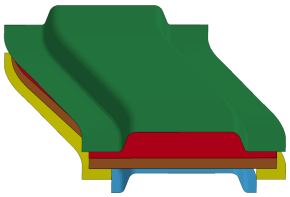


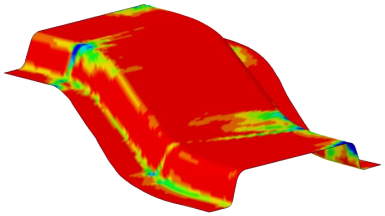


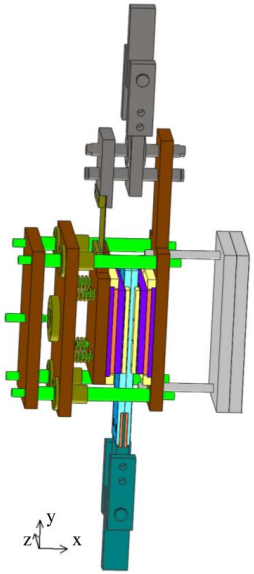
Summary

- ✓ Formulation for temperature dependent forming behavior of pre-consolidated fiber-reinforced thermoplastics
- ✓ Numerical modeling of thermoforming process
- ➢ Validation of material model (FRP) and determination of additional parameters





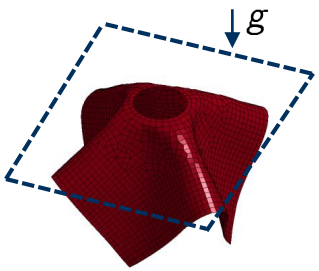


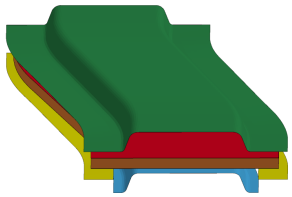


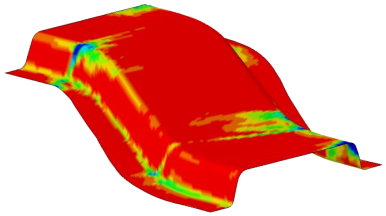
Summary

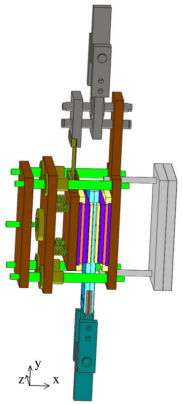
- ✓ Formulation for temperature dependent forming behavior of pre-consolidated fiber-reinforced thermoplastics
- ✓ Numerical modeling of thermoforming process

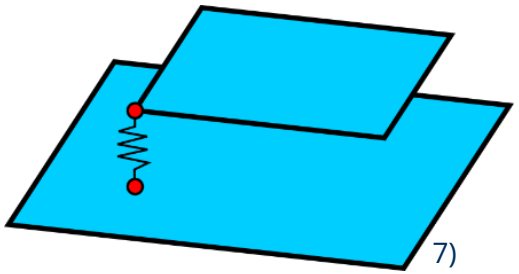
- ➢ Validation of material model (FRP) and determination of additional parameters
- ➢ Considering of delamination









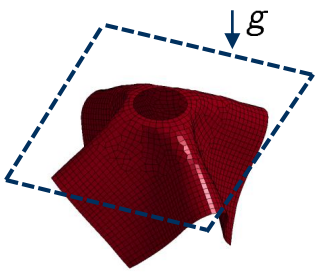


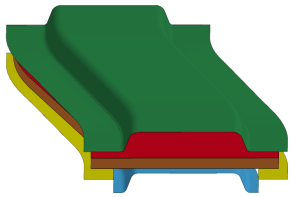
7) Dynamore

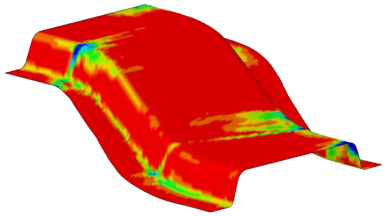
Summary

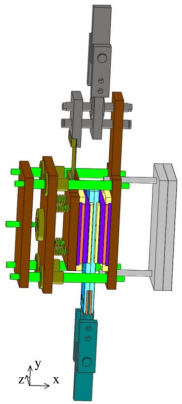
- ✓ Formulation for temperature dependent forming behavior of pre-consolidated fiber-reinforced thermoplastics
- ✓ Numerical modeling of thermoforming process

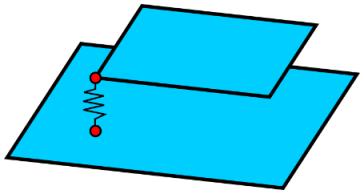
- ➢ Validation of material model (FRP) and determination of additional parameters
- ➢ Considering of delamination
- ➢ Parameter studies of thermoforming











7) Dynamore