COUPLED FINITE ELEMENT SIMULATION OF SMA-SHEET FOR MORPHING APPLICATIONS

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DLR

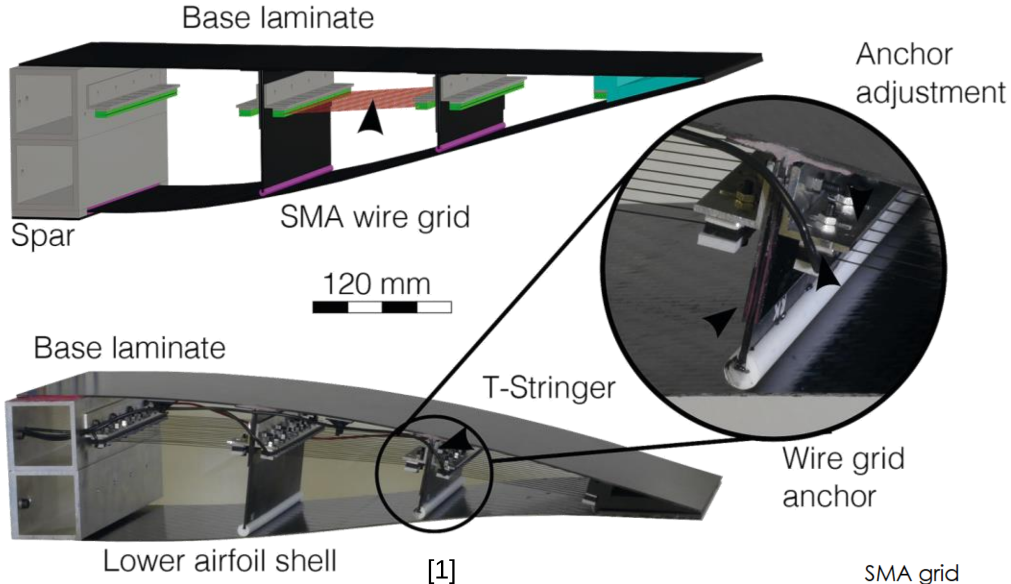
Background

SMA based morphing applications often rely on wire actuators as …

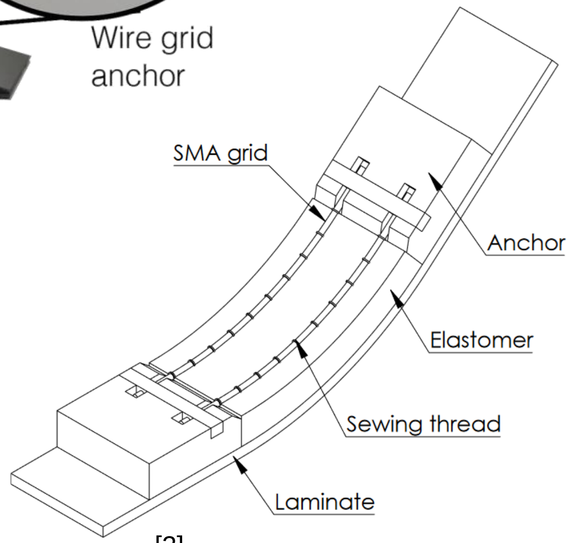
... pure tensioning devices …
... bending devices …

... to achieve a shape change.

→Great for small applications but not scalable



[1]



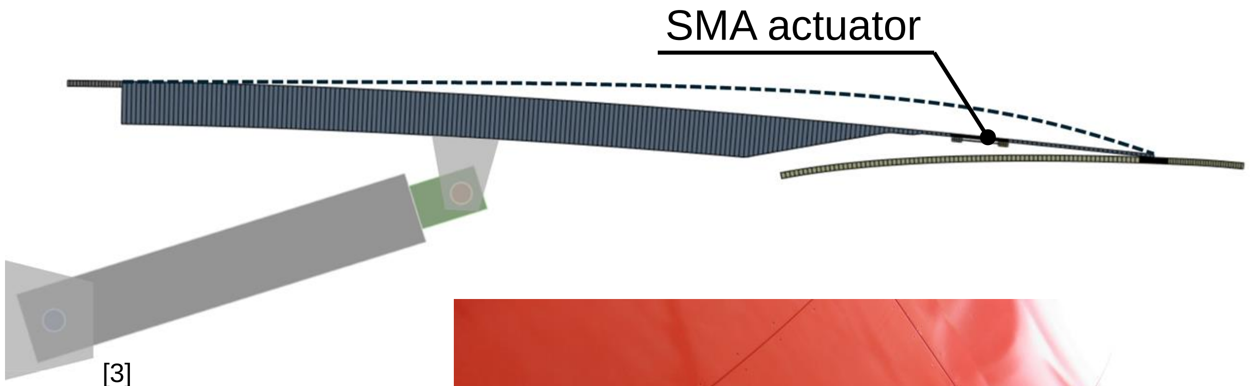
[2]

→ SMA sheets could enable those applications through the sheet's higher achievable force

[1] Max Kaiser, "Formadaptives Tragflächenprofil für ein Kleinflugzeug", https://www.ivw.uni-kl.de/de/projekte/formadaptives-tragflaechenprofil-fuer-ein-kleinflugzeug
[2] Max Kaiser, et al. , "Airfoil trailing edge morphing based on modified SMAHC concept: design, implementation, and experimental studies," Proc. SPIE 12043, (20 April 2022)

Potential Applications

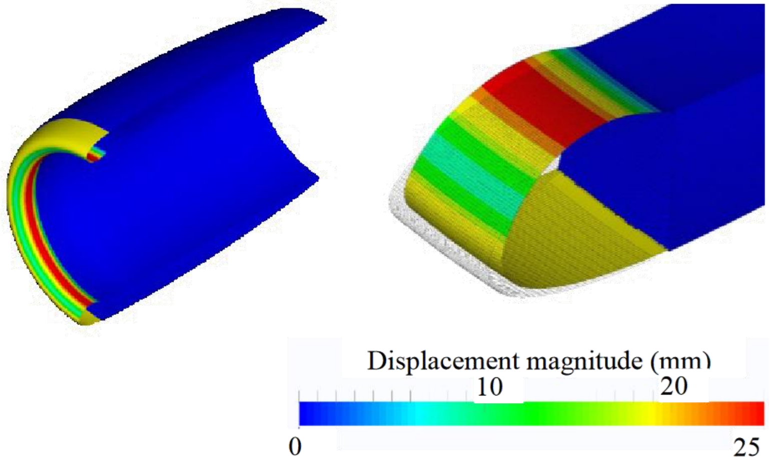
- Shock control bumps require deformation of 3 – 4 mm of CFRP with very limited space
- Ram Air Intakes have moving flaps with actuators and linkages, which can be simplified



[3]

[4]

- Engine inlets can be deformed to achieve better crosswind performance



[5]

[3] S. C. Künnecke, et al., "Adaptive Shock Control Bump With Shape Memory Alloy Wires on a Morphing Spoiler," in ASME 2024 Conference on Smart Materials, Atlanta, Georgia, USA: Sep. 2024
[4] CC Wikimedia, Olivier Cleynen, 2011
[5] . da Rocha-Schmidt et al., 'Progress towards adaptive aircraft engine nacelles'. 29th Congress ICAS September 7-12, 2014, St. Petersburg, Russia (2014)

Roadmap

Modeling a generic system within FEA to understand …

… the non uniform heating

… the influence of poison ratio

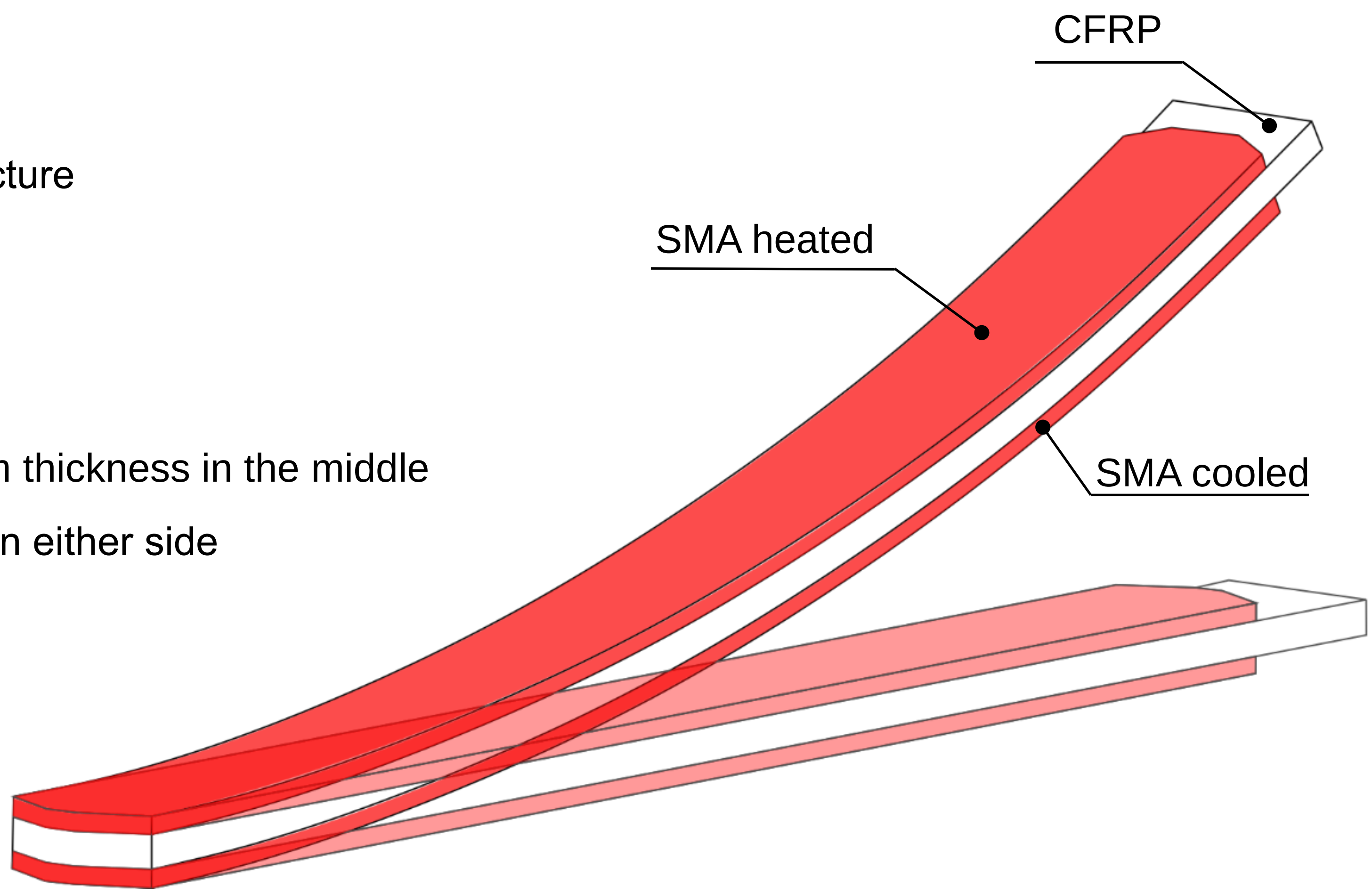
… the load transfer to the underlying structure

… the overall deformation potential

Therefore a system is modeled with a …

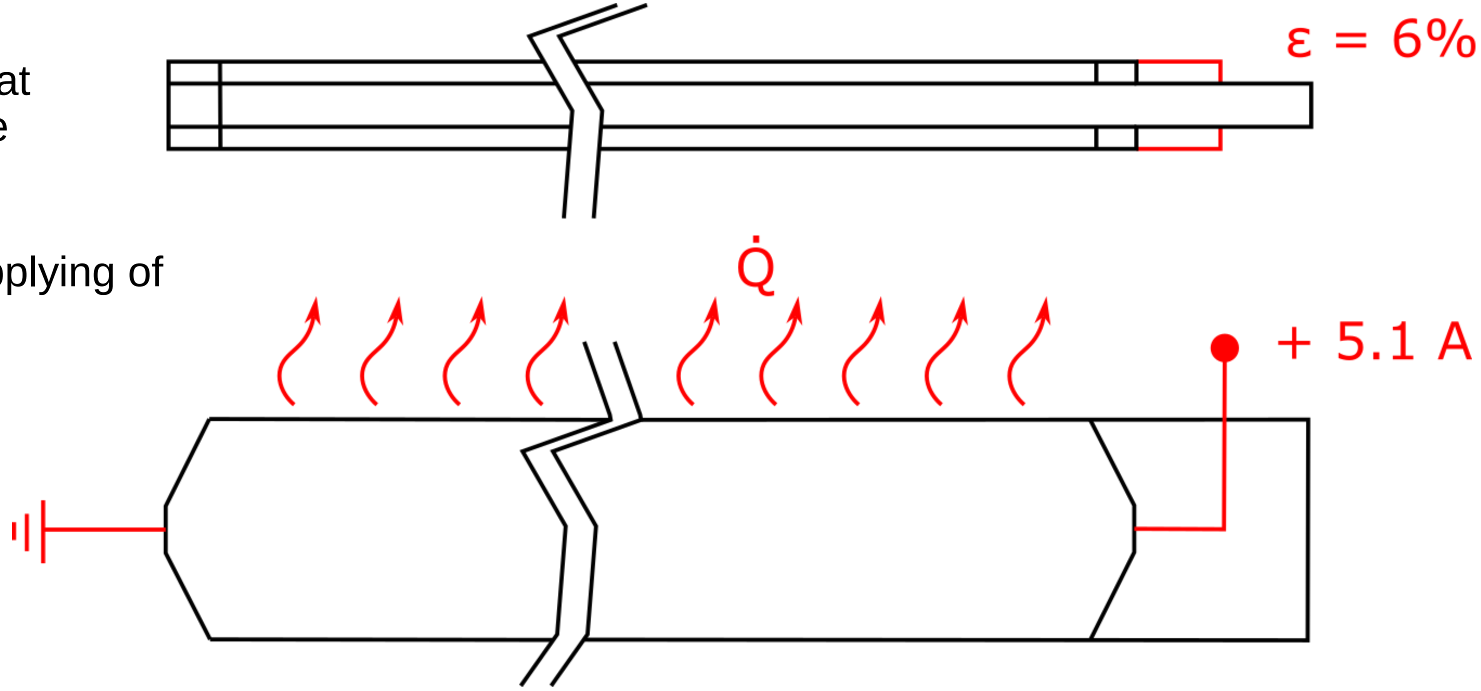
… quasi-isotropic CFRP structure of 1 mm thickness in the middle

… two SMA sheets of 0.5 mm thickness on either side



Simulation - Overview

1. Pre-tensioning of both SMA sheets so that they are fully in the detwinned martensite
2. Bonding of the SMA sheets to the CFRP
3. Heating of the top SMA sheet through applying of an electric current and cooling through natural convection
4. Cooling of the top SMA



Remarks

- Simulation done within ANSYS
- Use of the already implemented Auricchio Model
- Use of material properties from *Auricchio et al.* [6] to validate correct implementation and boundary conditions

[6] Auricchio, F. and Petrini, L. (2002), Improvements and algorithmical considerations on a recent three-dimensional model describing stress-induced solid phase transformations. Int. J. Numer. Meth. Engng., 55: 1255-1284

Results in upper SMA Sheet

After pre-tensioning:

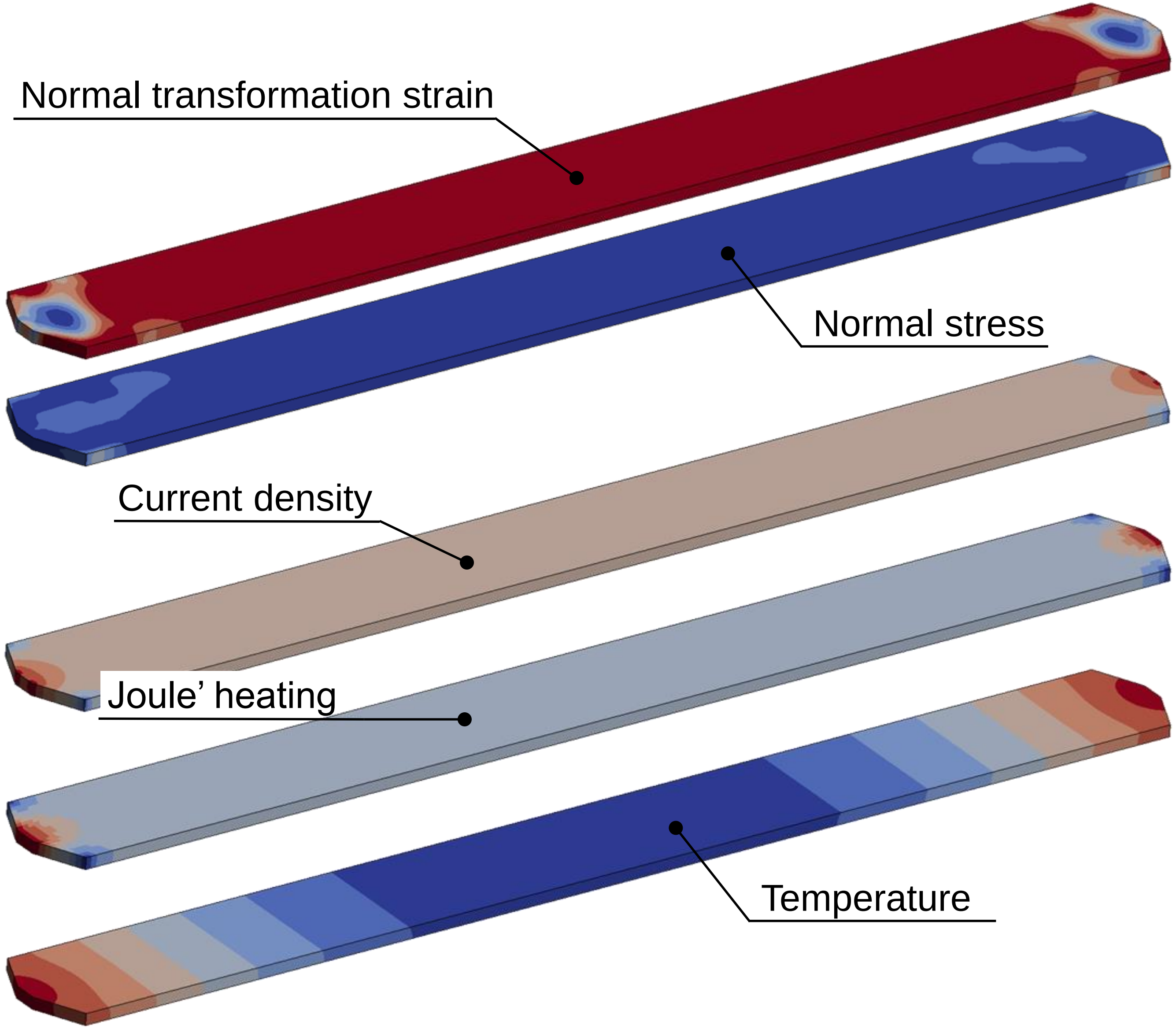
- Nearly the whole sheet is in detwinned Martensite (normal transformation strain in red)
- Normal stress is at 0 MPa nearly everywhere

→ Influence of crosswise contraction visible at the end

Heating:

- Point source of current leads to non uniform Joule' heating
- Temperature gradient mostly along the length of the sheet

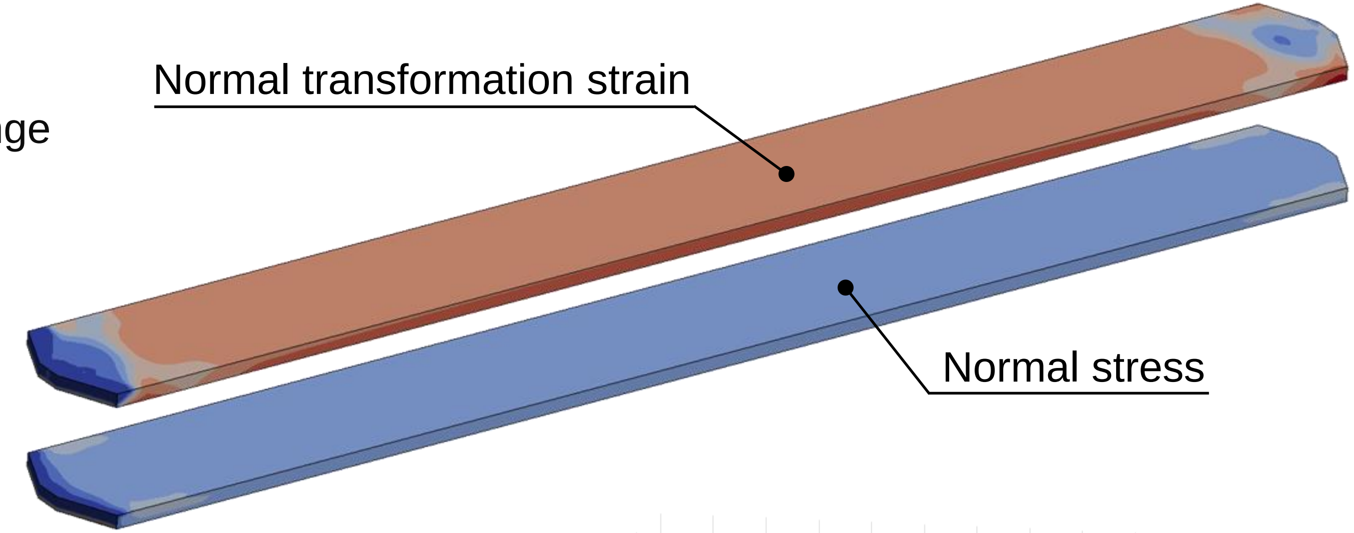
This is a static simulation, effect much more important within transient simulation !

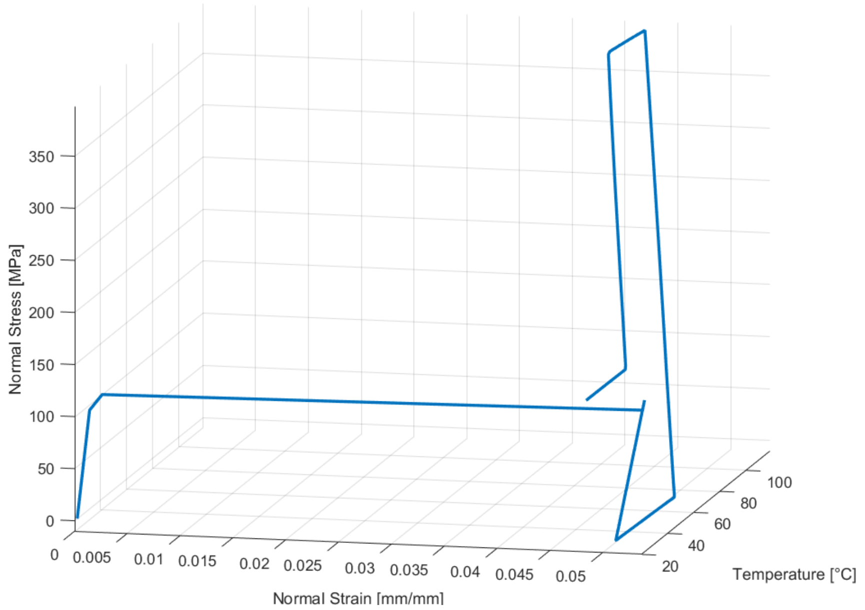


Results in upper SMA Sheets

- Normal strain gets recovered through phase change to Austenite
- Normal stress dominated by stresses through bending

- Stress-Strain-Temperature diagram shows incomplete hysteresis: Stiffness of CFRP is not sufficient to bring system back into undeformed state

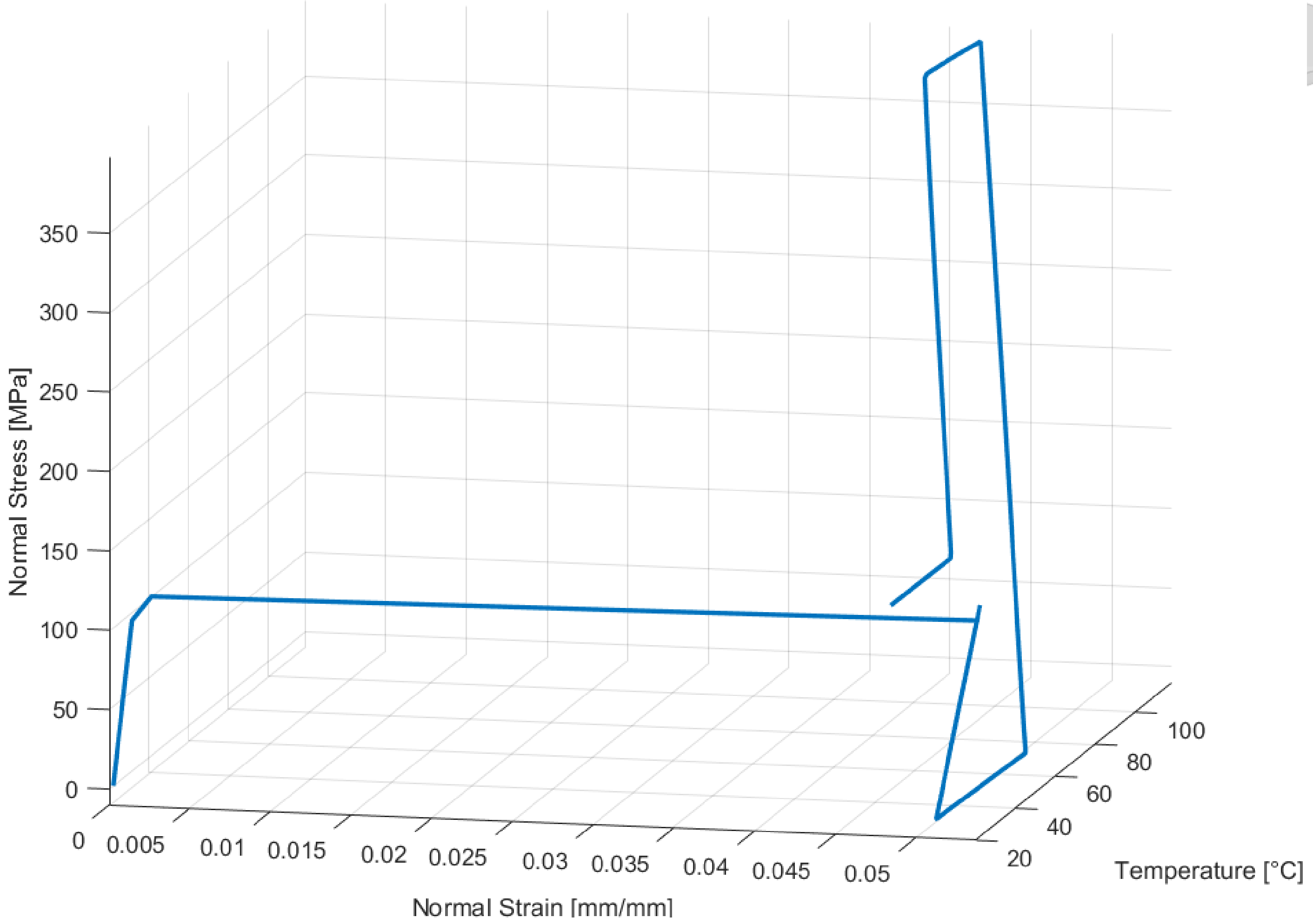




Simulation Results – High Temperature

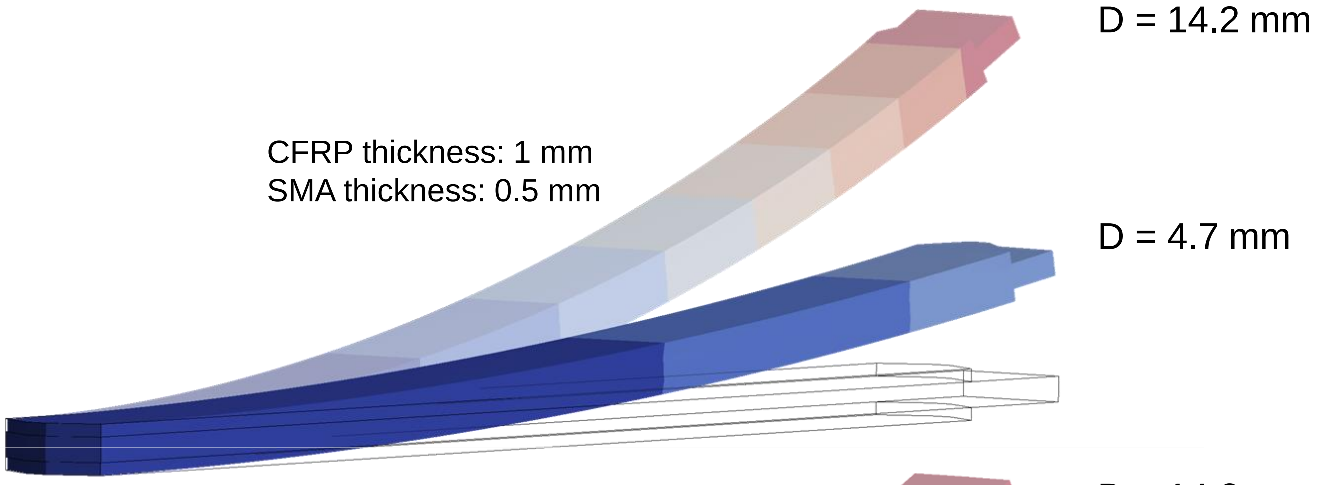
- Normal strain gets recovered through pha
  to Austenite
- Normal stress dominated by stresses through bending

- Stress-Strain-Temperature diagram shows incomplete hysteresis: Stiffness of CFRP is not sufficient to bring system back into undeformed state



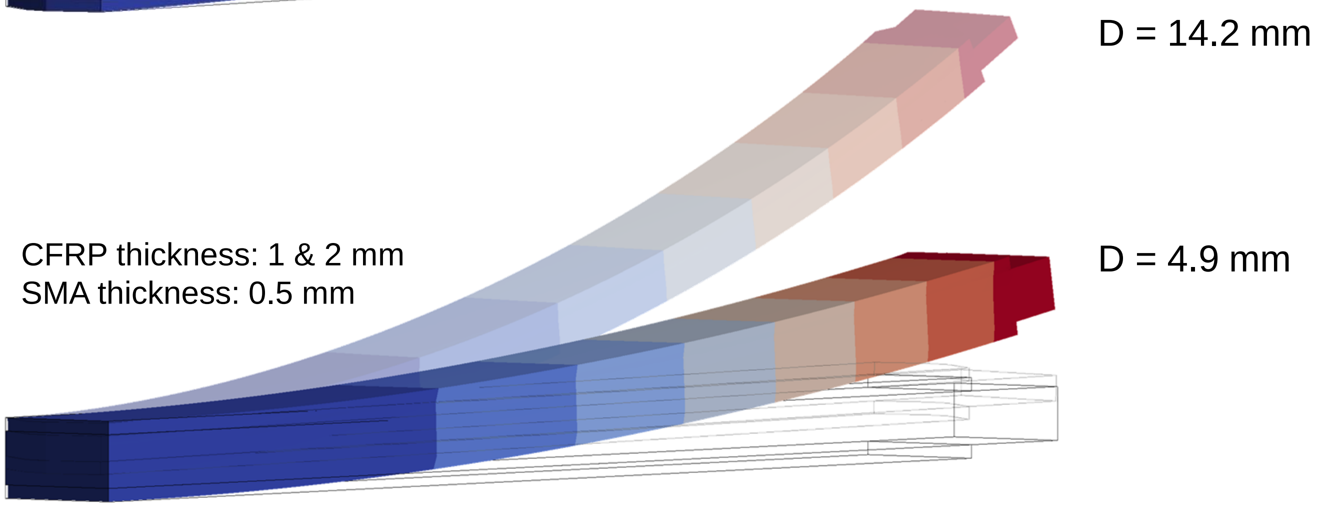
Deformation potential

- Maximum deformation is at 14.2 mm (overall length of SMA is 50 mm)
- Remaining deformation is at 4.7 mm



Comparison with CFRP thickness of 2 mm:

- Reduction of deformation to 4.9 mm

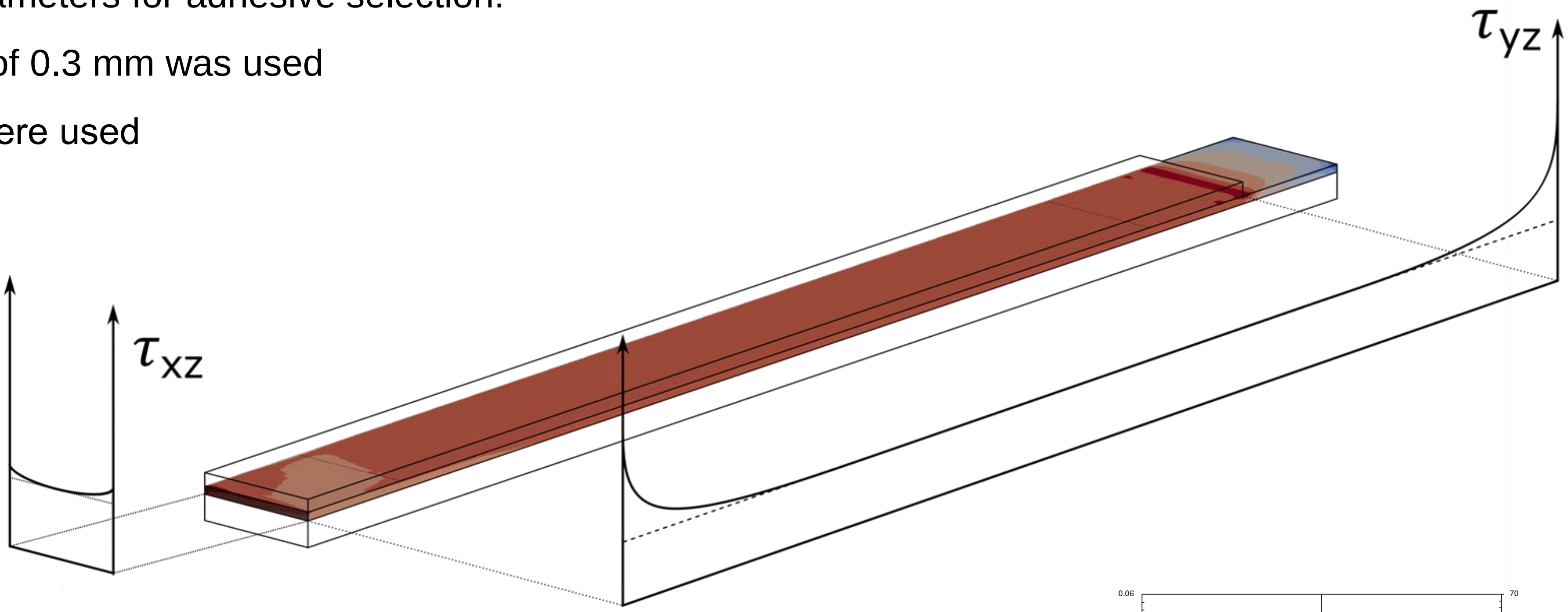


Simulation with adhesive material

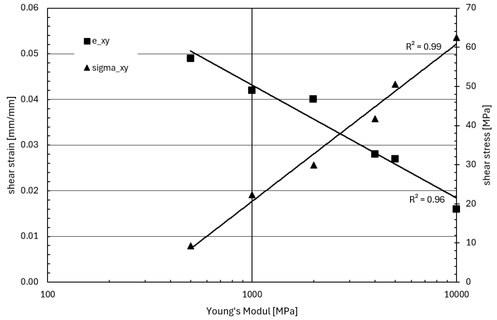
The goal is to get design parameters for adhesive selection:

- For now a fixed thickness of 0.3 mm was used
- Different Young's moduli were used

- Very long adhesion length results in high peak stresses and strains
- Means to reduce peak τ_{yz} should be implemented



- No convergence for low Young's moduli
- First extrapolation reveals manageable stresses and strains



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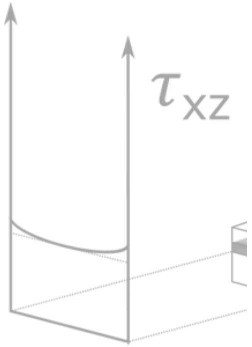

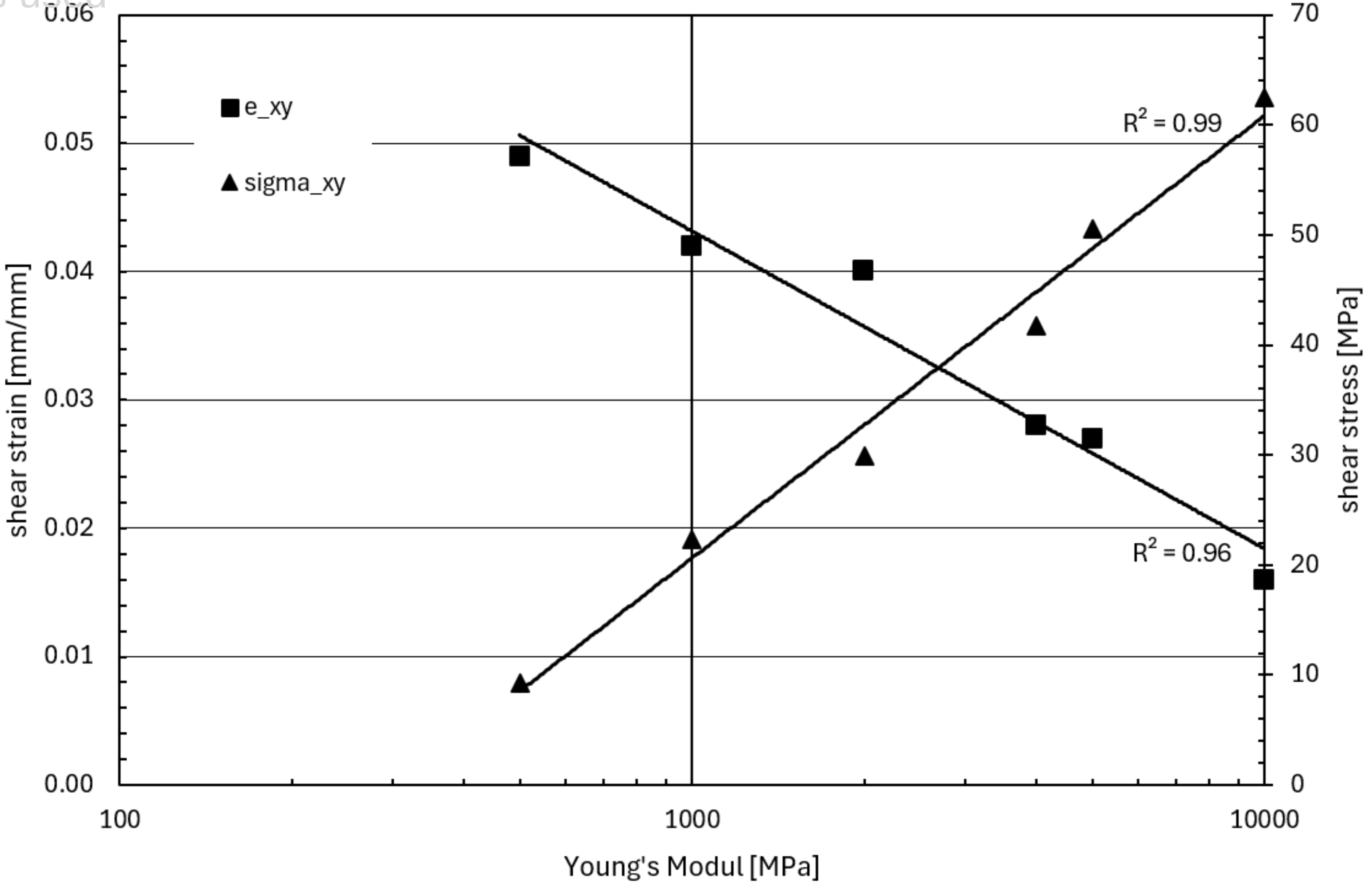

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Conclusions

Overall conclusions:

- SMA sheets promising for deformation of stiff structural elements
- Coupled Field Simulation of shape memory effect is possible
- Non uniform pre-tensioning and heating have effect at the ends of the SMA sheets

Specifics to model:

- Pre-bending is necessary for CFRP as recovery force
- First calculations with an adhesive layer confirm possibility of a planar load transfer from SMA to CFRP

Outlook:

- Detailed design of adhesive layer and selection of suitable adhesives
- Manufacturing of samples and validation of shown results

Contact

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