FEM Simulation of Deformations in Strings of Shingled Solar Cells Subjected to Mechanical Reliability Testing

Nils Klasen[1,2], Pascal Romer[1], Andreas Beinert[1], Achim Kraft[1], Marc Kamlah[2]

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[2] Karlsruhe Institute of Technology (KIT), IAM-WBM

8th Workshop on Metallization & Interconnection for Crystalline Silicon Solar Cells
Konstanz, 14.05.2019

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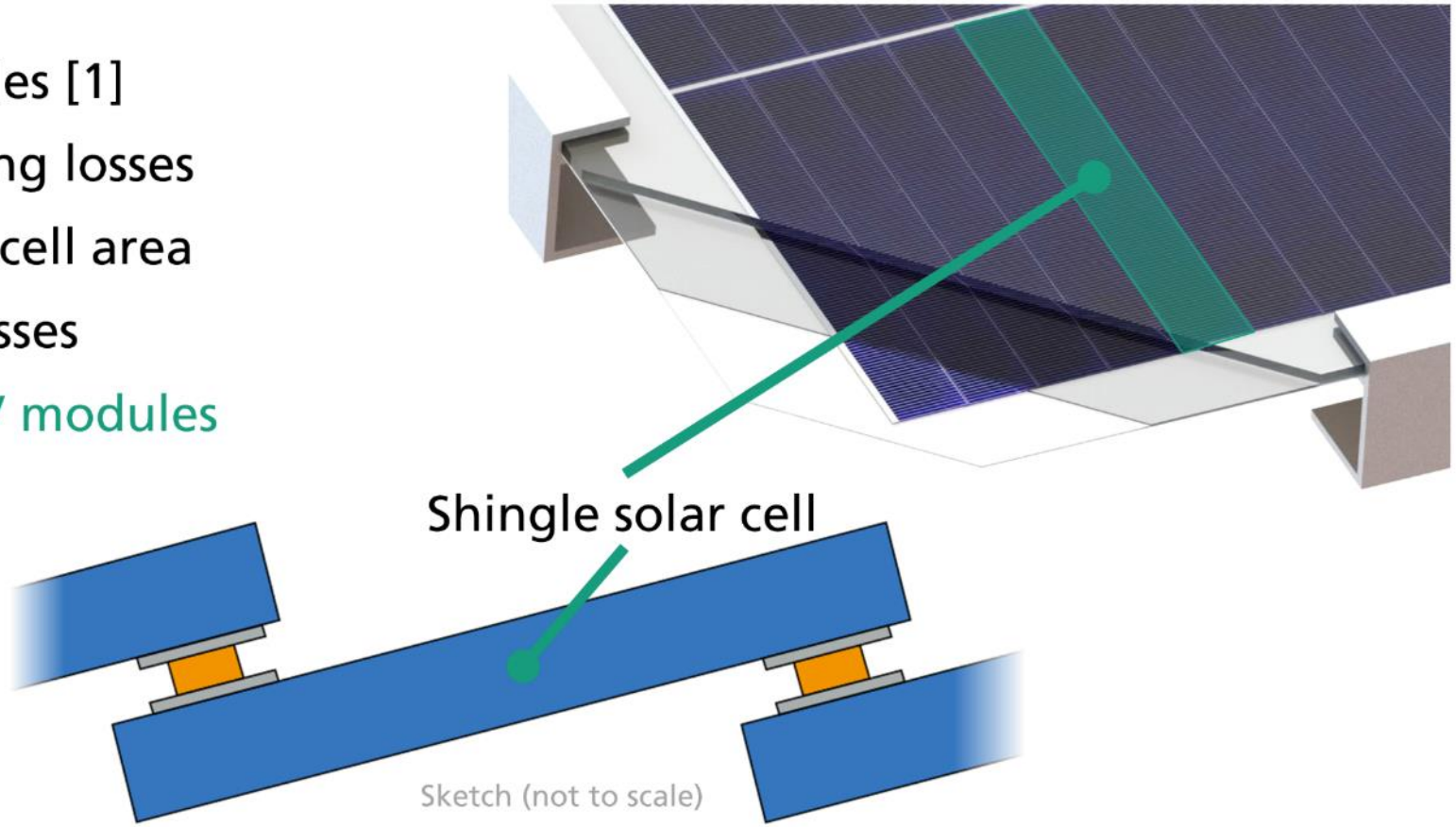
Introduction – Shingled Cell Interconnection

- Shingled cell modules [1]
  - No ribbon shading losses
  - Increased active cell area
  - Low electrical losses
  - ➔ High efficient PV modules



[1] Baliozian et al (2018): Bifacial p-type silicon shingle solar cells - the pSPEER concept. DOI: 10.1002/solr.201700171.

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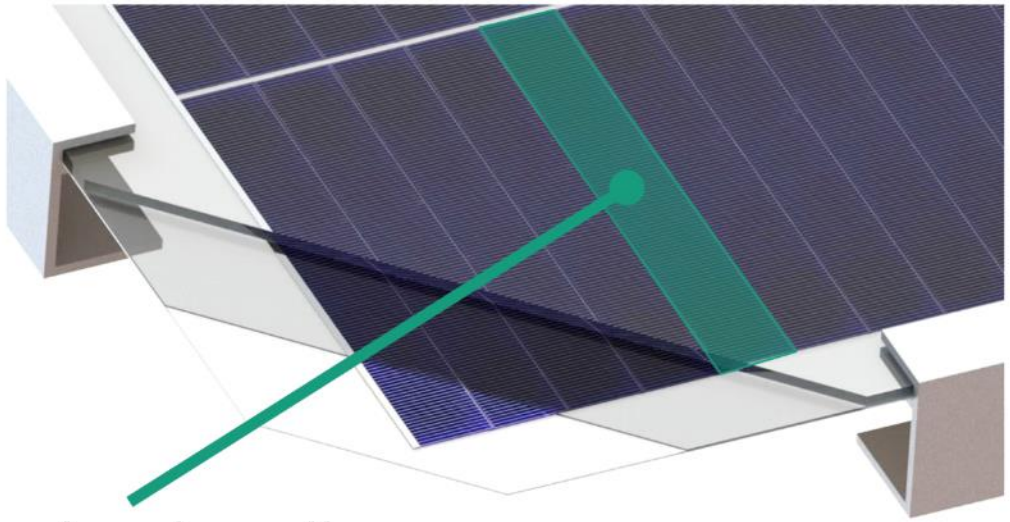
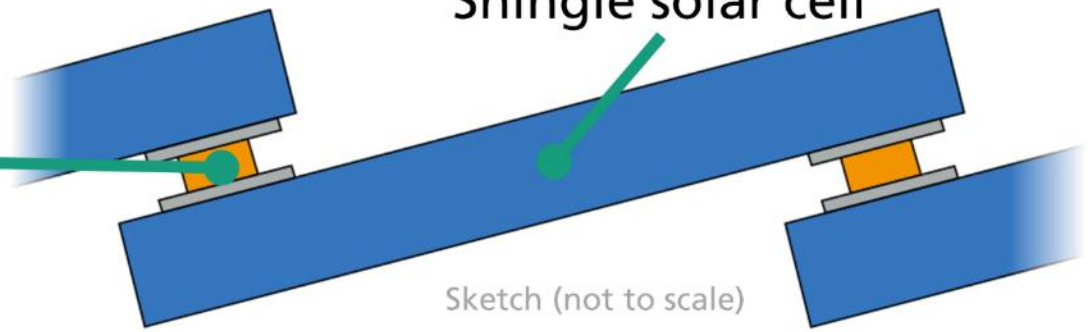


Shingle solar cell

- **Joint reliability?**



Sketch (not to scale)

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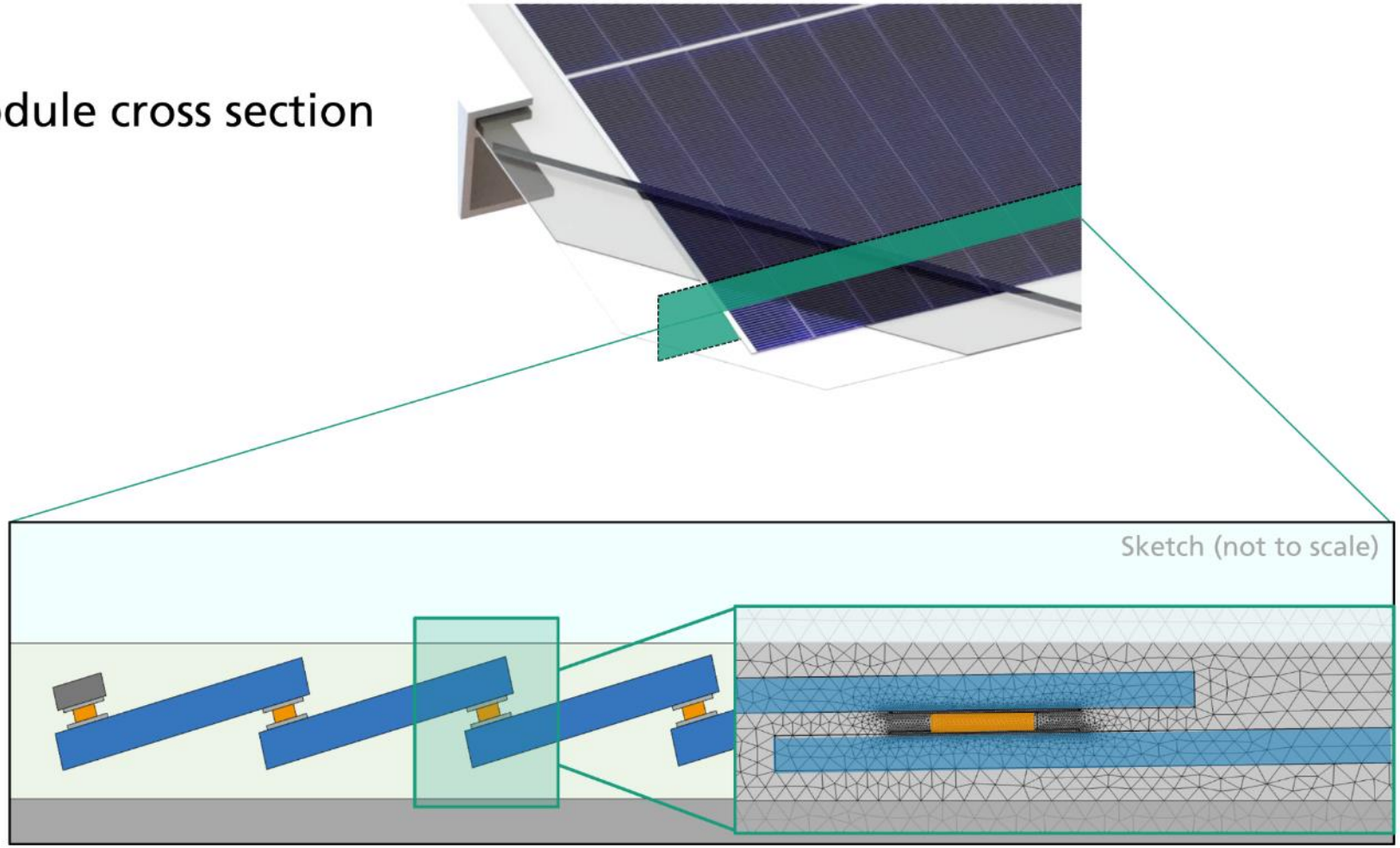
FEM Simulations – Geometry and Loads

- Simplification: 2D module cross section



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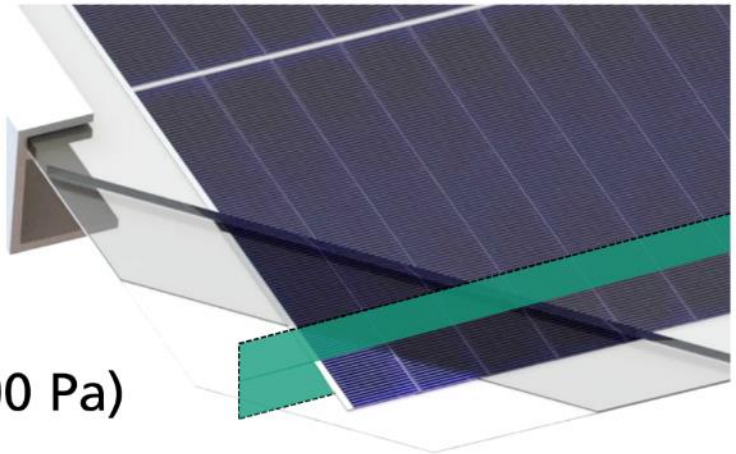
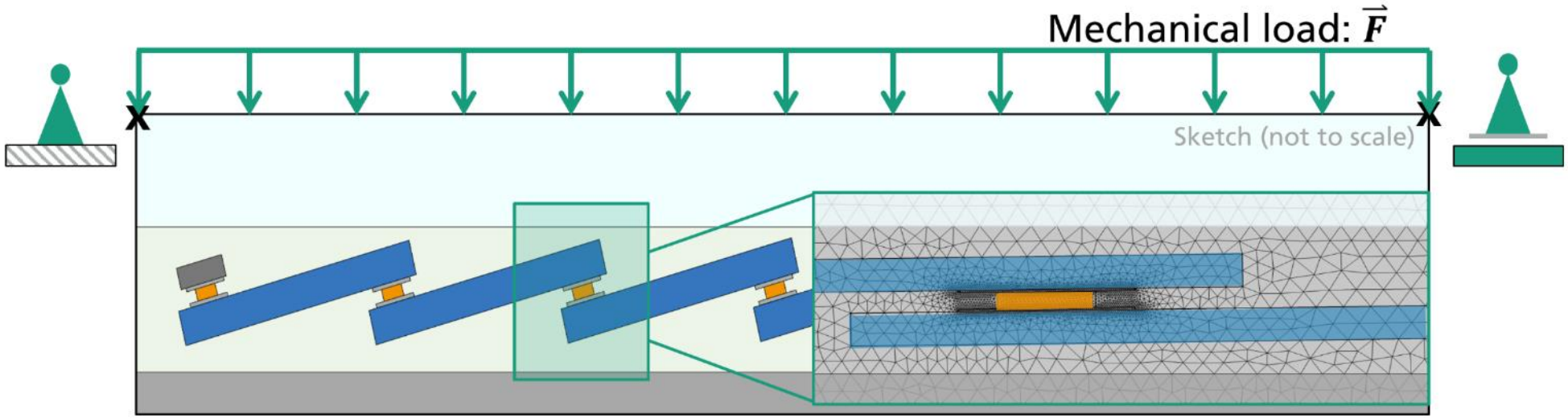


- Loads [2]
  - Mechanical load test (ML) (2400 Pa, 5400 Pa)



[2] IEC 61215-1-1, 2016

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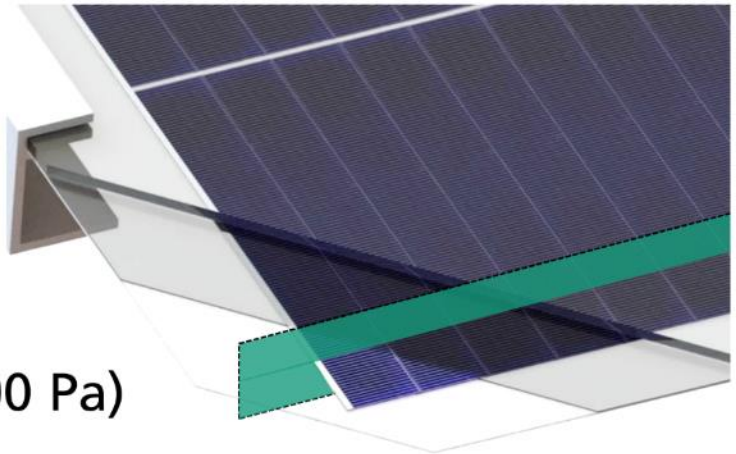
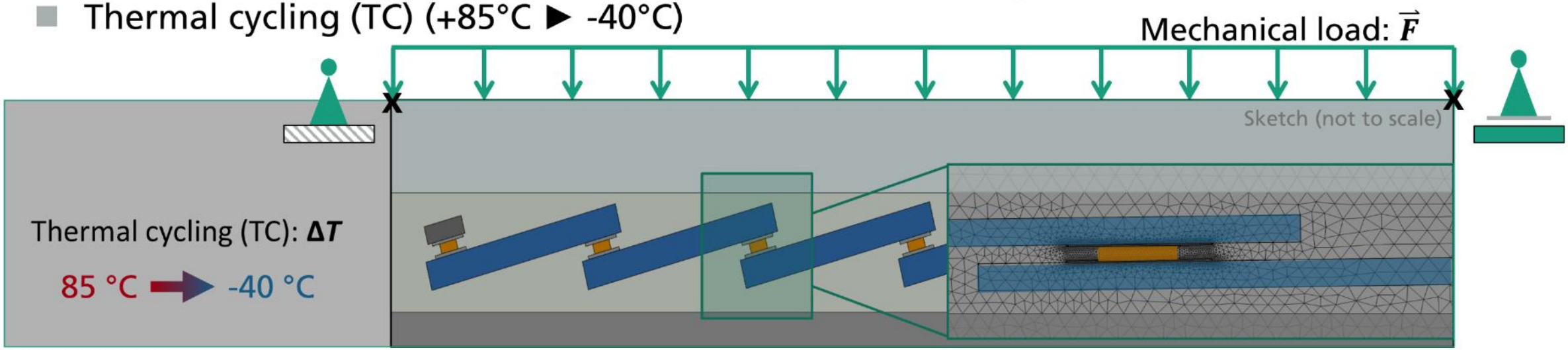


- Loads [2]
  - Mechanical load test (ML) (2400 Pa, 5400 Pa)
  - Thermal cycling (TC) (+85°C ► -40°C)



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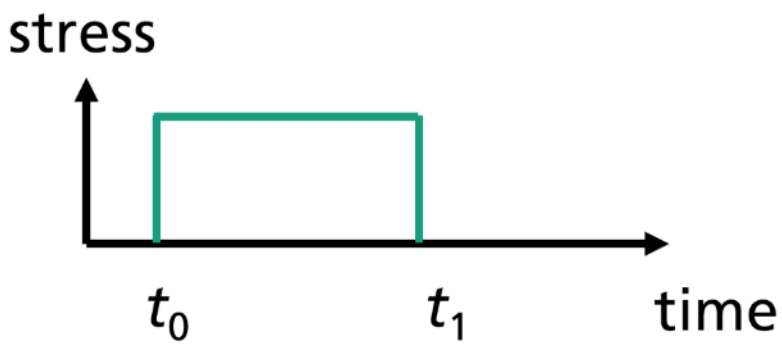
FEM Simulations – Material Modelling

- Compare material models
  - T-dep. elasticity, f(T)
  - Viscoelasticity [3], f(T,ω)

Excitation



[3] Ward, Sweeny (2013) Mechanical Properties of Solid Polymers: Third edition. DOI:10.1002/9781119967125

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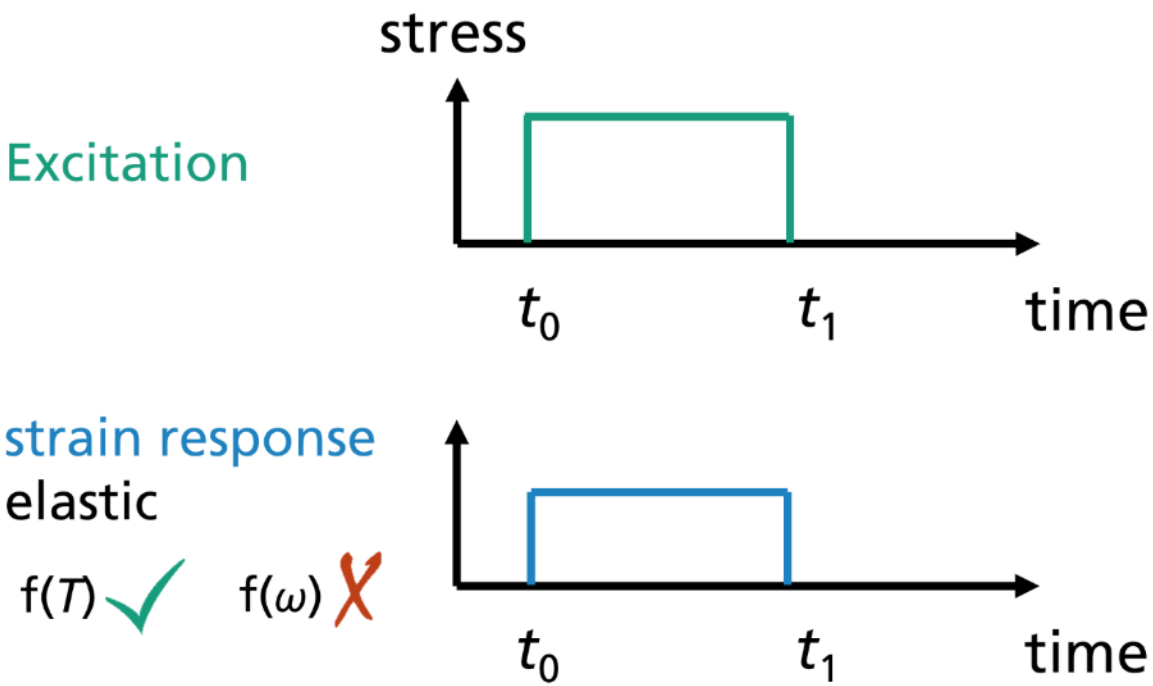

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FEM Simulations – Material Modelling

- Compare material models
  - T-dep. elasticity, f(T)
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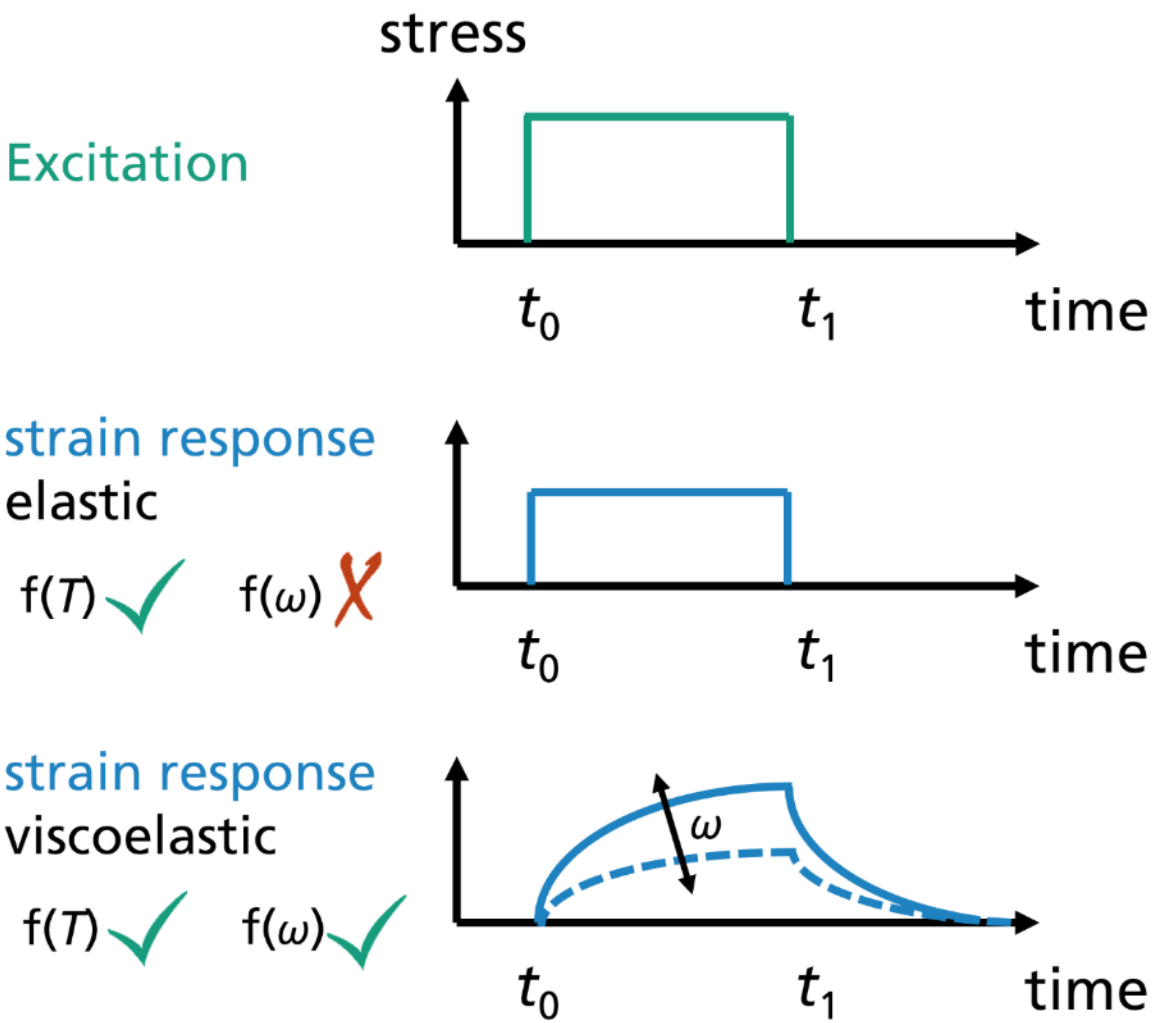
- Polymer stiffness depends on
  - Temperature f(T)
  - Loading frequency f(ω)
  - Significant creep and relaxation



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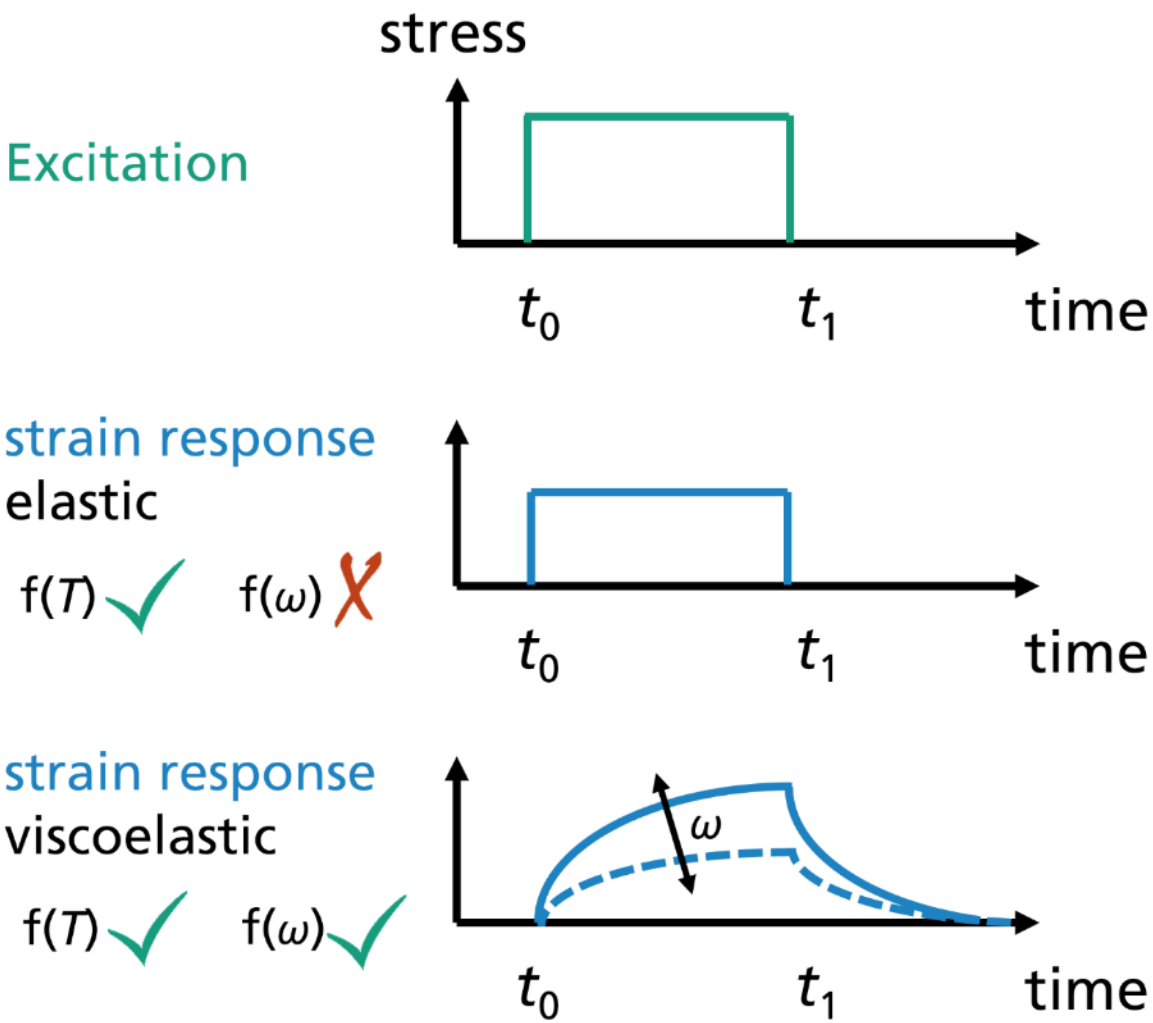
- Polymer stiffness depends on
  - Temperature f(T)
  - Loading frequency f(ω)
  - Significant creep and relaxation
- Viscoelasticity requires transient studies

  ➔ Increased computation time



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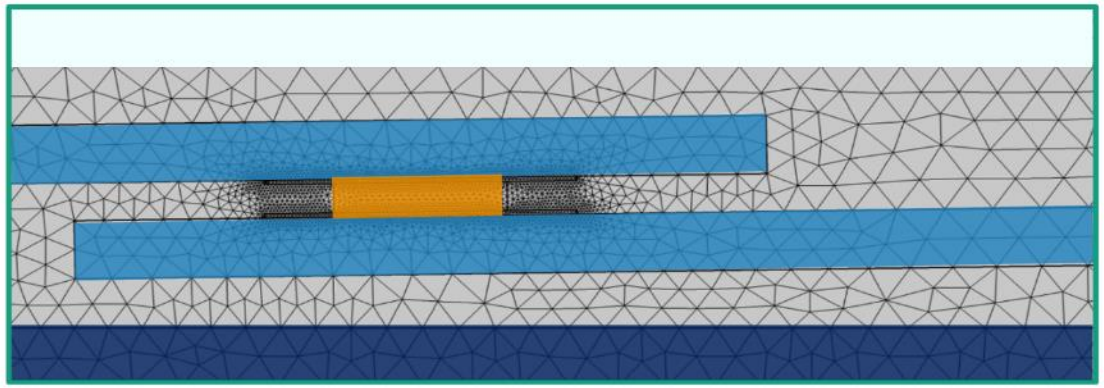
FEM Simulations – Material Modelling

Material	Mech. Model
Glass	linear elastic
Silicon	linear elastic
Backsheet	linear elastic [4]



[4] Eitner (2011) Thermomechanics of Photovoltaic Modules

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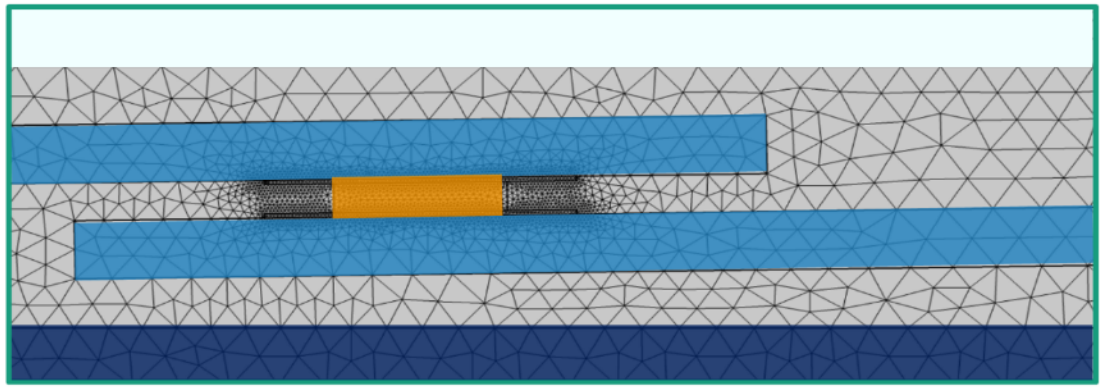

- For details on charaterization of EVA and ECA ► see publication

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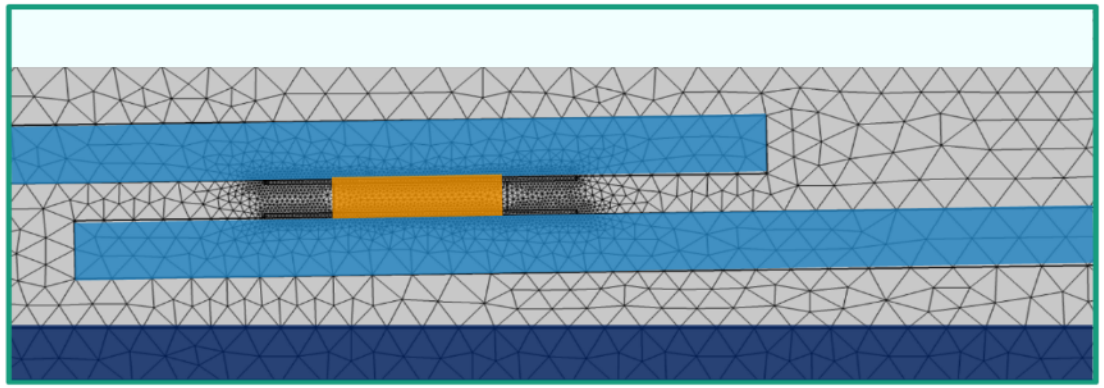

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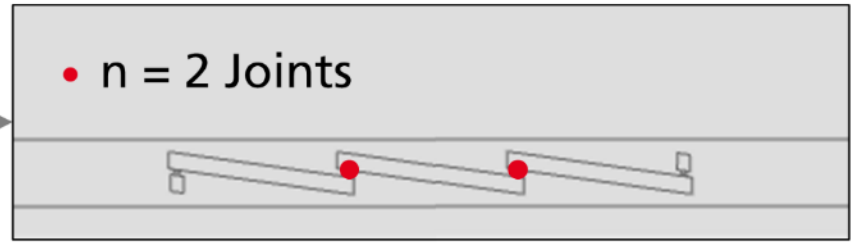
ECA	EVA	DoFs in FEM
elastic	elastic	~120 000
viscoelastic	viscoelastic	~2 400 000



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Studies of Material Models and Applied Loads

- Comparison string, TC, **n = 2 joints**
  - T-dep. linear elastic
  - Viscoelastic, 12.5 K/s TC
  - Viscoelastic, 0.025 K/s TC
  - Viscoelastic, stationary

  EVA & ECA

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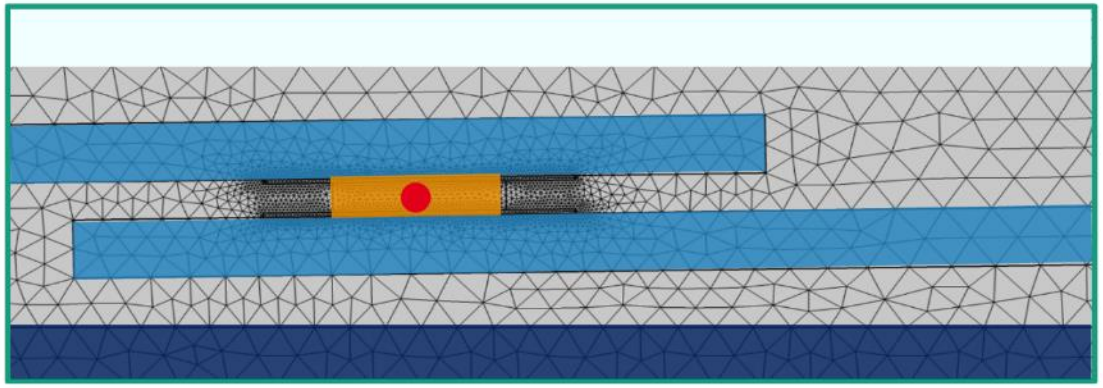
  EVA & ECA

- Compare string, **n = 20 joints**
  - Thermal cycling (TC)
  - Mechanical load (ML)

- Assessment criterion
  - Stress σ_{xy}, Strain ε_{xy}
  - Tensor $\boldsymbol{\sigma}$, principal stress directions



● Point of Interest

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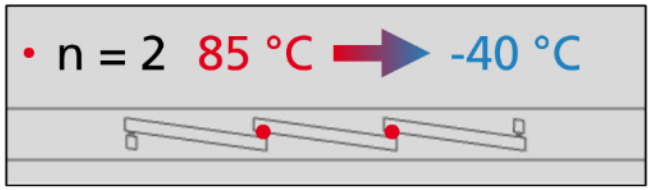
Comparison of T-dep. Linear Elasticity to Viscoelasticity



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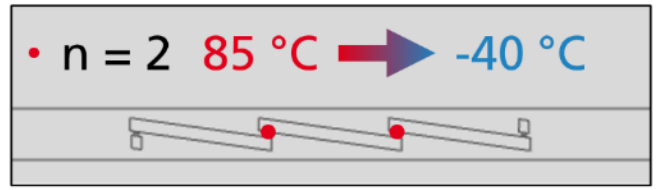
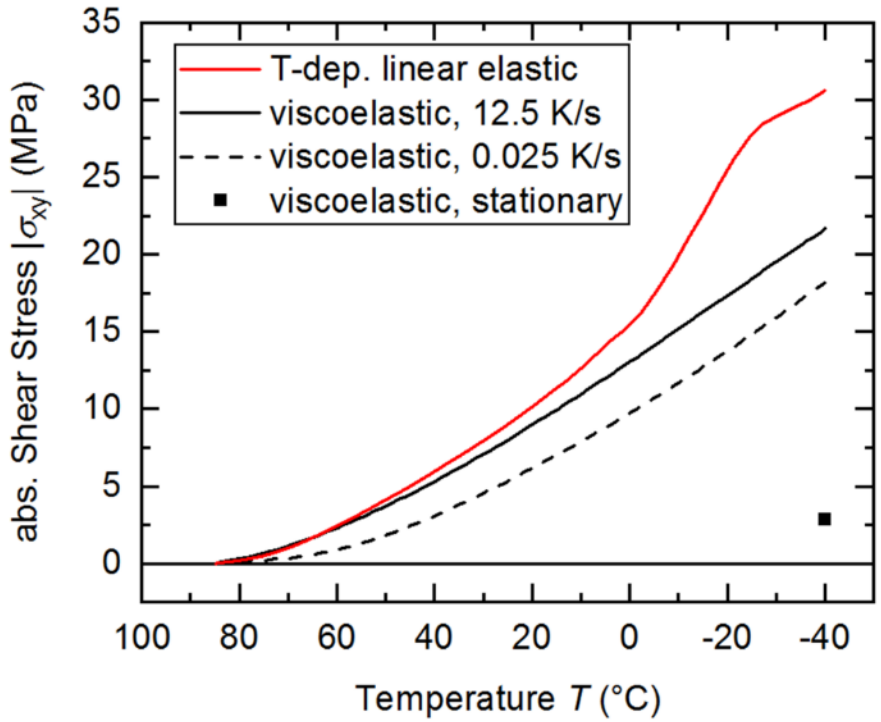
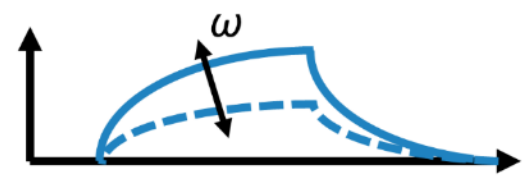




- Different development of stress during thermocycling
- Viscoelasticity changes absolute values with time ➔ **creep & relaxation!**



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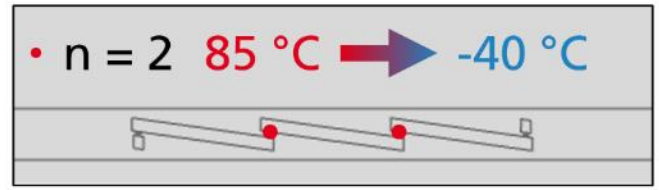

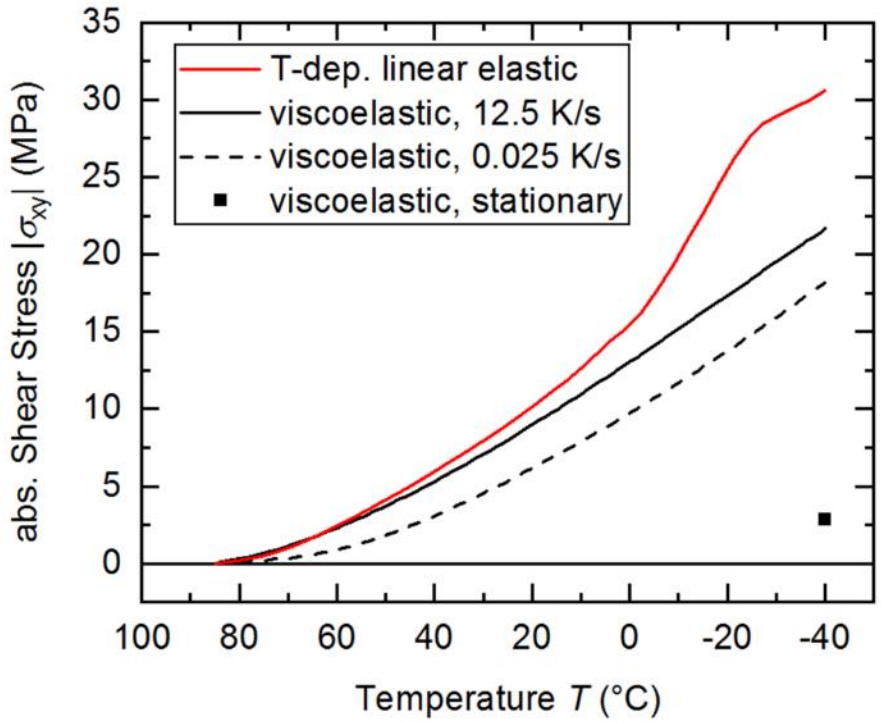

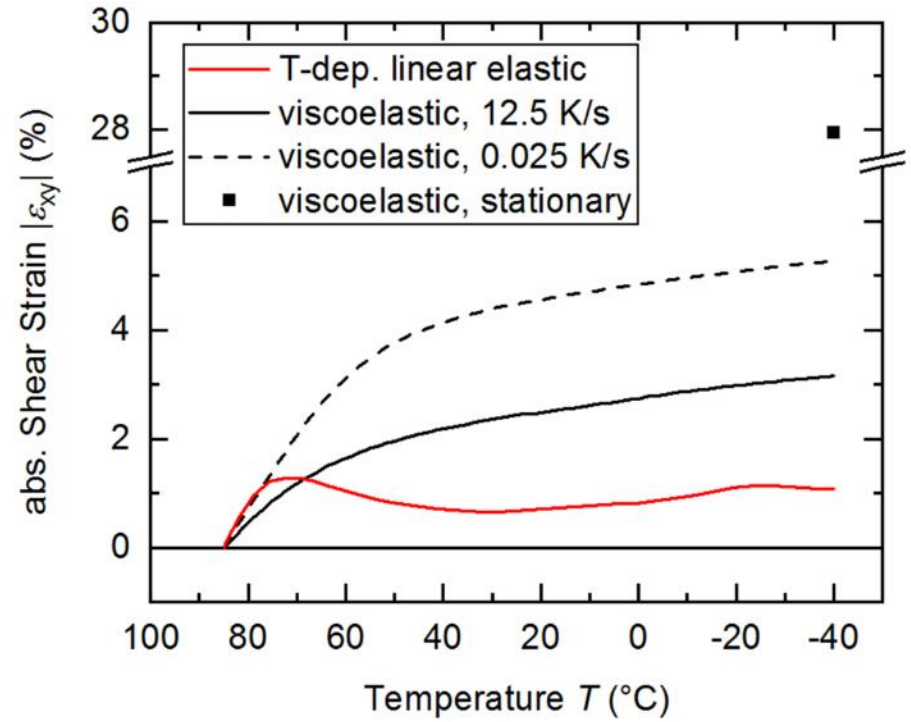

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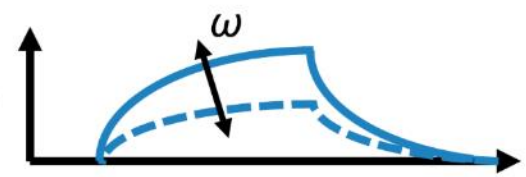

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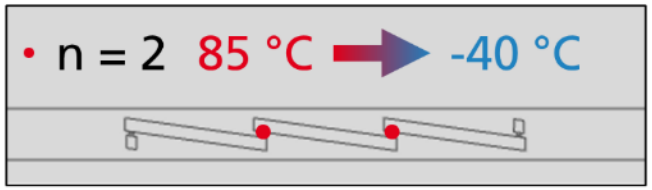
Comparison of T-dep. Linear Elasticity to Viscoelasticity – Tensoranalysis



- Tensor describes state of stress
- Tensor analysis ▶ Principle stress directions

$$\boldsymbol{\sigma}_{xy} = \begin{pmatrix} \sigma_x & \tau_{xy} \\ \tau_{xy} & \sigma_y \end{pmatrix}$$

- Maximum shear stress τ_{max} at ±45°
  Maximum normal stress at 0°

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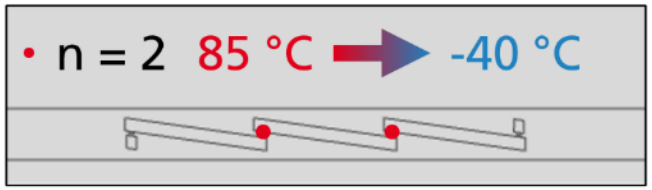

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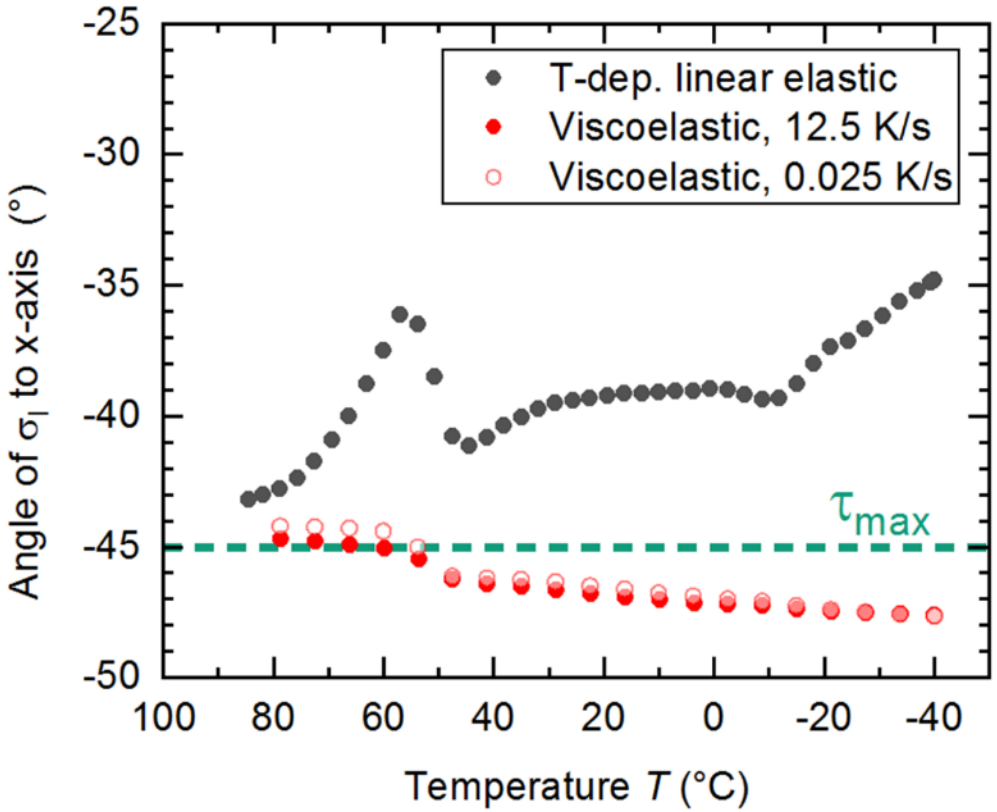
- Viscoelastic: **close to maximum shear mode**
- T-dep. linear elastic: **intermediate mode**



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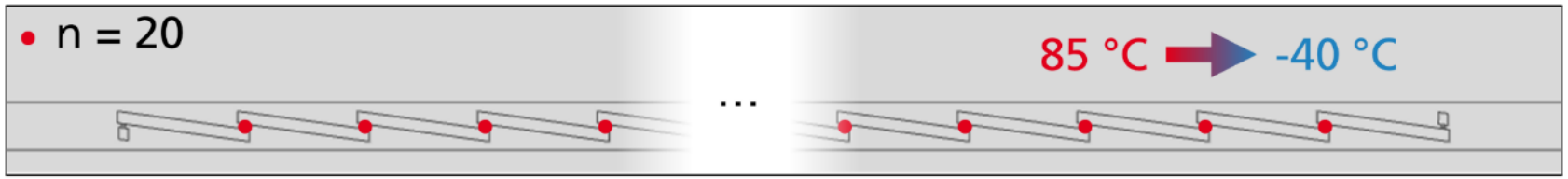
Comparison String – Thermal Cycling (TC)



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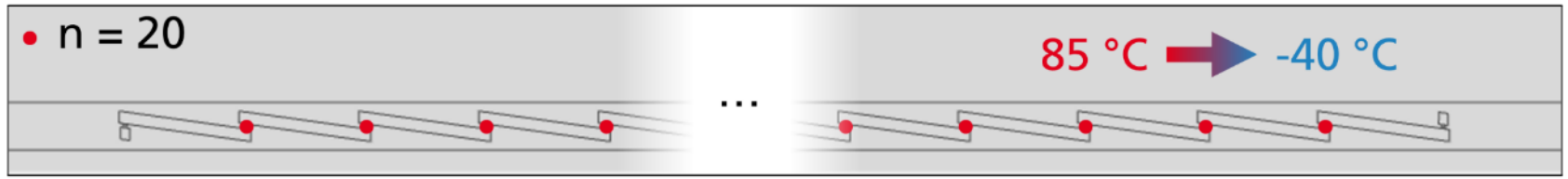

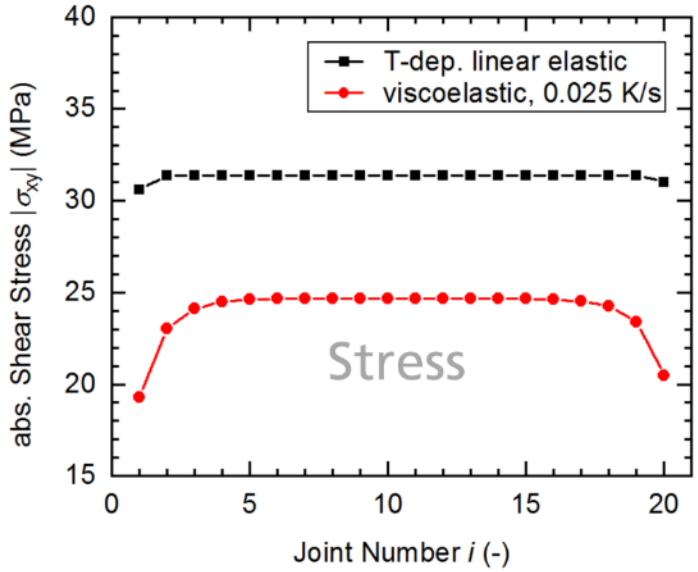

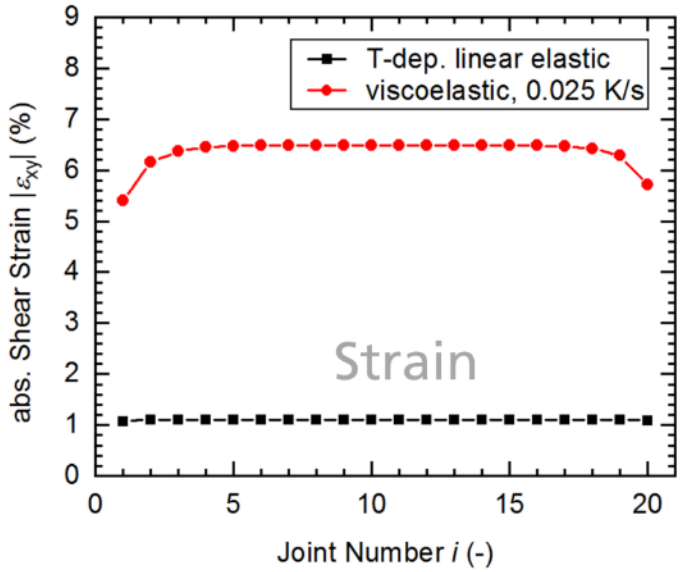

- Stress and strain differ in absolute values
- Similar curve shape

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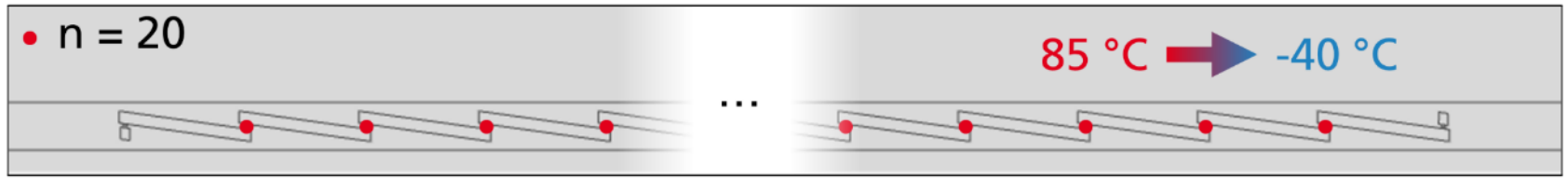

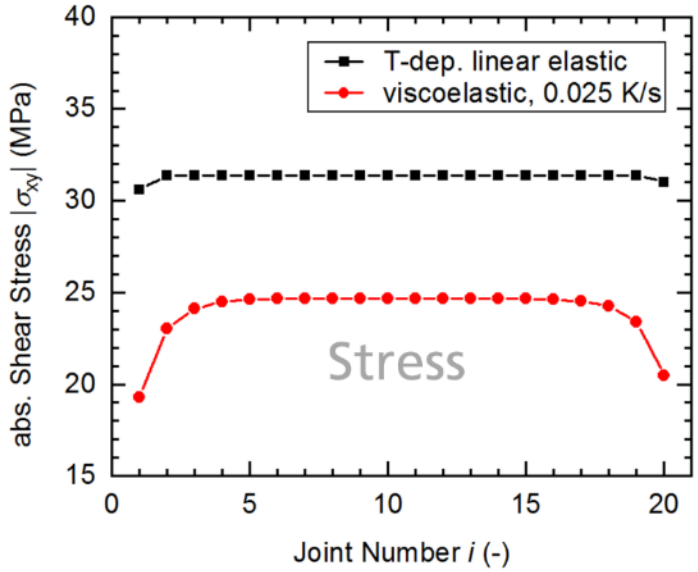

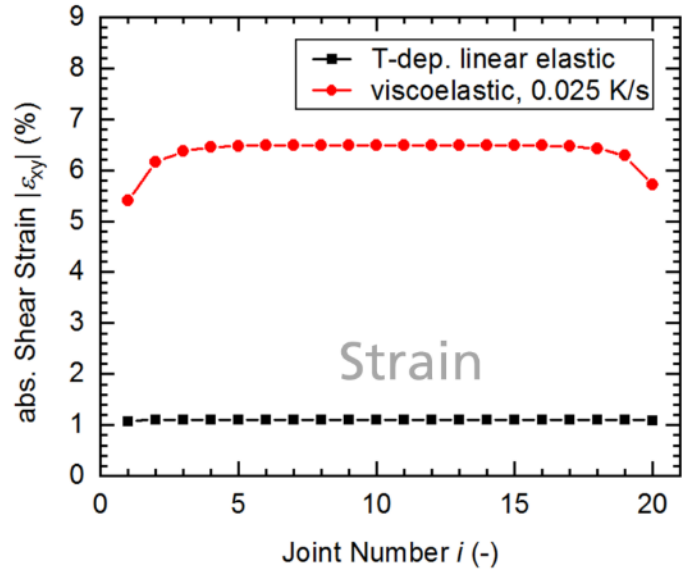

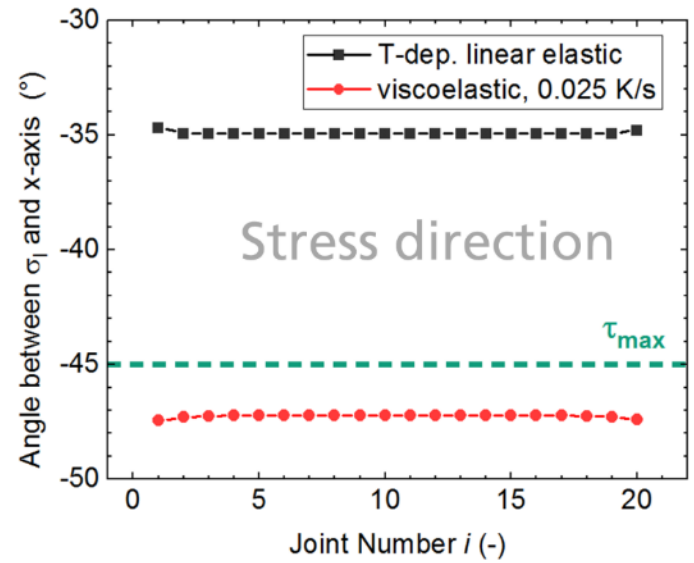

- Stress and strain differ in absolute values
- Similar curve shape

- Diverging between models
- Homogeneous within string

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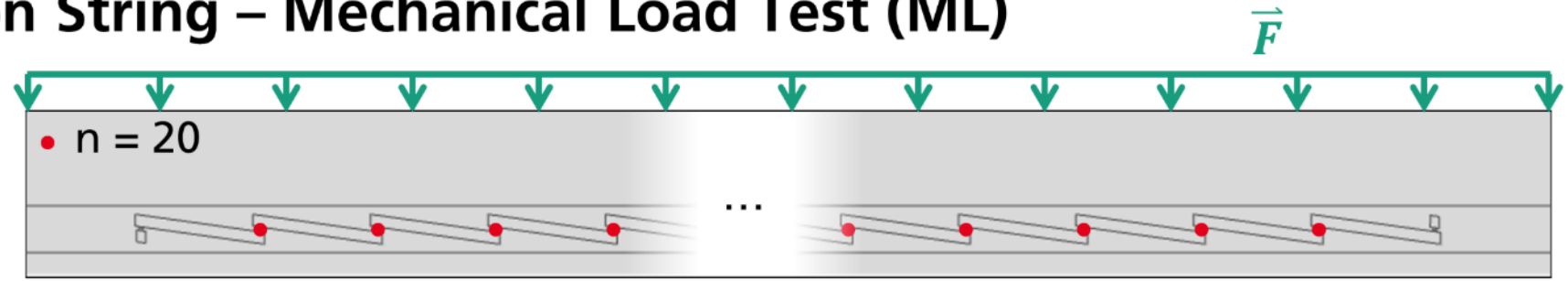
Comparison String – Mechanical Load Test (ML)



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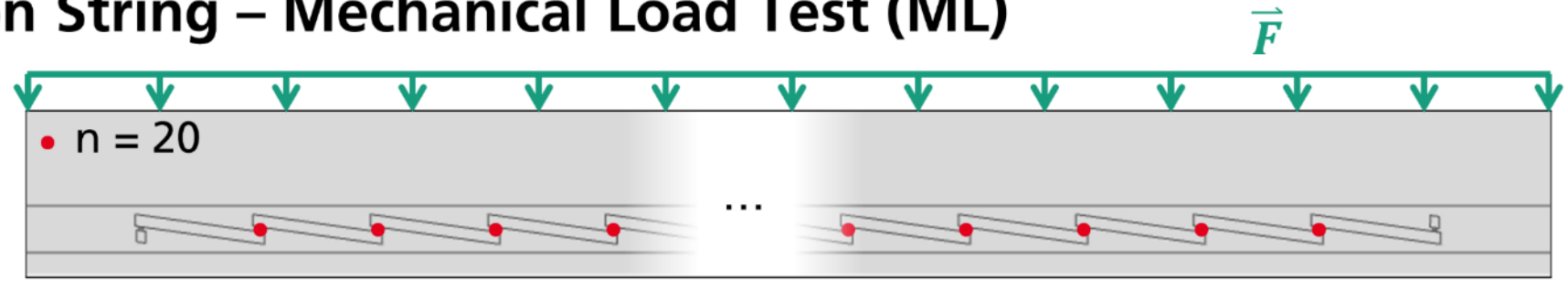

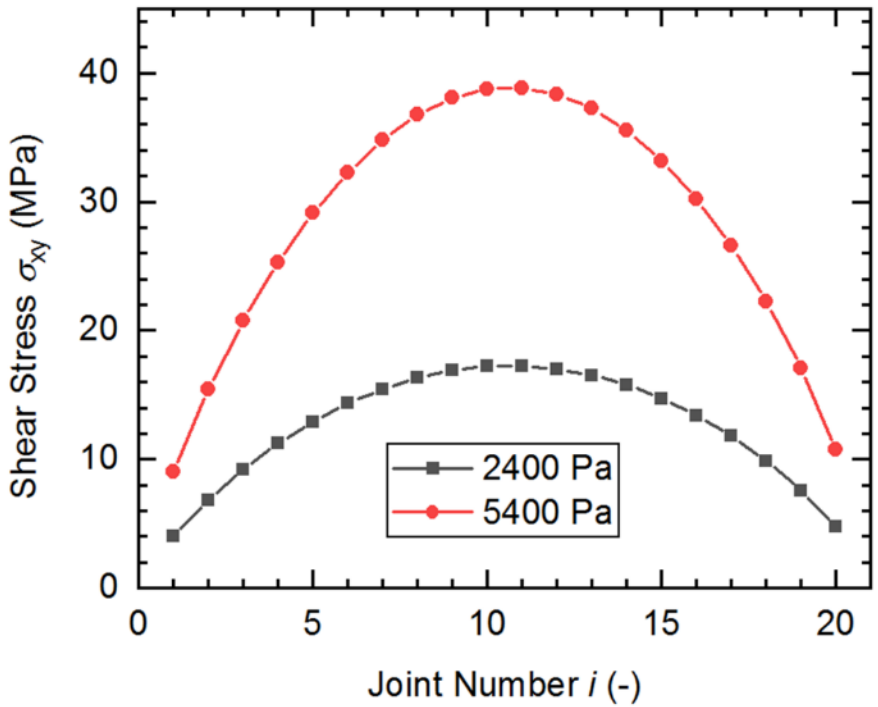

- String middle faces maximum stress

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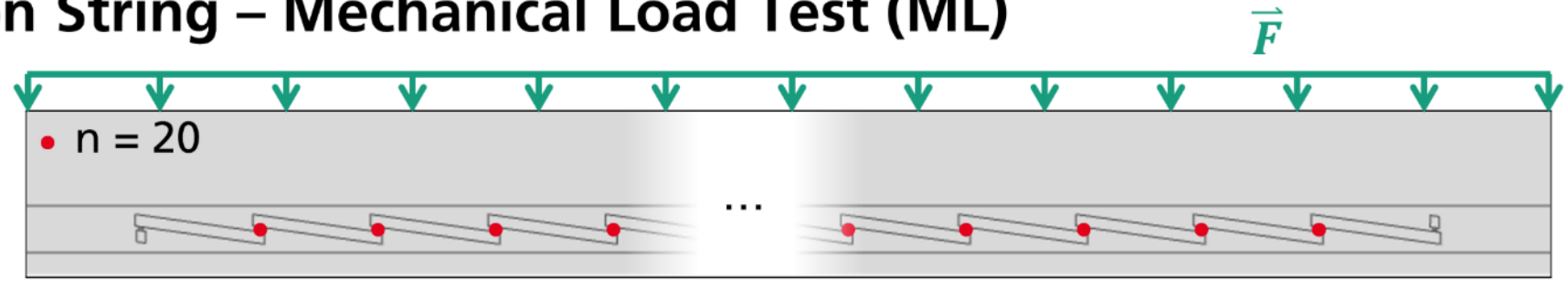
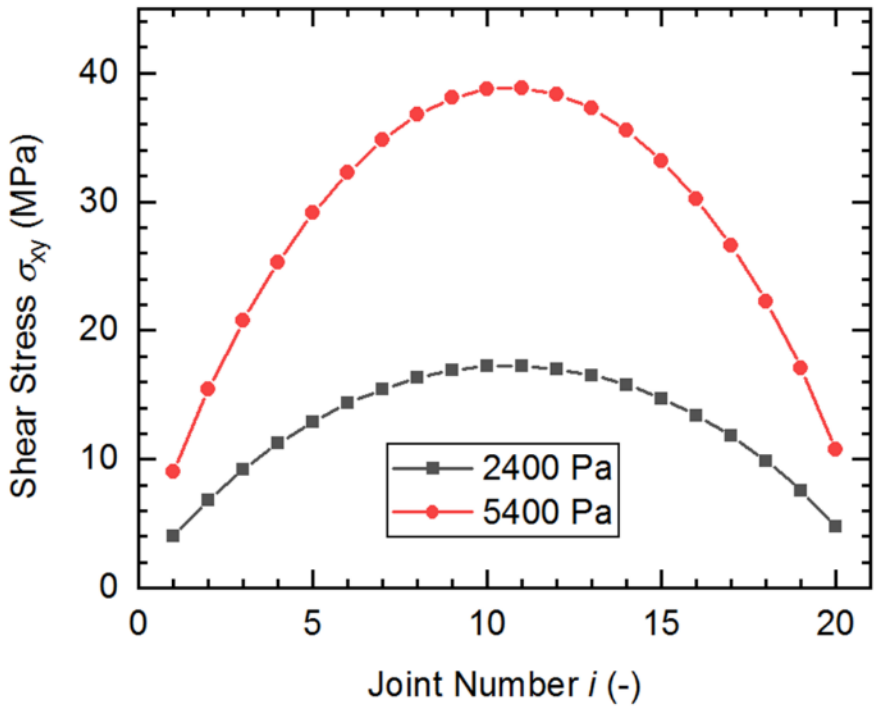
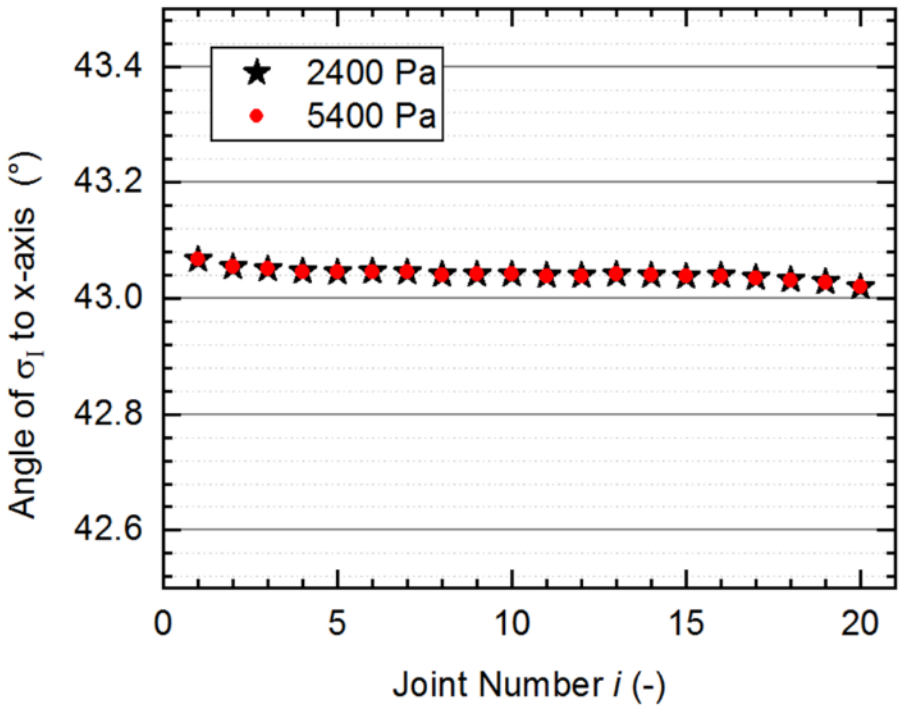
Comparison String – Mechanical Load Test (ML)







- String middle faces maximum stress
- Homogeneous distributed deformation mode
- Close to max. shear mode

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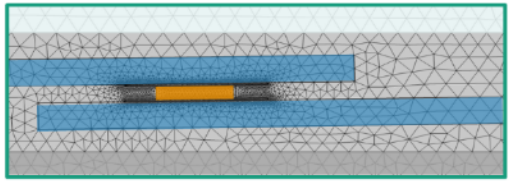
Summary and Conclusion

- 2D FEM simulations of shingled cell string
  - T-dep. linear elasticity
  - Viscoelasticity



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Summary and Conclusion

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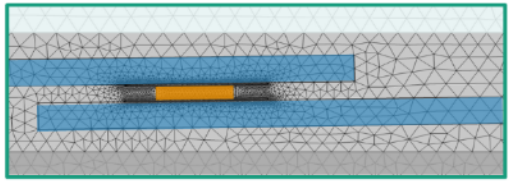
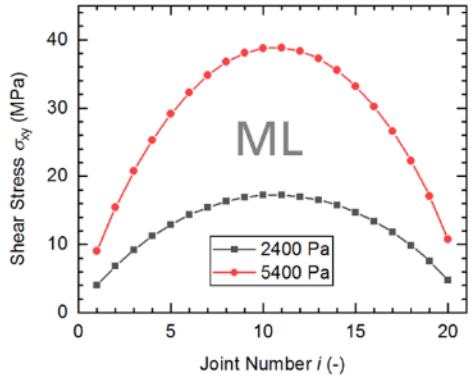
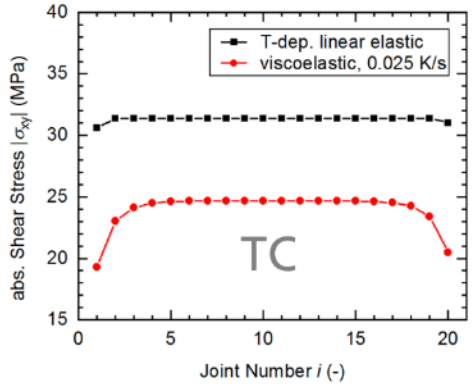
- Homogeneous loading of joints in thermal cycling
- Inhomogeneous loading of joints in mechanical load







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Summary and Conclusion

- 2D FEM simulations of shingled cell string
  - T-dep. linear elasticity
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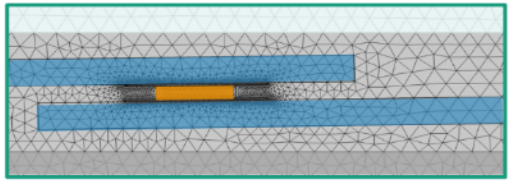
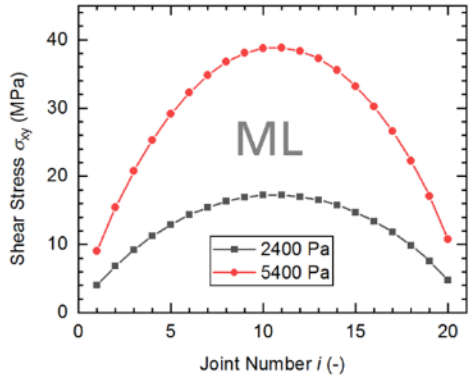
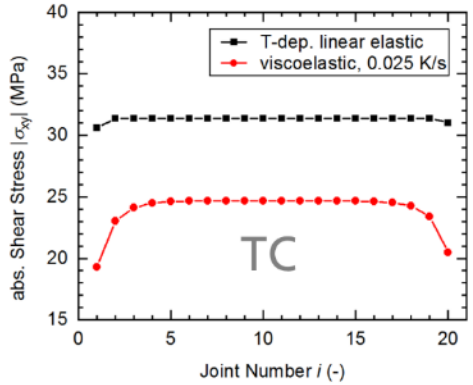
- **Relative results** can be obtained by T-dep. linear elasticity
- When aiming for **absolute values: viscoelasticity**







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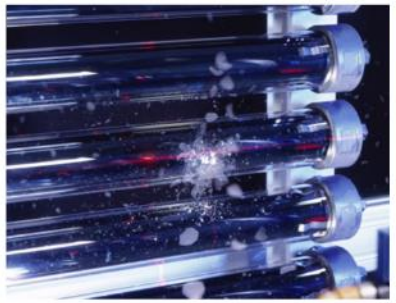
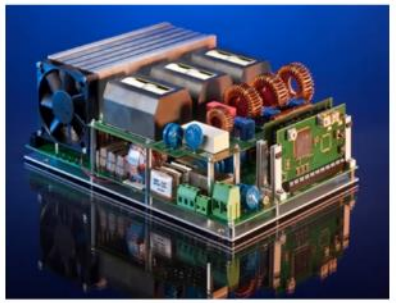
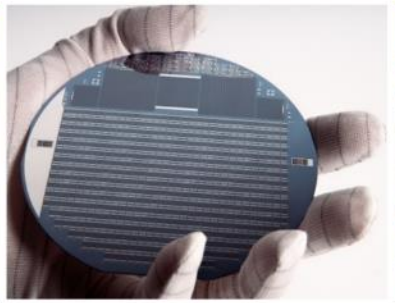
Thank you for your Attention!

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