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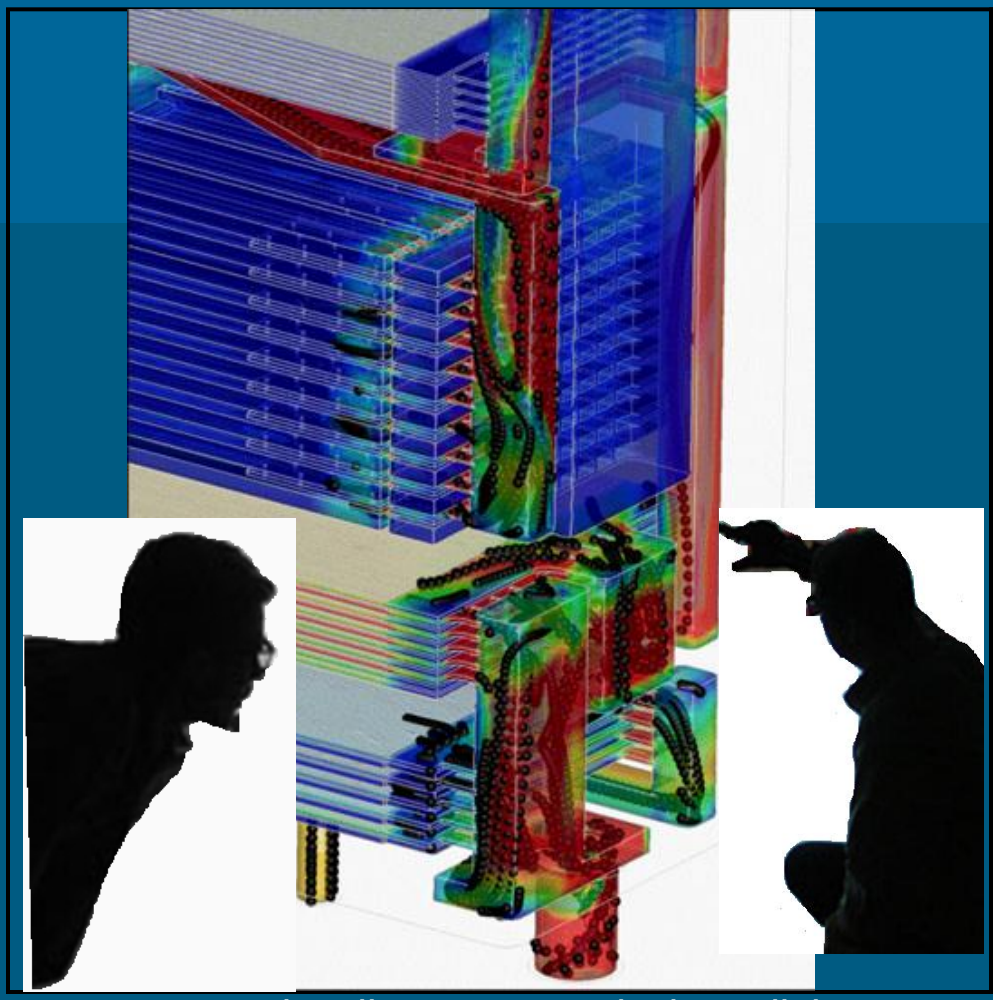

3D Fuel Cell System Analysis -Jülich

Thermomechanical Modelling of High Temperature Fuel Cells

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Syllabus

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- Introduction
  - What is thermomechanics?
- Thermomechanically induced strain and stress
- Thermomechanical modelling aspects
  - Thermomechanical material properties and behaviour
  - Geometrical approximations
- Thermomechanical issues in fuel cell systems
- Case study- Thermomechanical modelling of a solid oxide fuel cell stack.
- Concluding remarks

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Rivet heater and rivets

Road pothole

Petrol gauge

Soil and railway

Glaze firing

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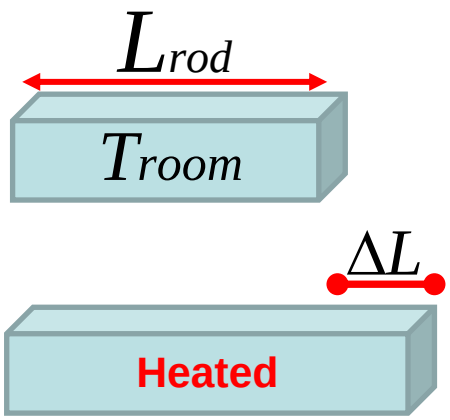
- **Simple Strain-Stress Problem**
  A brass rod is stress-free at room temperature (22°C)
  It is heated up, but prevented from elongation
  At what T does the stress reach -150MPa?



Strain (ε) due to ΔT causes a stress (σ) that depends on the modulus of elasticity (E):

$$\varepsilon_{thermal} = \frac{\Delta L}{L_o} = \alpha(T - T_o)$$

Constraint! $\Delta L = 0$, stress i.e., σ occurs

10^5 MPa

20×10^{-6} /C

$$\sigma = E(-\varepsilon_{thermal}) = -E\alpha(T - T_o)$$

-150MPa

22C

Answer: 97C

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- Decide the target of the problem and desired output
- Determine the employed computer geometry
- Set the applied load
- Decide on the physics that must be included
- Description of the material behaviour
- Analysis type
- Solution and Post-processing-Validating

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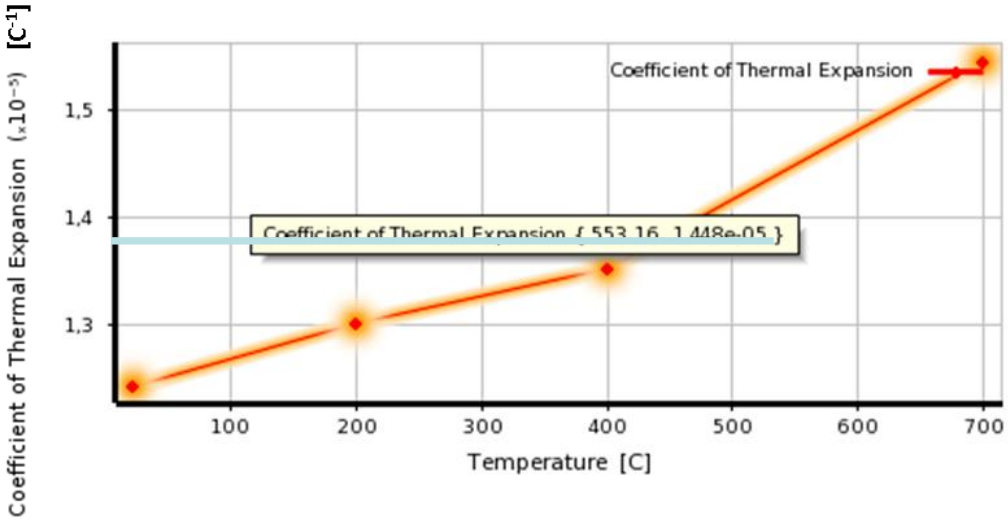
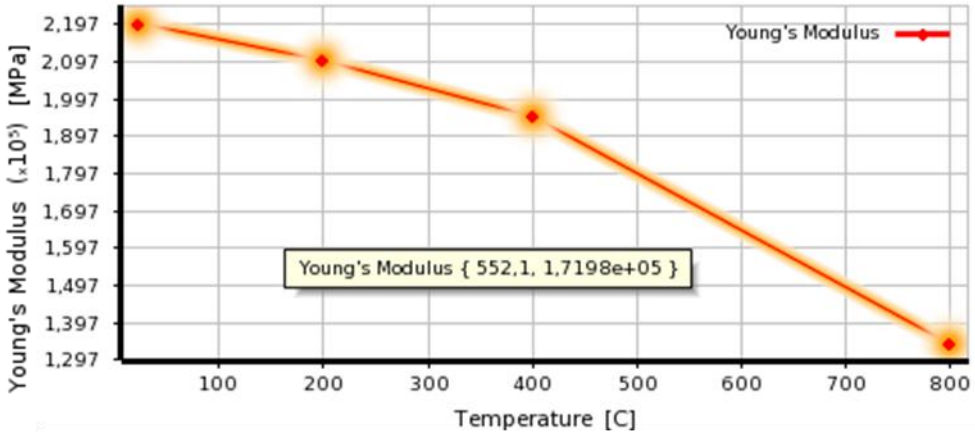
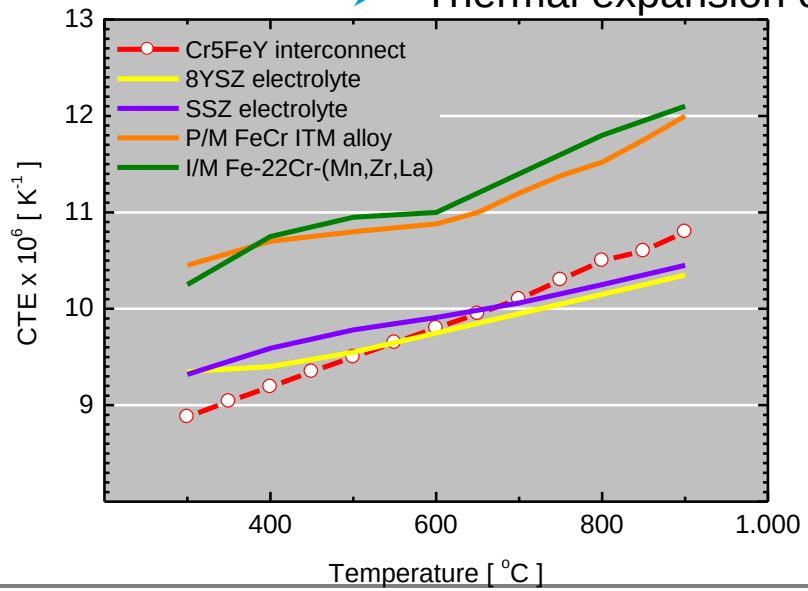


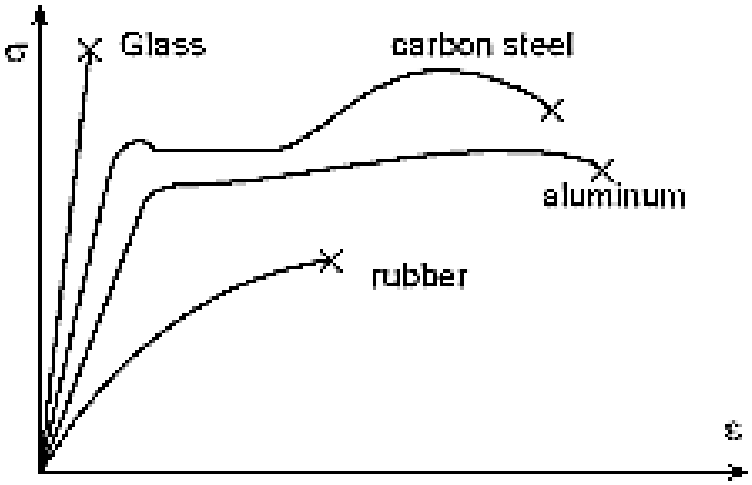


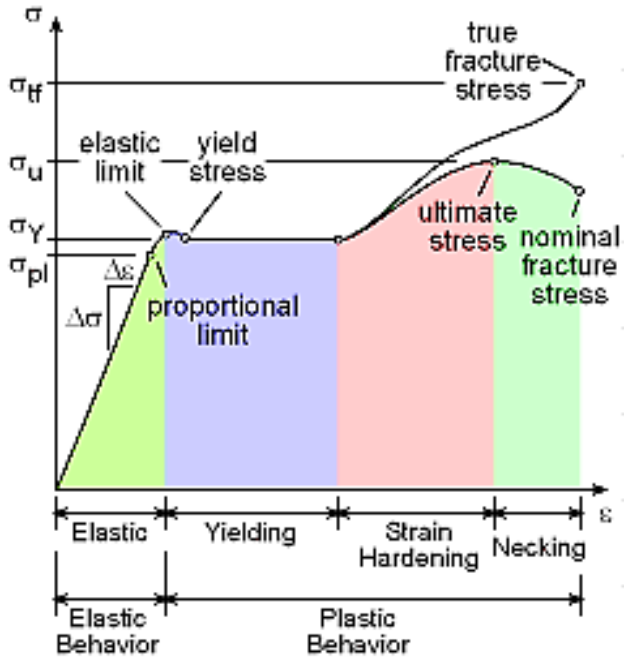
➢ Thermal expansion coefficient and Young's modulus of steel sample



- Heat capacity
- Thermal conductivity
- Young's modulus
- Thermal expansion coefficient
- Strength

CTE of different SOFC-relevant materials





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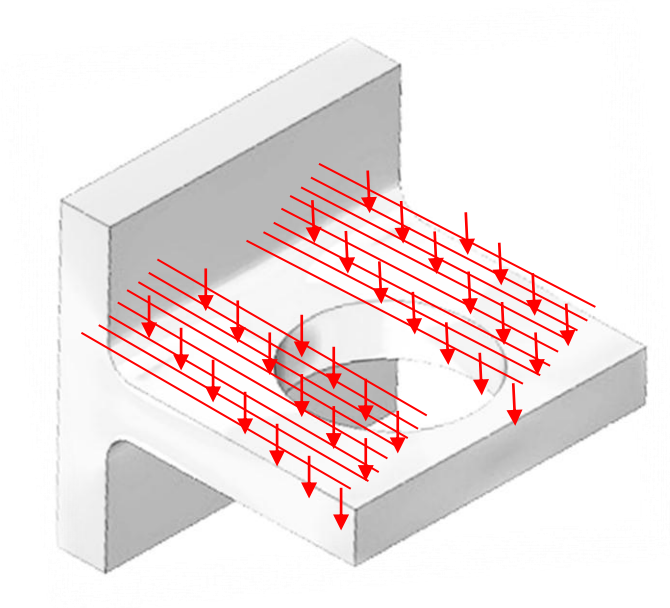
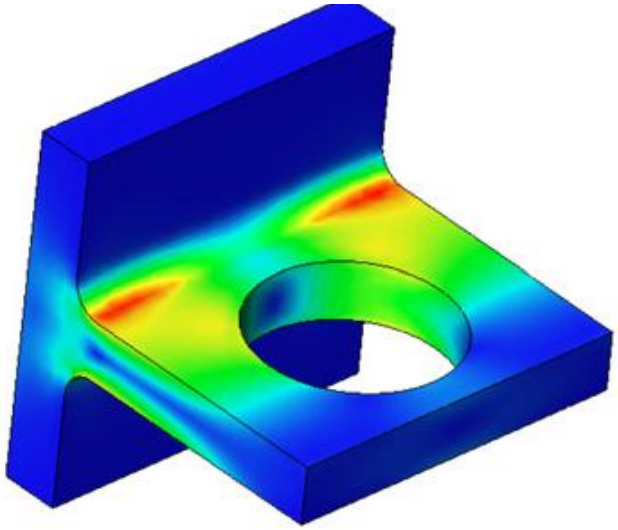
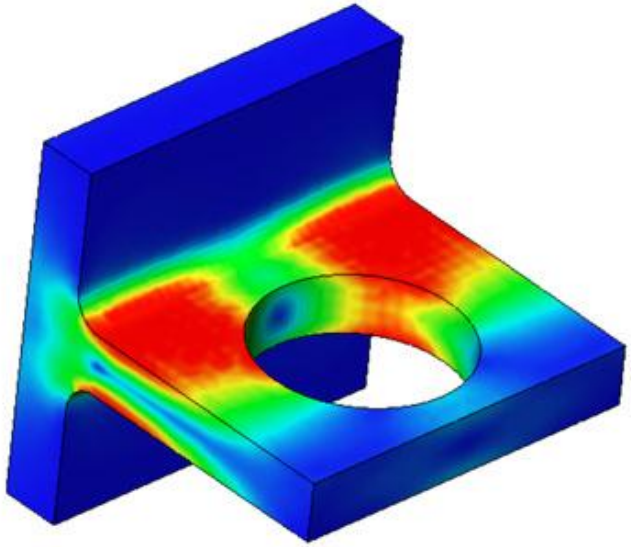




Linear elastic



Rate independent plastic

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Simplifying the problem

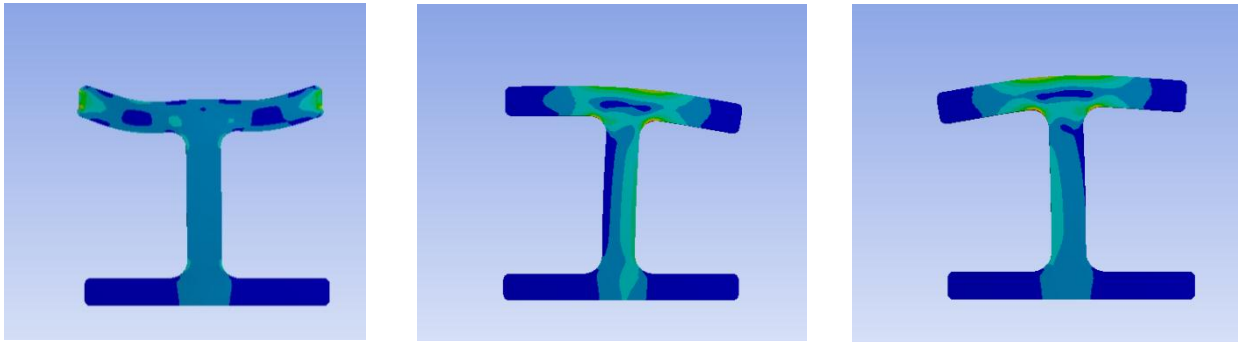
Geometry and Material non-linear

Geometry linear
Material non-linear

Geometry non-linear
Material linear

Geometry and Material linear

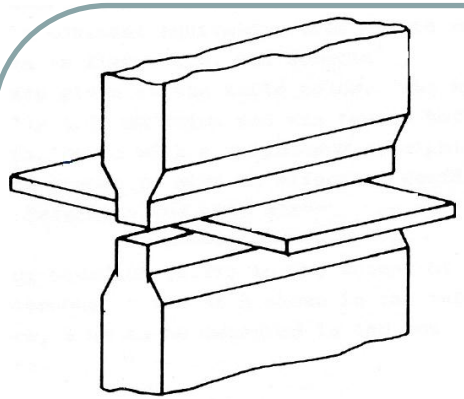
Complexity of the analysis



Support-Constraints

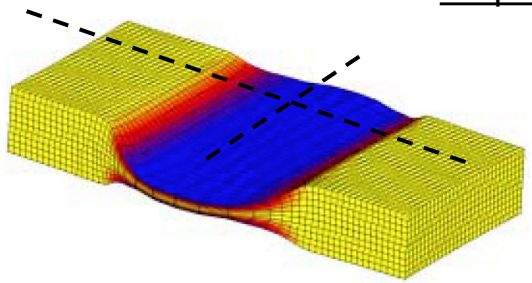
Shape

Material type

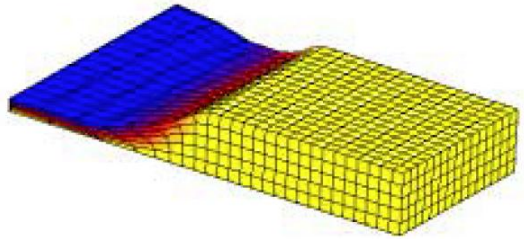


Compression load test

Displacement

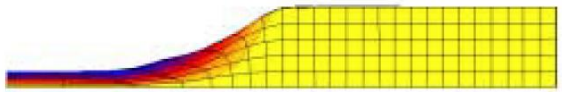


3D approach

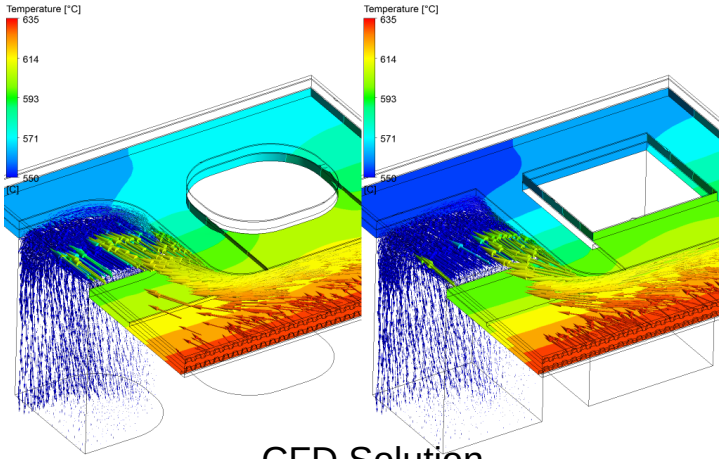


3D quarter

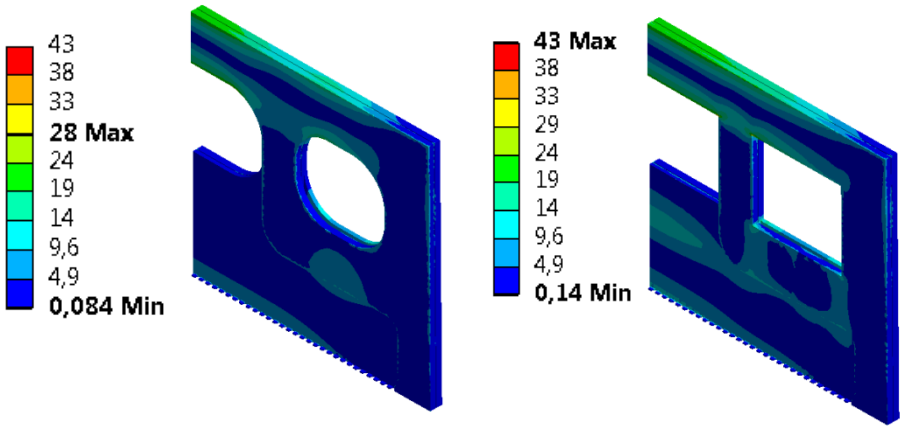
2D approach



2D quarter



CFD Solution



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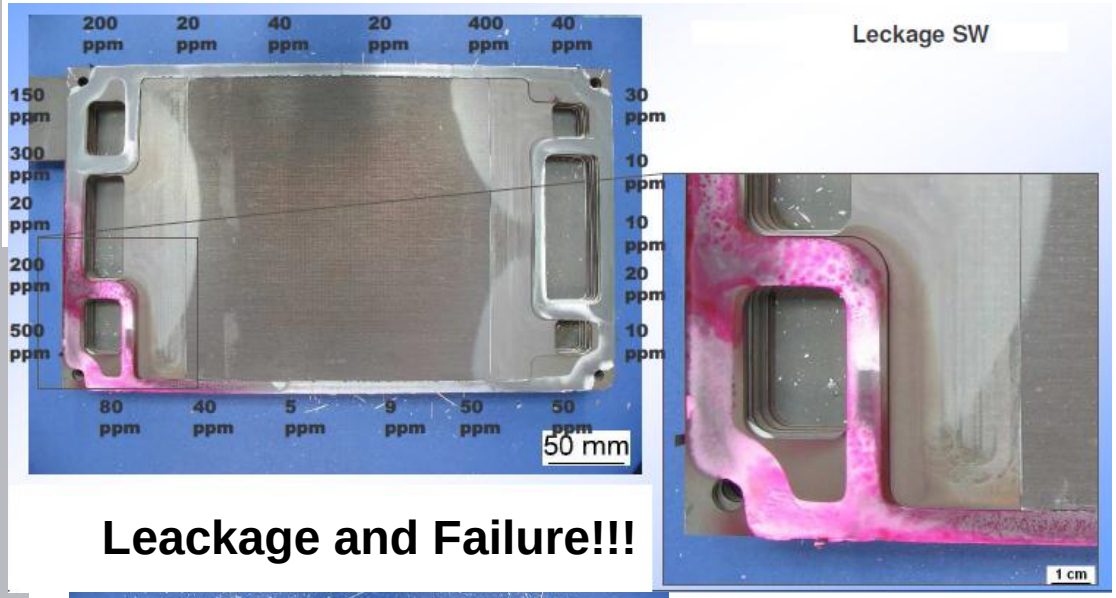
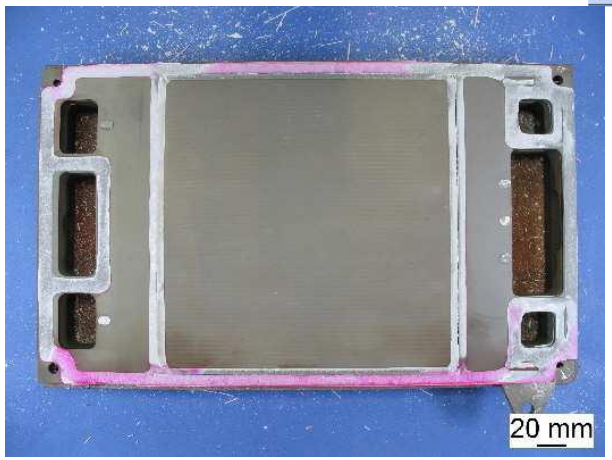


Leackage and Failure!!!



- Manufacturing
- Non-uniform heat generation
- Internal reforming
- Malflow distribution
- Thermal cycling
- Flow rates; % concentrations

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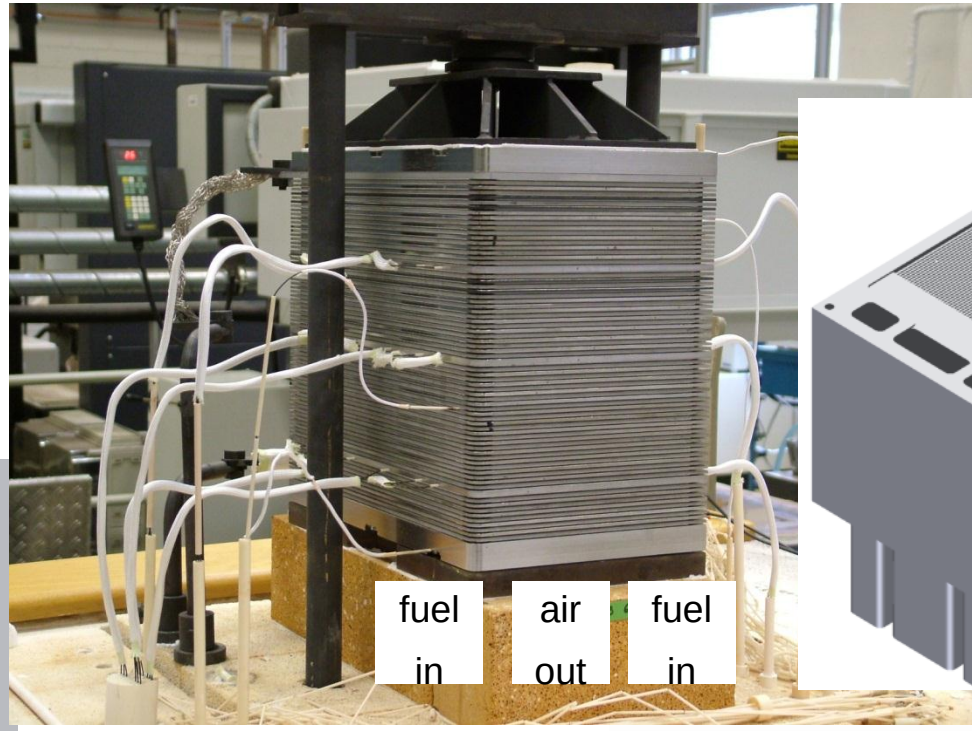

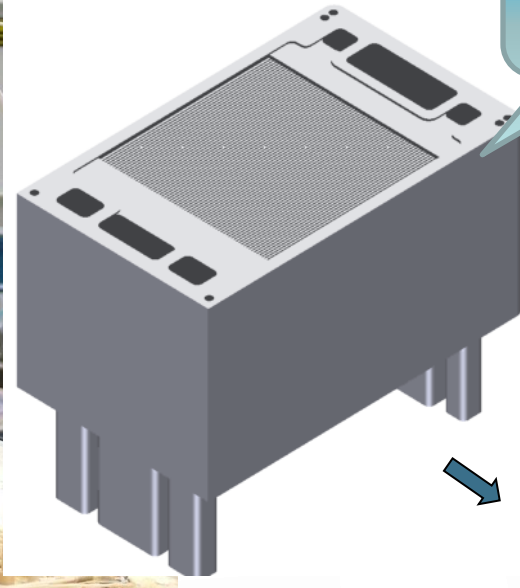

Idealised Model

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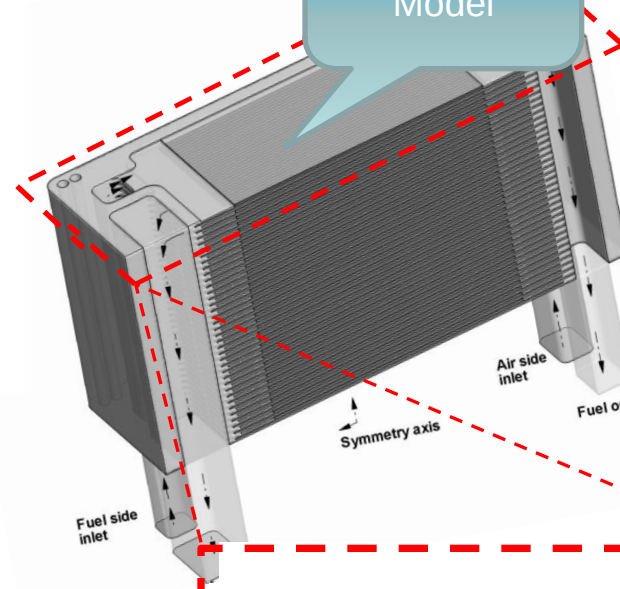
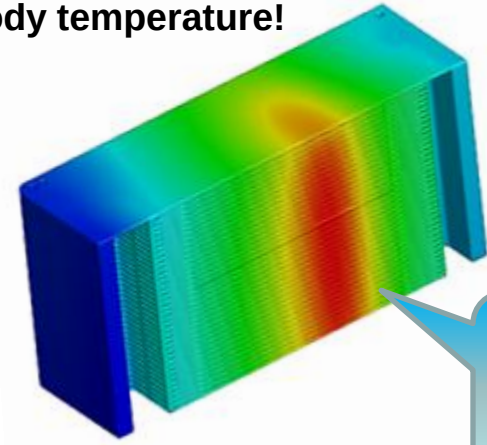
Employed Model

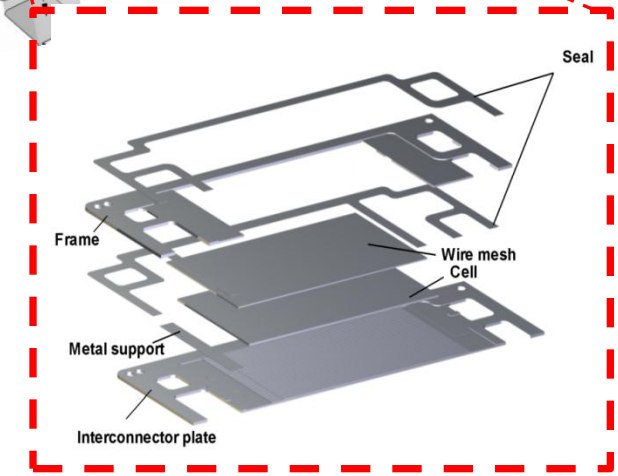


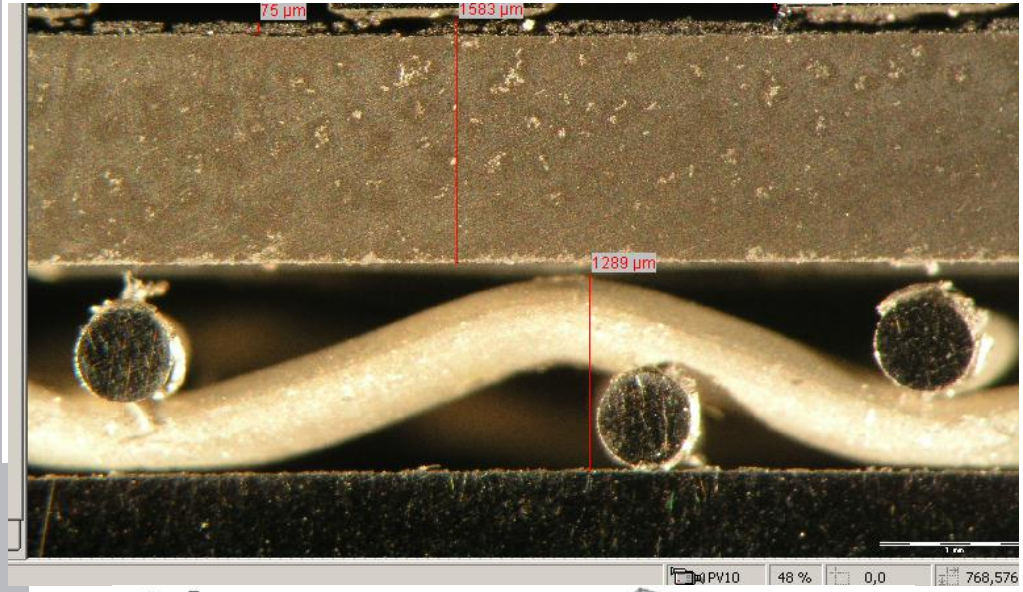
Solid body temperature!

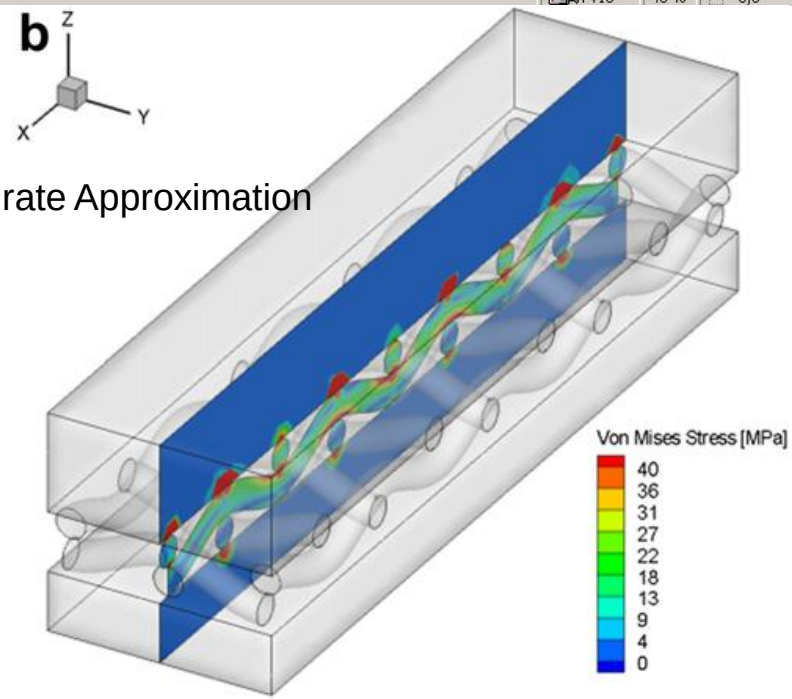


CFD analysis

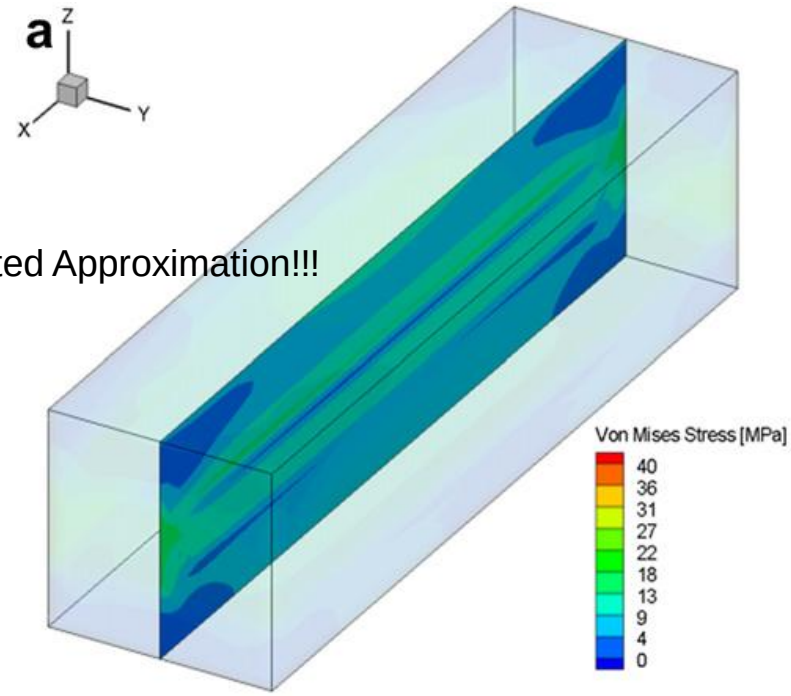
Input for structural analysis



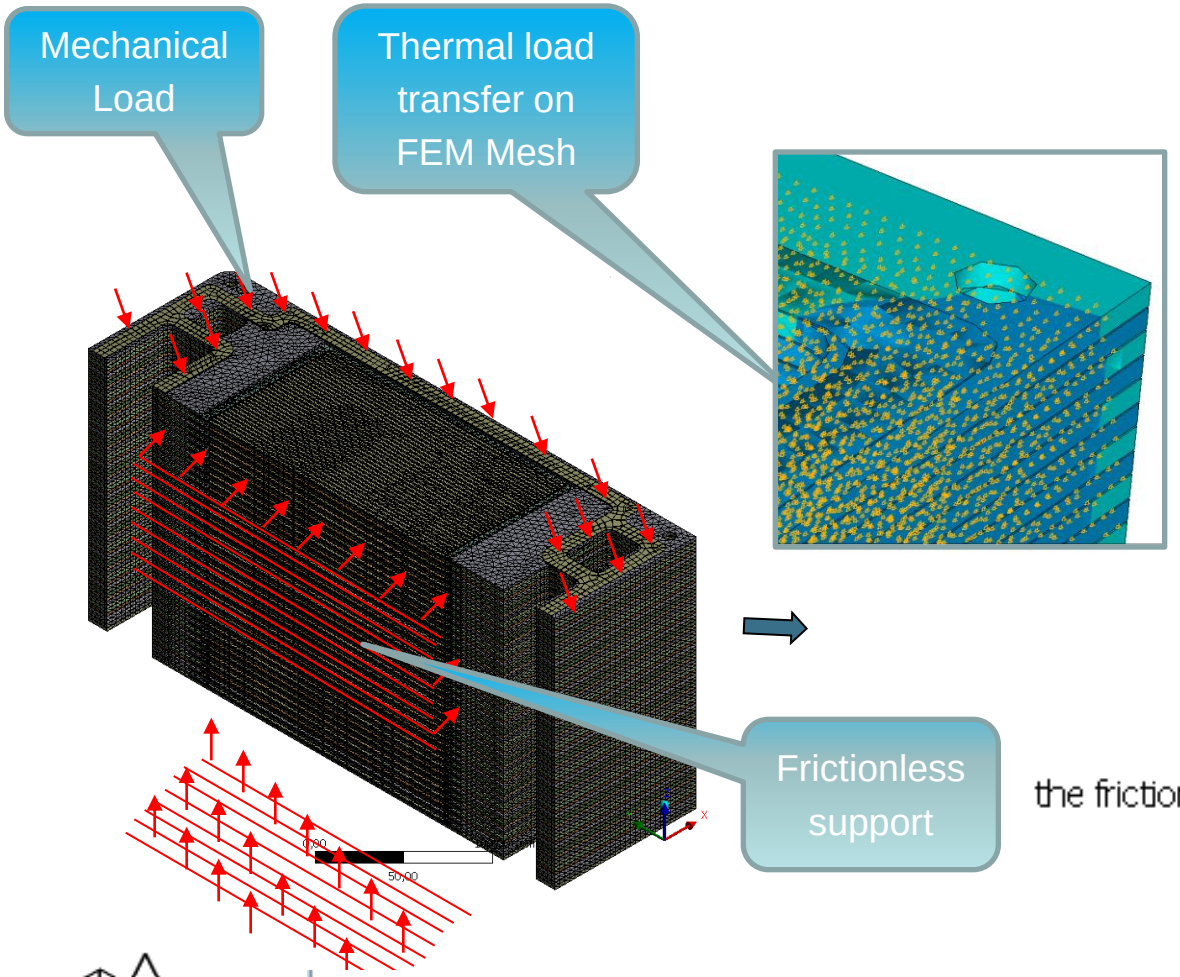




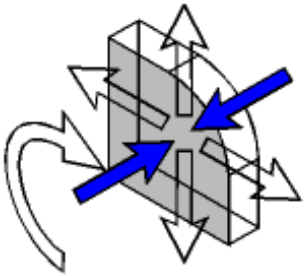
Accurate Approximation



Limited Approximation!!!



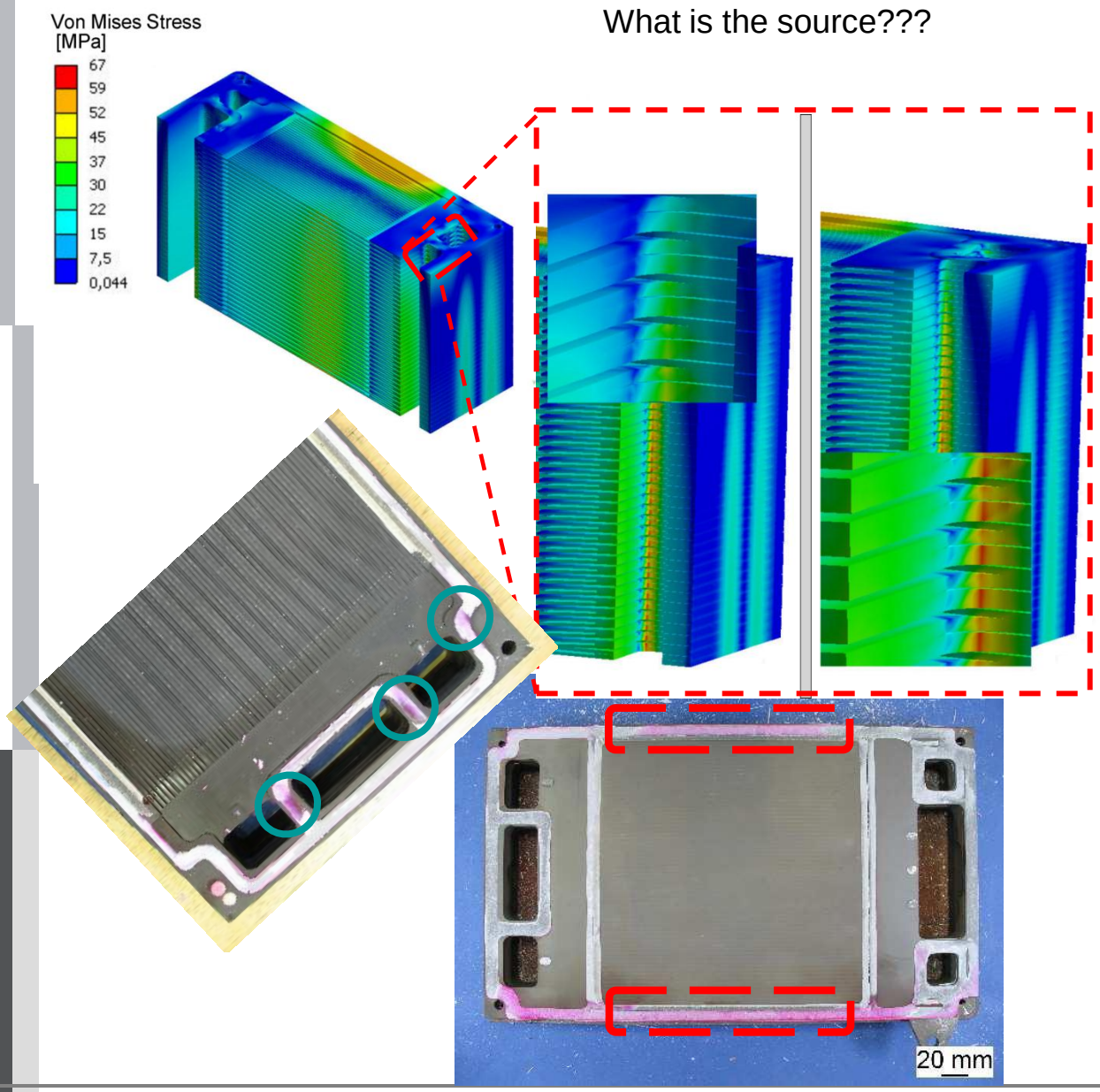
the frictionless support is equivalent to a symmetry condition.

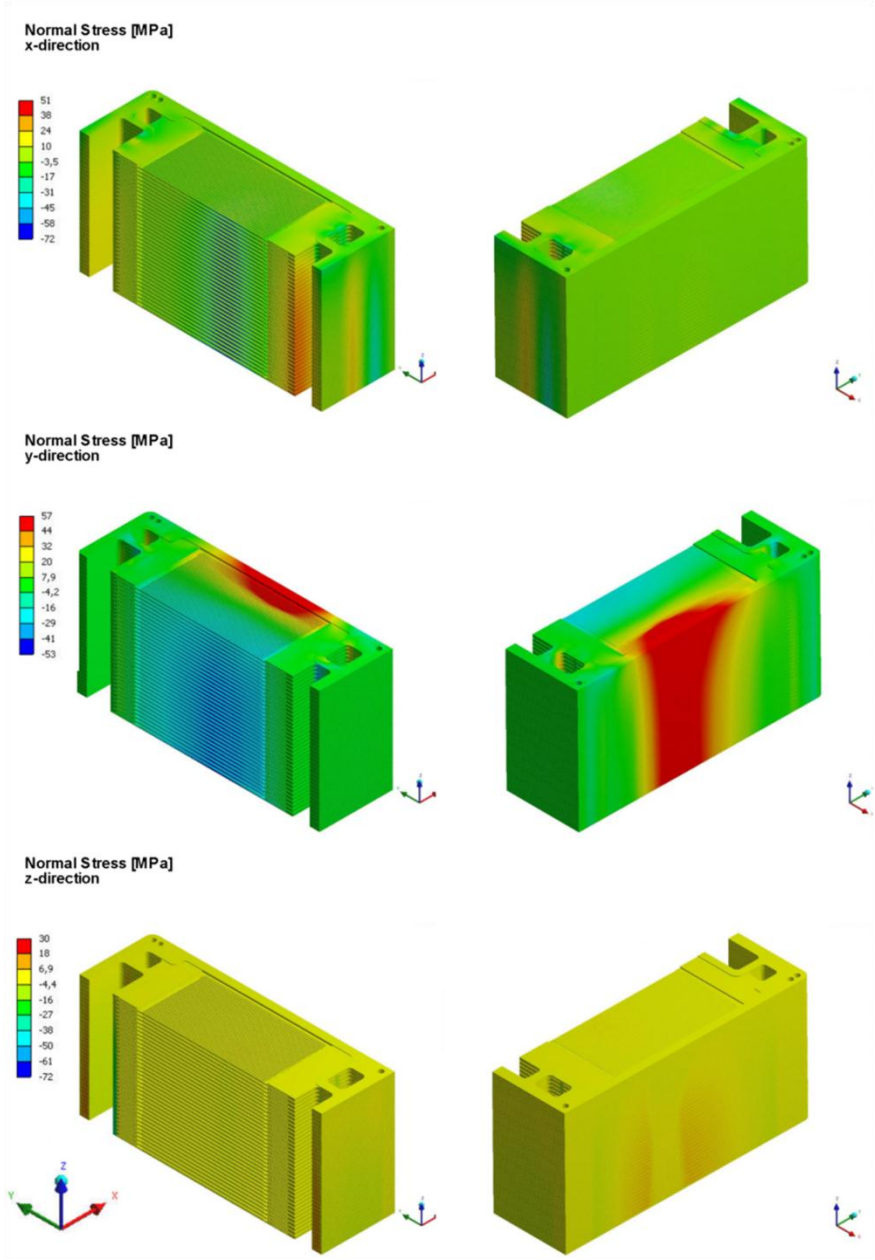


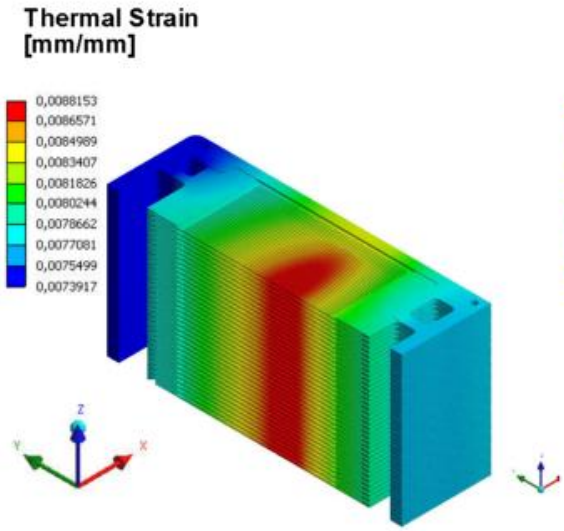
- ☐ Tangential directions. The surface body is free to move, rotate, and deform tangential to the face.
- ■ Normal direction relative to the face. No portion of the surface body can move, rotate, or deform normal to the face.

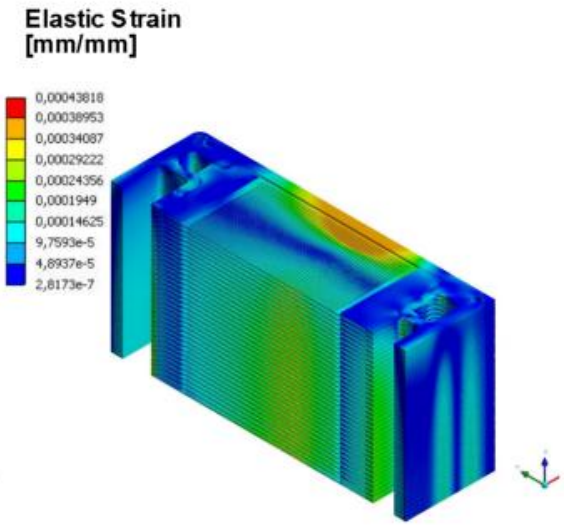
σ_{max}= manifolds & Outer regions!

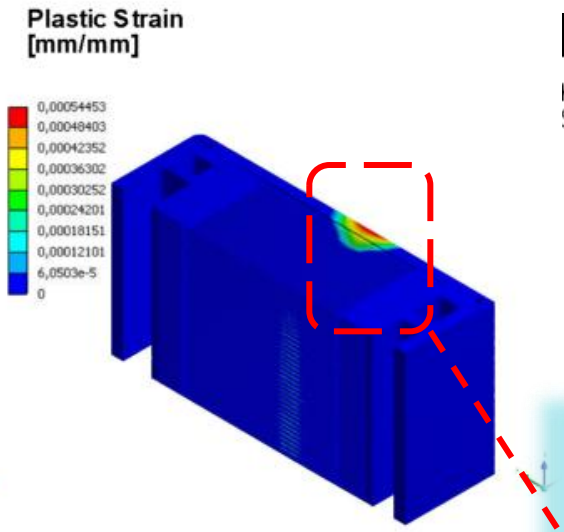
What is the source???











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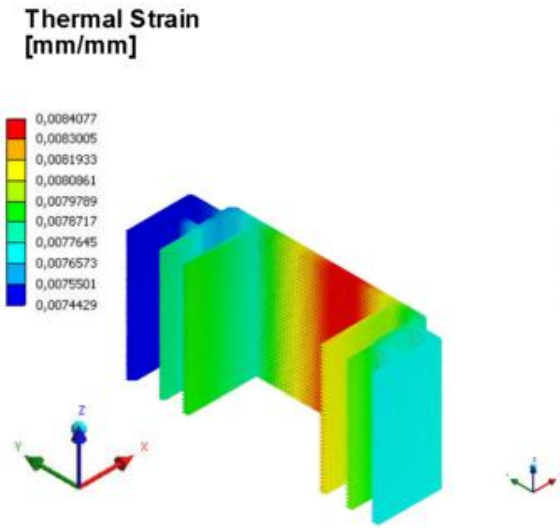

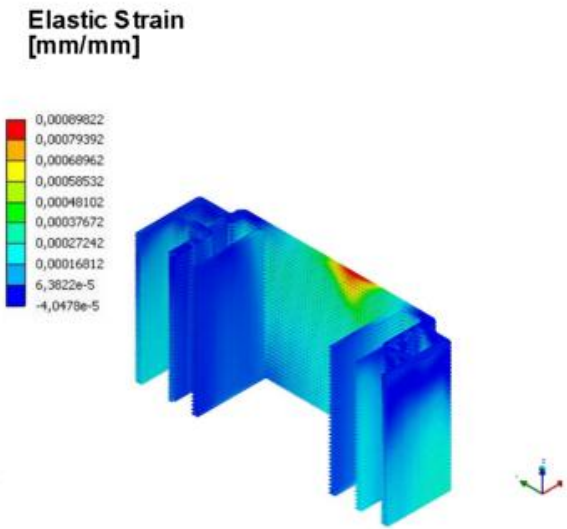

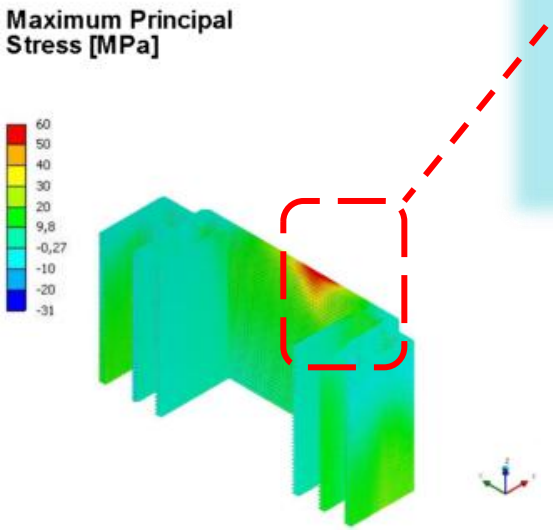

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Thermomechanical Modelling of High Temperature Fuel Cells

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- Thermomechanics is a discipline practiced to improve the quality and understanding of coupled thermal and mechanical load related issues.
- Fuel cell systems are a core investigation area in thermomechanics.
- Many well-established modelling approaches can be adopted for fuel cell structures and materials.
- Modelling of thermomechanics in fuel cell systems is a very challenging task due to:
  - Complex materials and geometries (high non-linearity and sophisticated structures)
  - Highly coupled multiphysics (requires expertise in many fields)
  - Difficulties in testing (is very limited and prohibitive)
- 3D thermomechanical modelling exemplifies how intensely computer aided analysis may be applied in fuel cell systems.

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Thank You for Your Attention!

A modern vitruvian man