Numerical simulations: Coupling between microstructure and component properties

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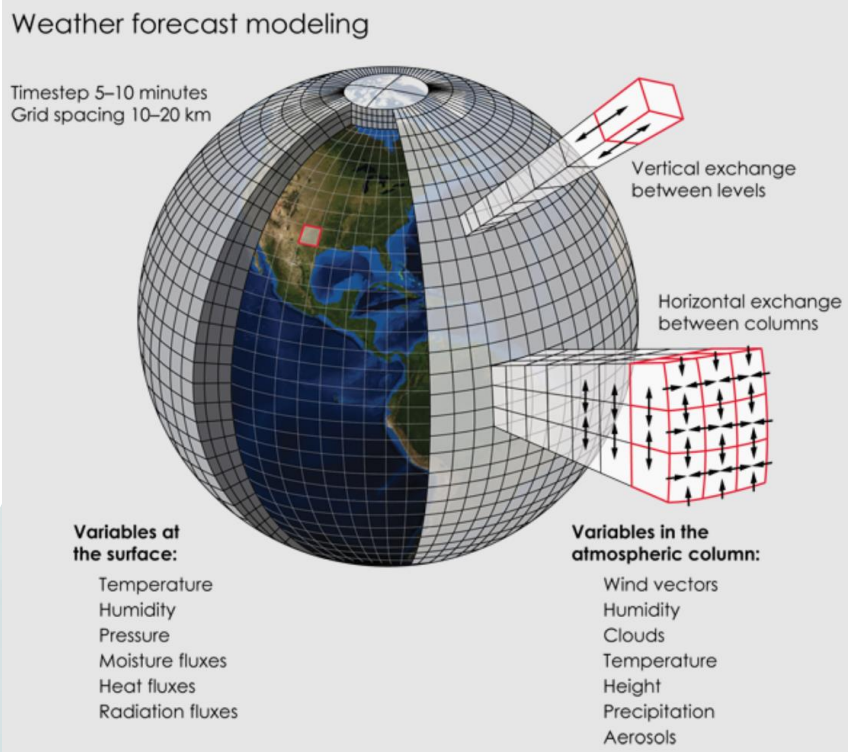
Outline

- Generalities – numerical simulations
- Classical welding simulations
- Multiphysics welding simulations
- Future work
- Conclusion

Numerical simulations

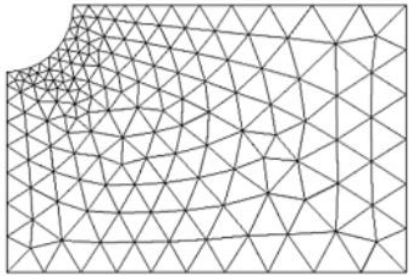


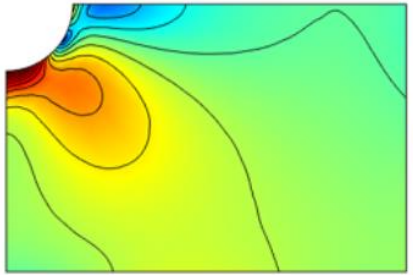
Numerical simulations

Preprocessing
- geometry
- material properties
- discretization in space / time
- boundary / initial conditions
- loads

Linear / non-linear solution scheme
- **evaluation of system energy and minimization**
- known state at a given time, at given points
- increment in time / load
  - explicit solver (many small steps, simpler)
  - implicit solver (advanced, always stable)
- new known state

Postprocessing
- field plots
- text files and curves





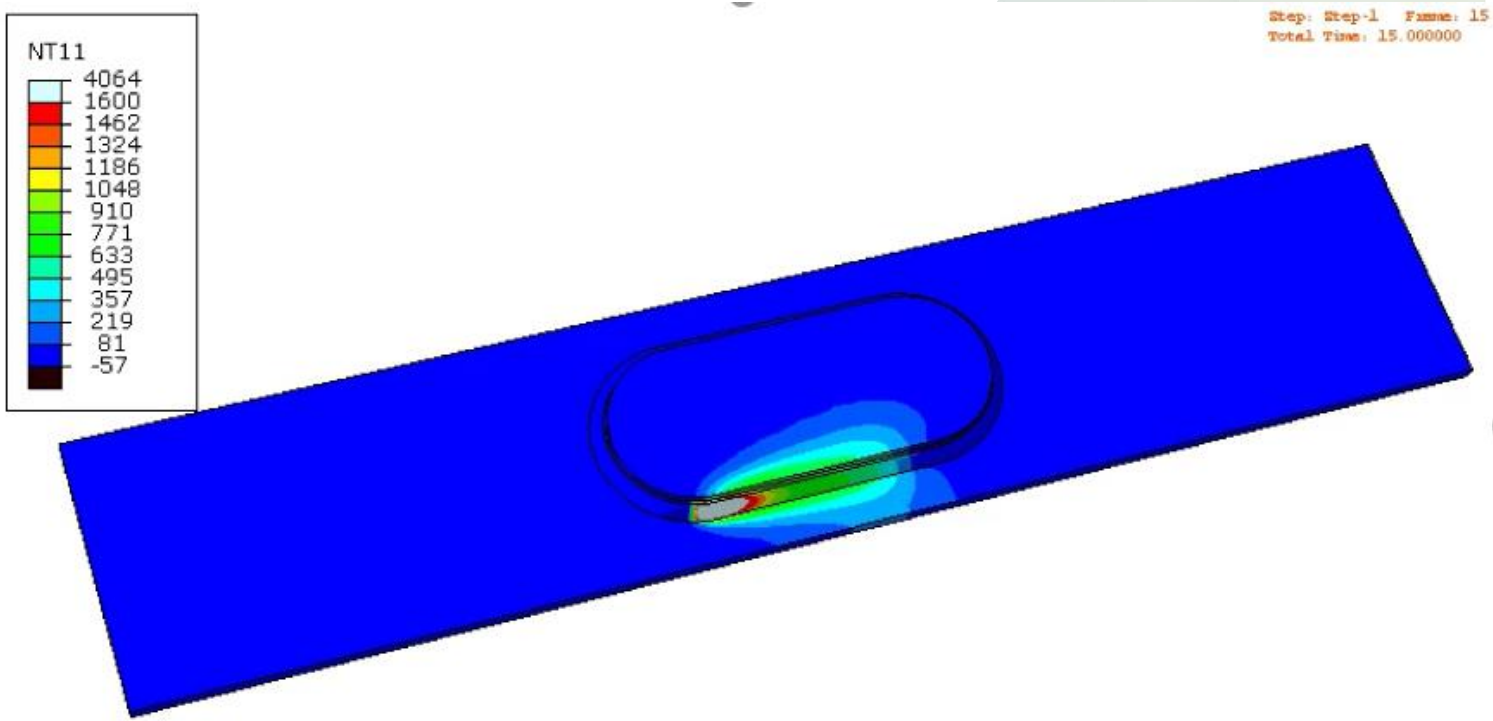
Welding simulations

Trial-and-error always possible
- cross-sections
- measurements

Advantages
- access to data during welding – transient simulations
- access to data difficult to measure – residual stresses
- sensitivity analyses – deformations

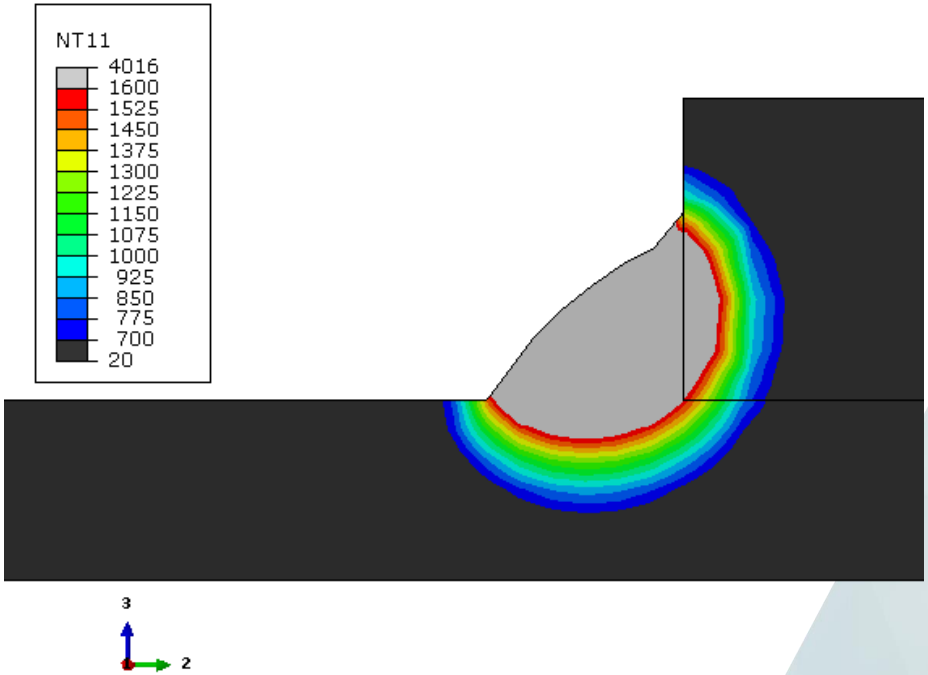
Classical welding simulation
- thermal analysis
- mechanical analysis

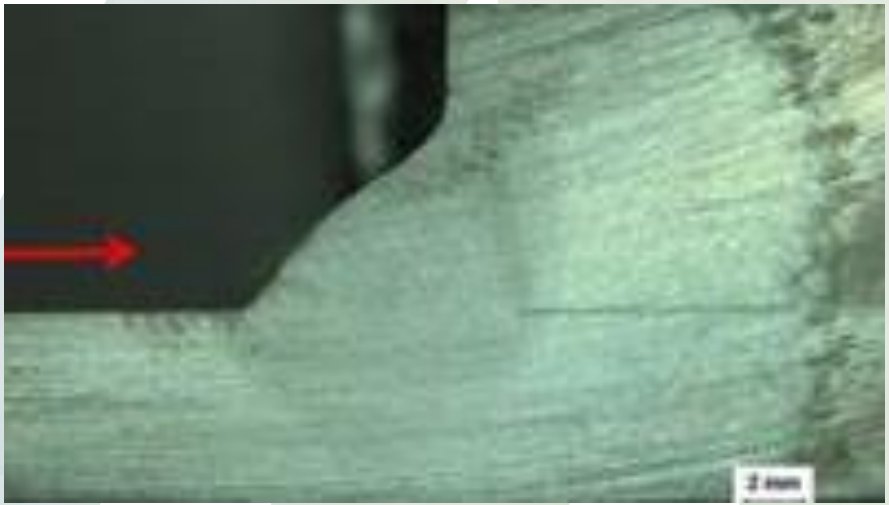
Welding simulations – thermal



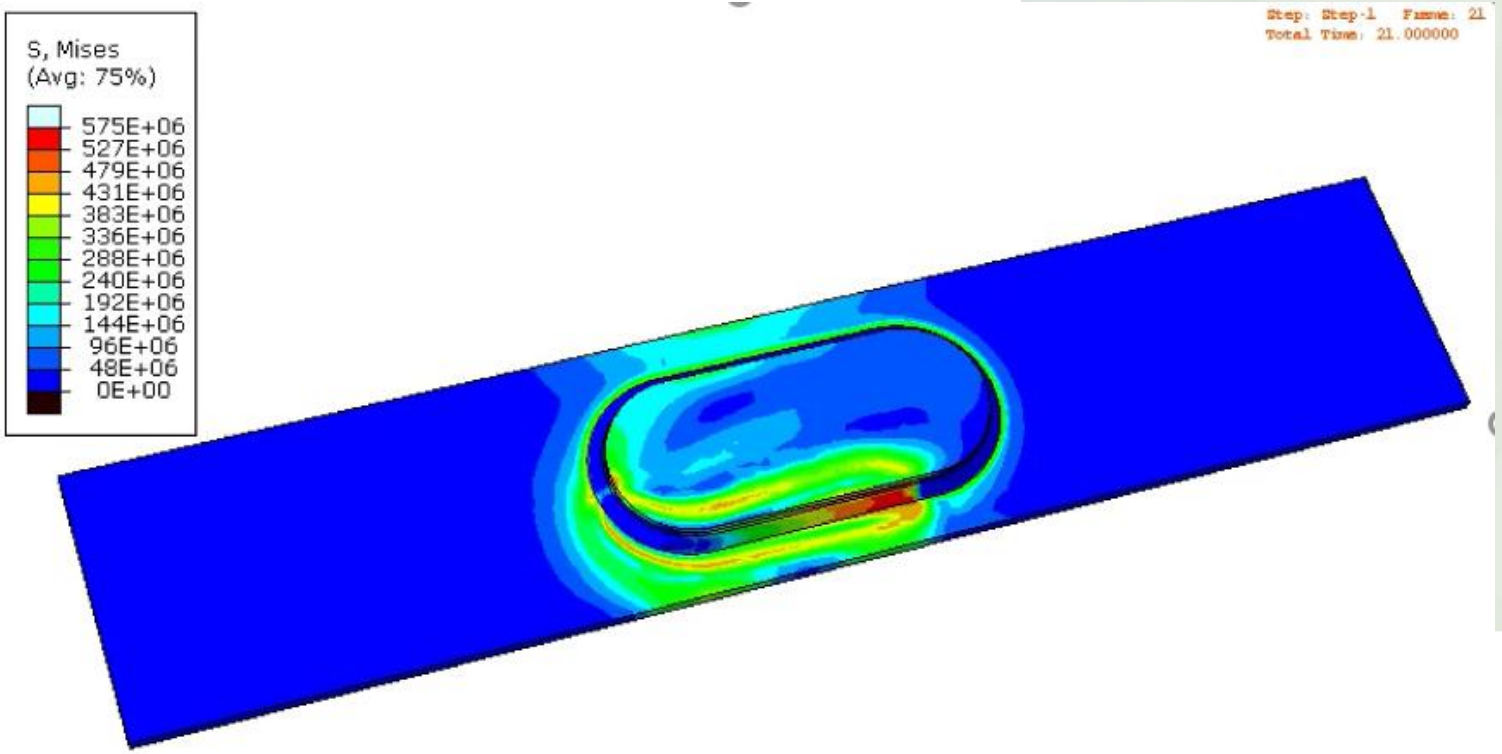
Welding simulations – thermal

Calibration





Welding simulations - mechanical



Welding simulations

Trial-and-error always possible
- cross-sections
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Advantages
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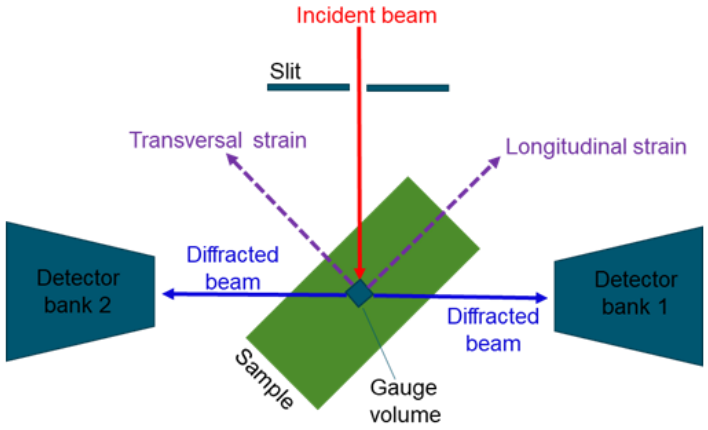
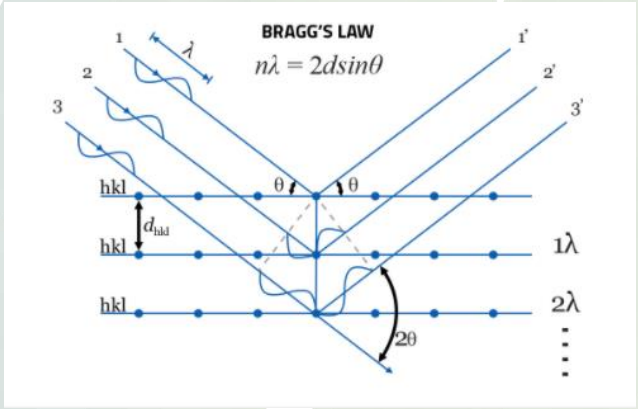
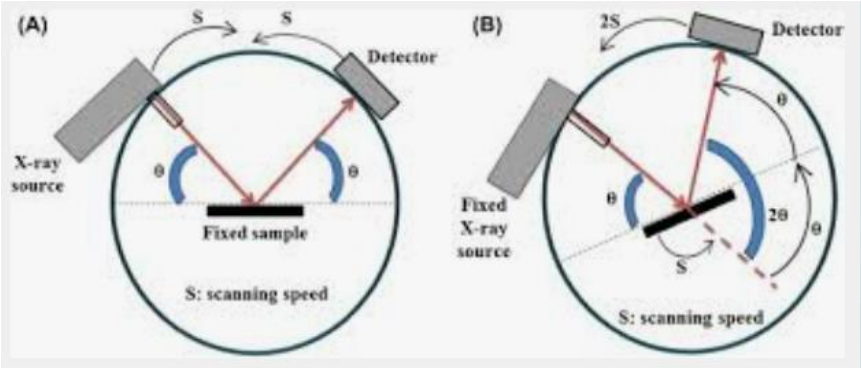
Classical welding simulation
- thermal analysis
- mechanical analysis

Neutron diffraction and x-ray diffraction

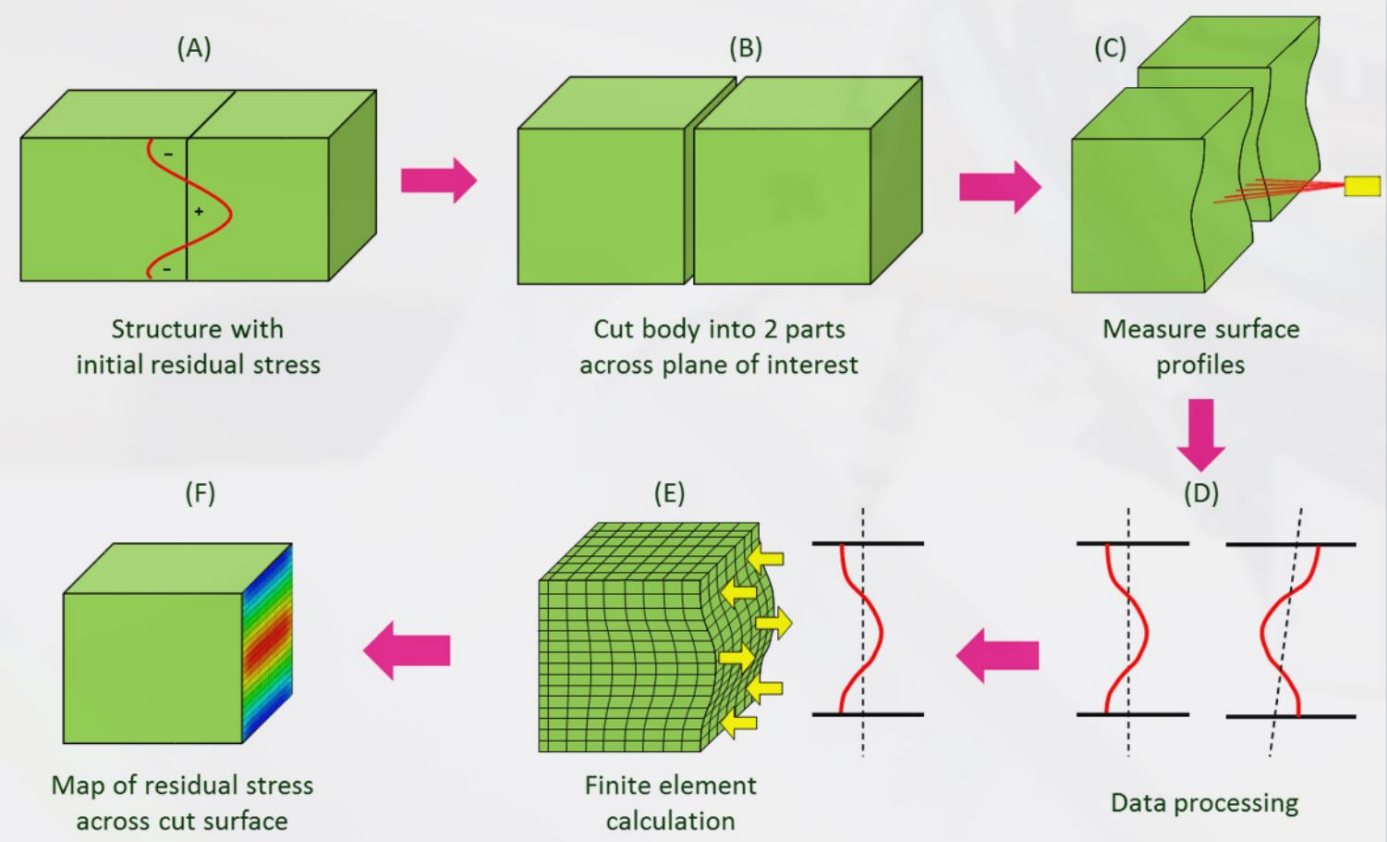




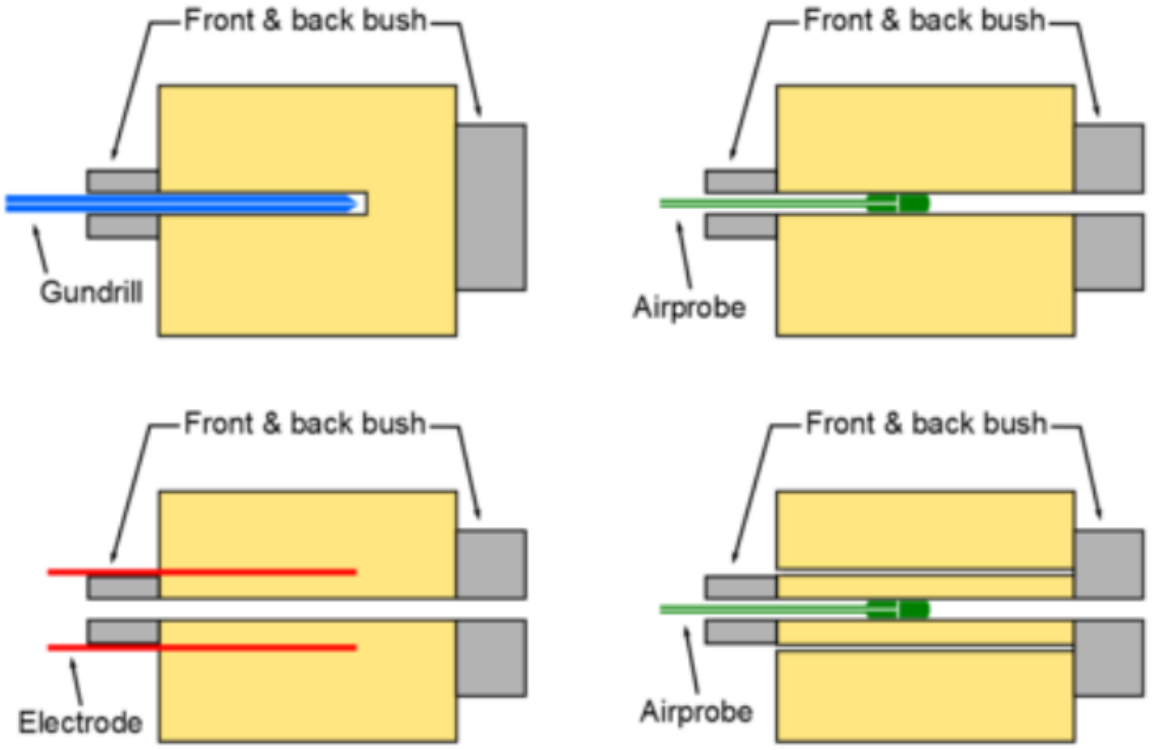


Distance between atom plans
Strains
Stresses

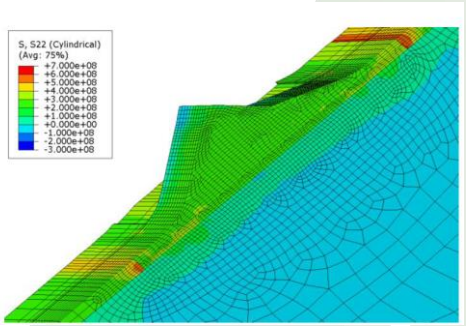
Contour Method



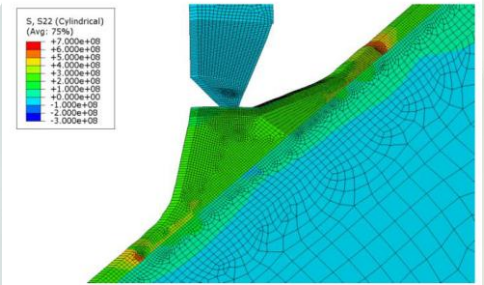
Deep hole drilling

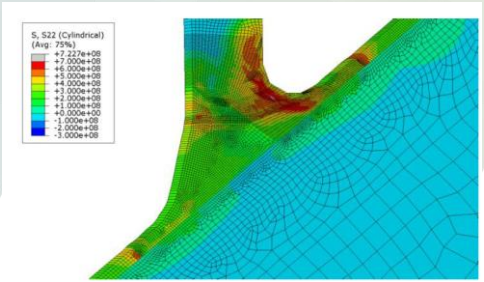


Application:
stress corrosion cracking



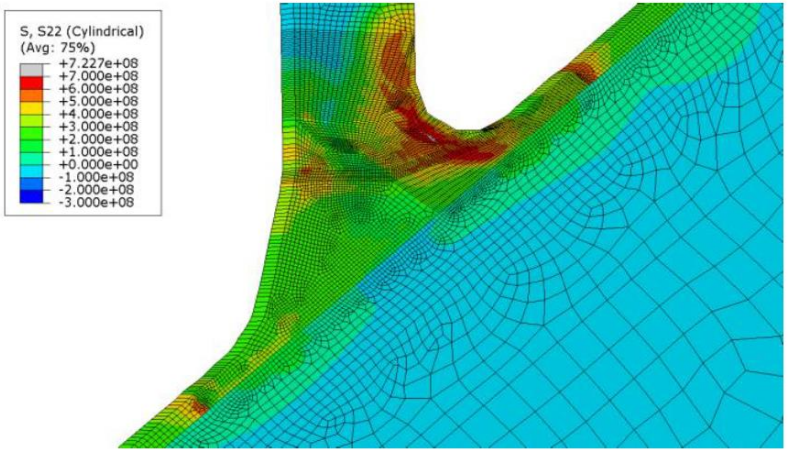
Buttering
56 beads

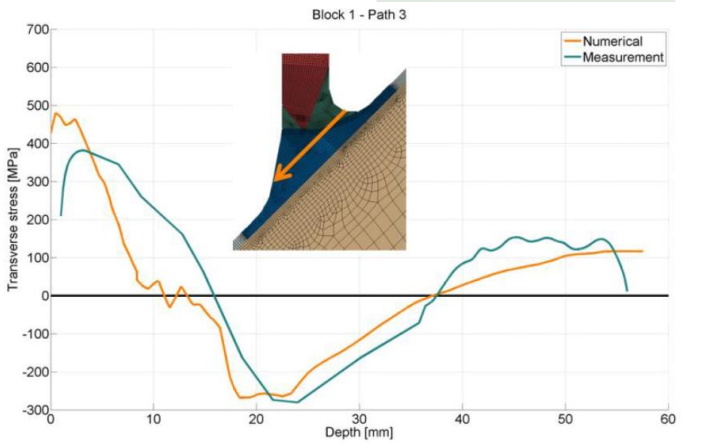


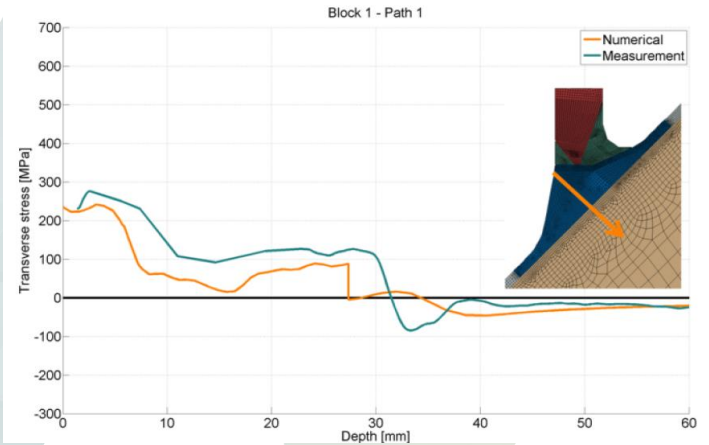


Weld
44 beads

Application:
stress corrosion cracking







Mutual confirmation
Inspection intervals

Welding simulations

Trial-and-error always possible
- cross-sections
- measurements

Advantages
- access to data during welding – transient simulations
- access to data difficult to measure – residual stresses
- sensitivity analyses – deformations

Classical welding simulation
- thermal analysis
- mechanical analysis

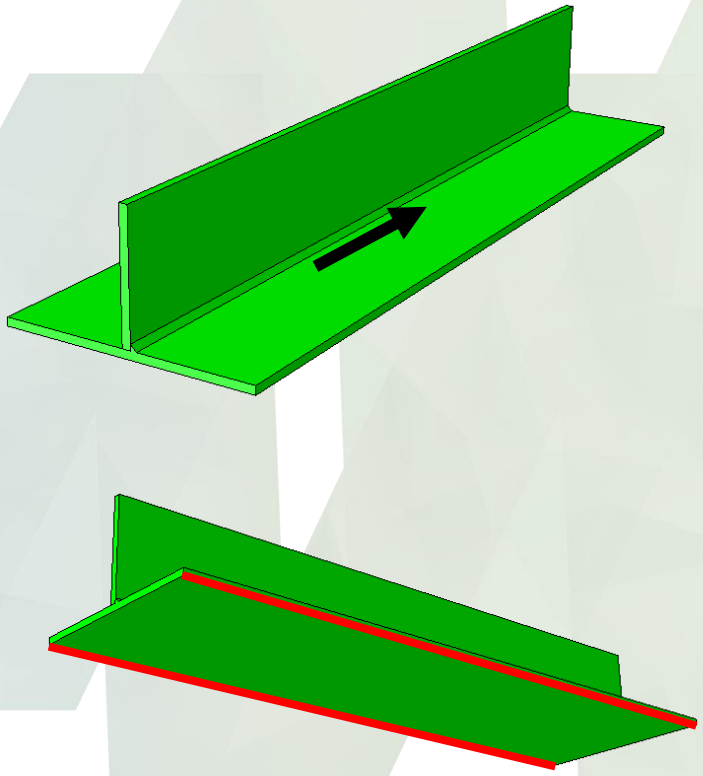
Sensitivity studies

T-Joint
- weld on one side only
- a = 5 mm

Dimensions
- length: 1000 mm, width: 300 mm, height: 150 mm
- plate thickness: 10 mm

Boundary conditions
- 2 lines at the long edges
- locked in the vertical direction

Heat source
- from one side to the other
- line energy 1.4 kJ/mm



Alternatives

Alternative 1
Base case

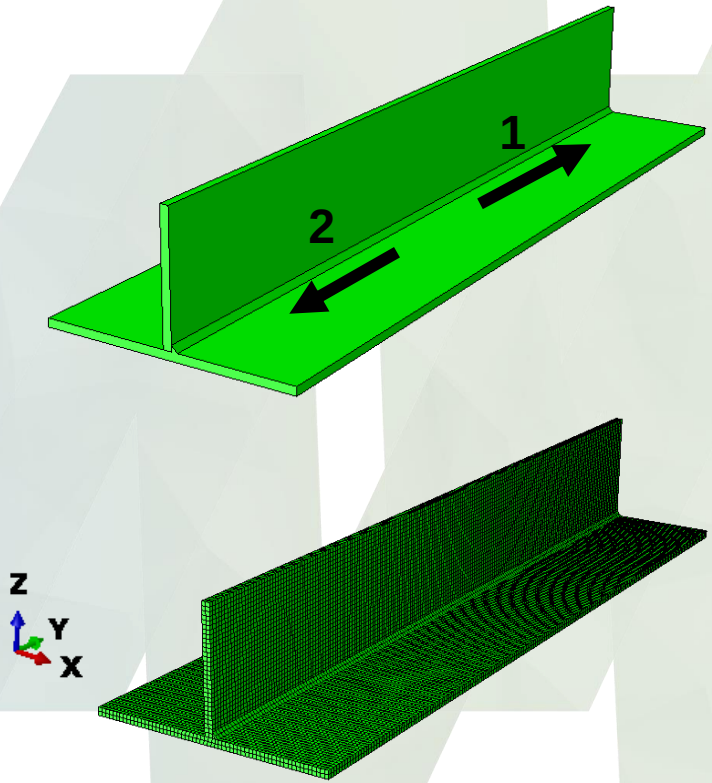
Alternative 2
Half the line effect: 1.4 kJ/mm → 0.7 kJ/mm

Alternative 3
Split weld sequence: 1 line → 2 half lines

Alternative 4
Half the line effect (alt. 2)
Split weld sequence (alt. 3)

Alternative 5
Totally unconstrained geometry

Alternative 6
Totally constrained geometry



Results: displacement magnitude

Upper limit: 13.4 mm
Lower limit 0 mm

Alternative 1
Base case

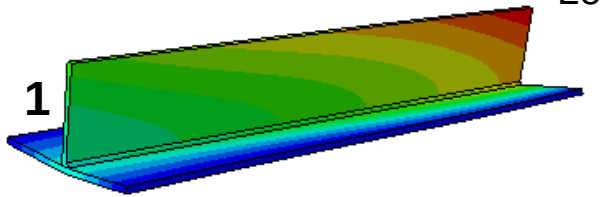
Alternative 2
Half effect

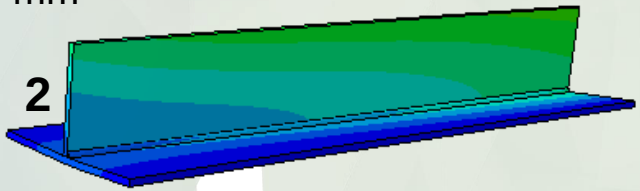
Alternative 3
Split weld sequence

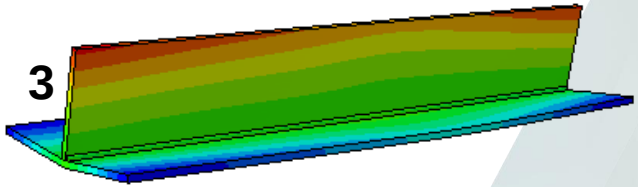
Alternative 4
Half the line effect
Split weld sequence

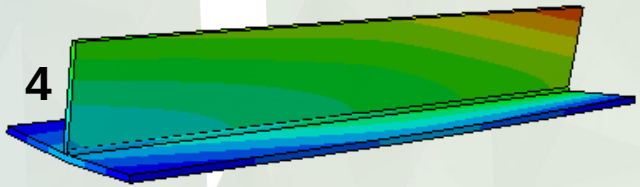
Alternative 5
Unconstrained

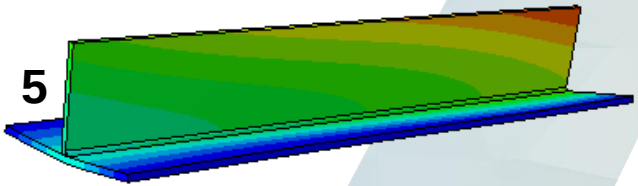
Alternative 6
Over constrained

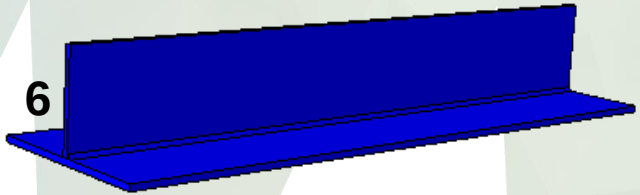












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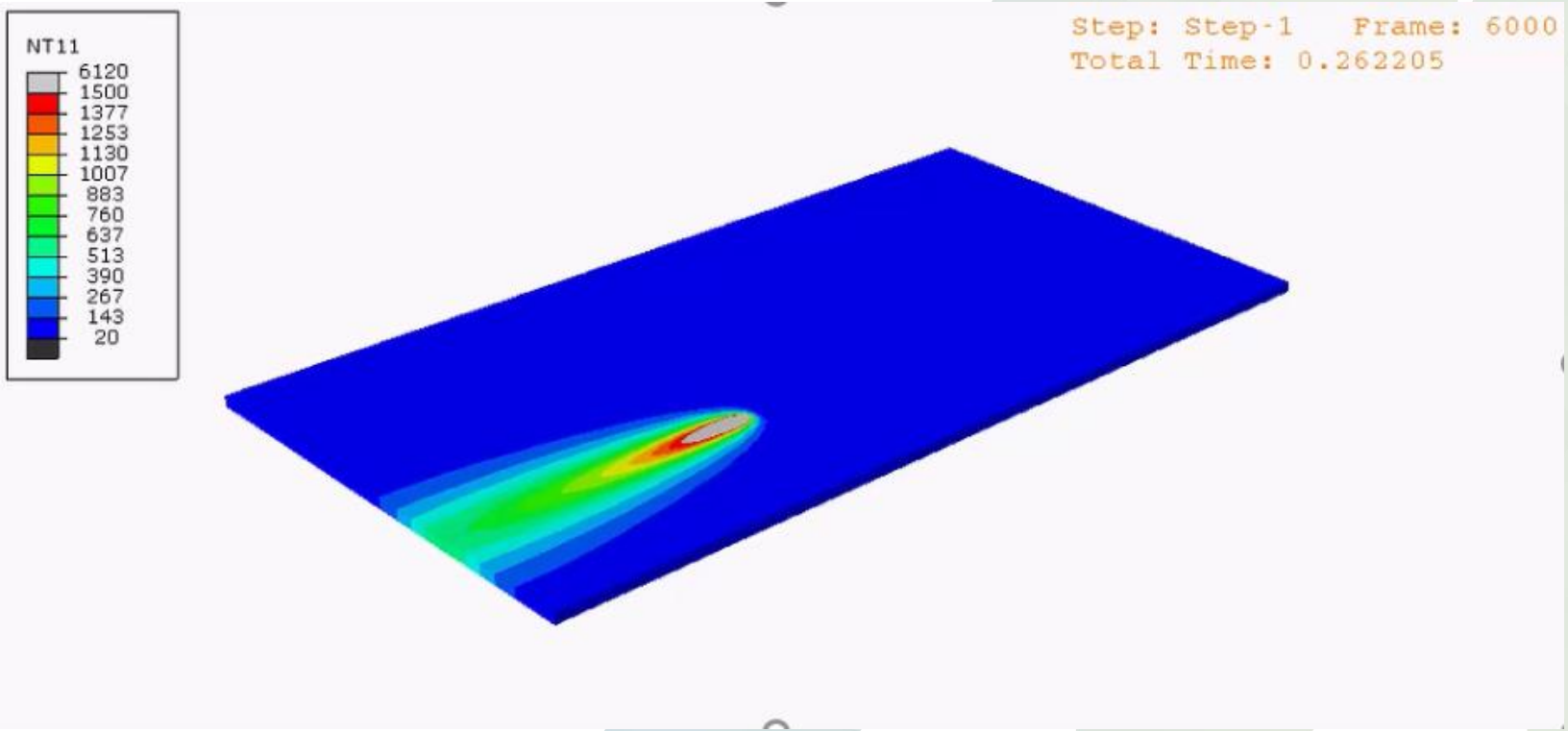
Multiphysics simulations

- Finite Element **(FEM)** - thermal → Finite Element **(FEM)** - mechanical

- Finite Element **(FEM)** - thermal → Phase Field **(PF)** → Crystal Plasticity **(CP)**

1) Thermal FEM simulation



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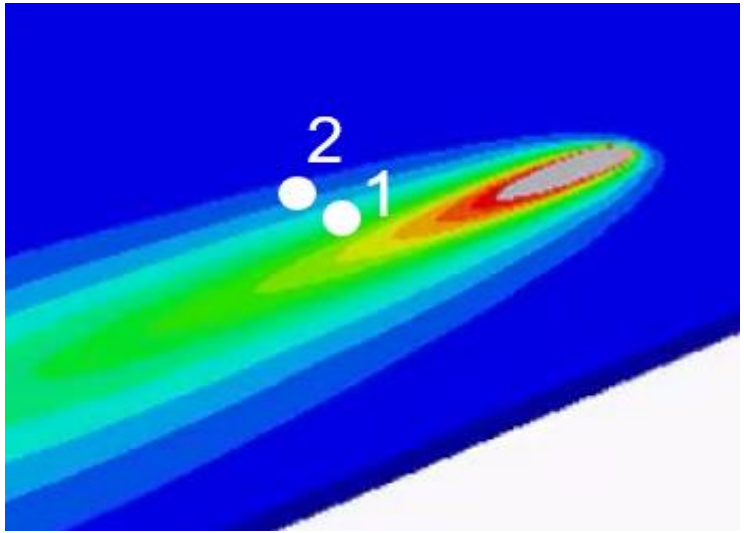
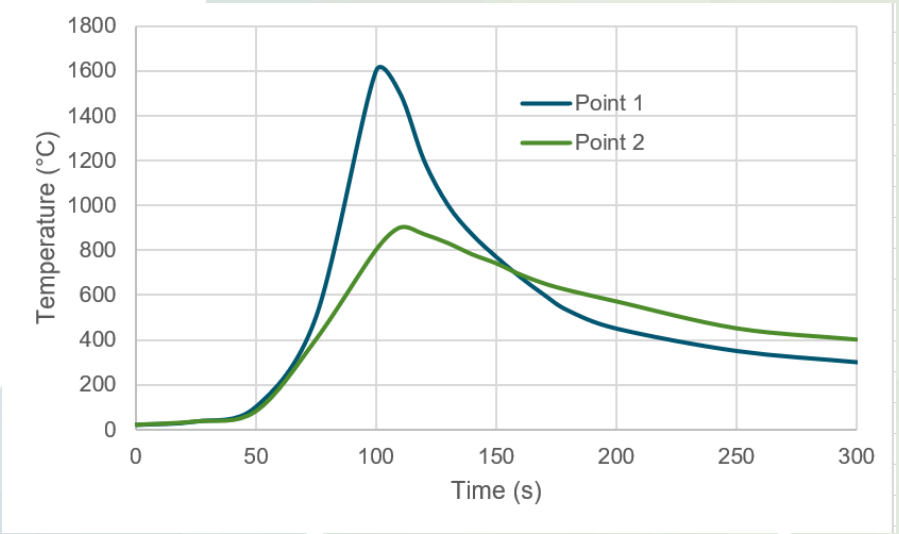
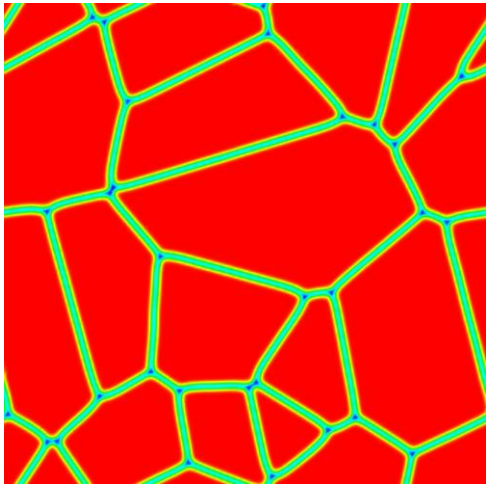
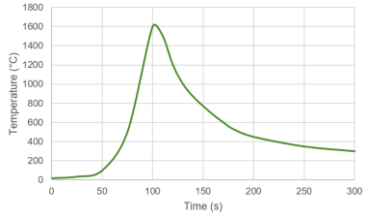
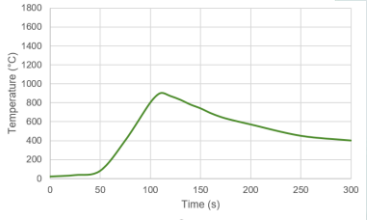


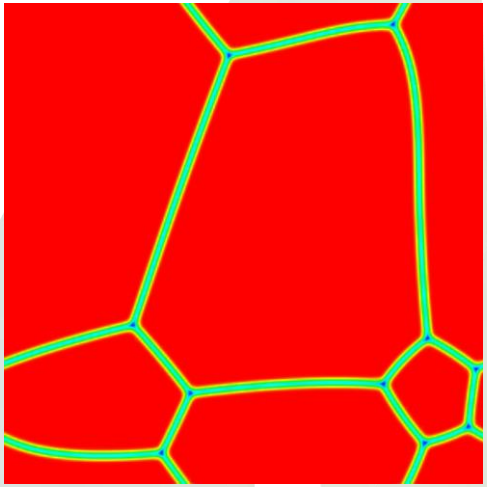


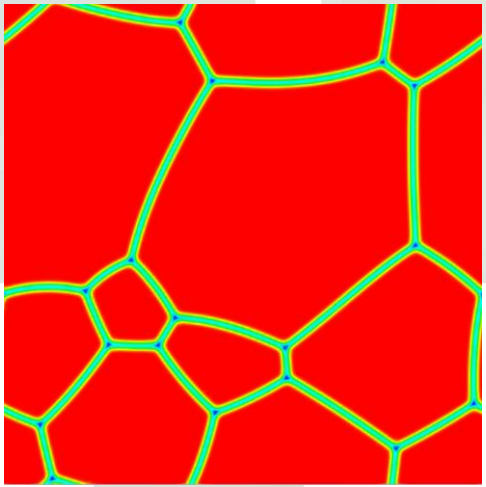
2) Phase Field (PF) simulations



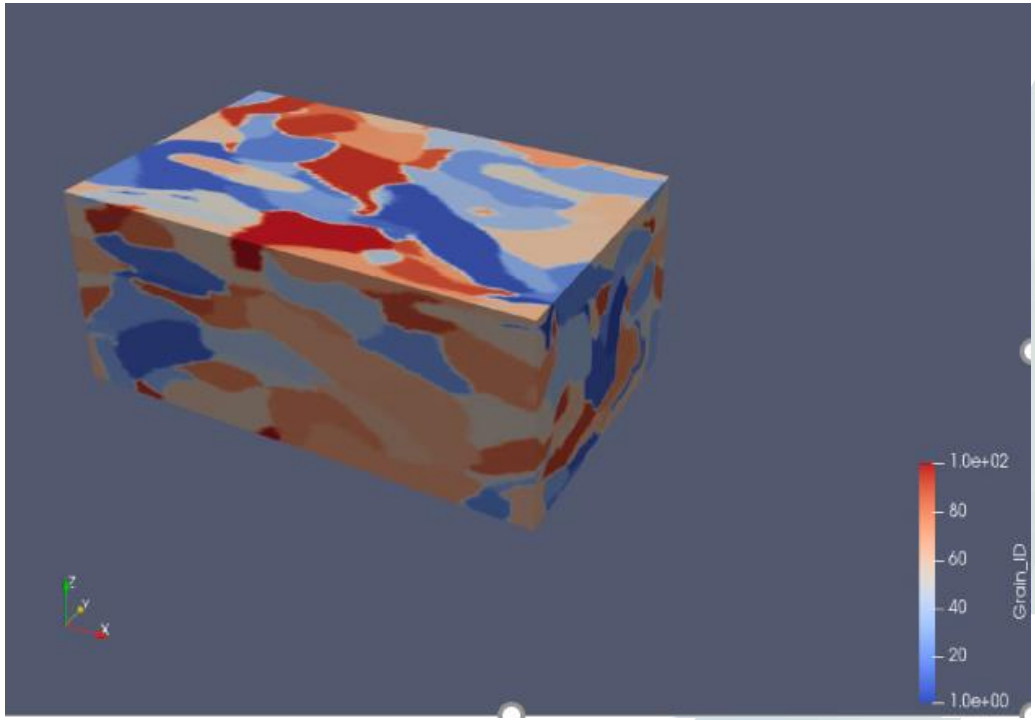


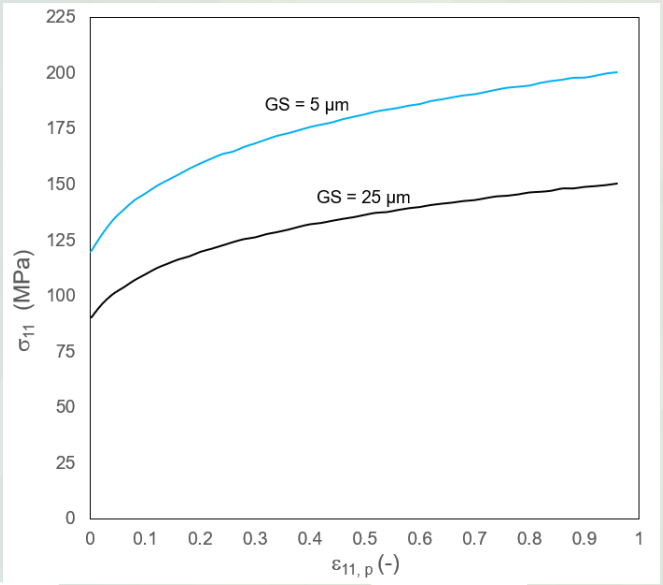






3) Crystal Plasticity (CP) simulations





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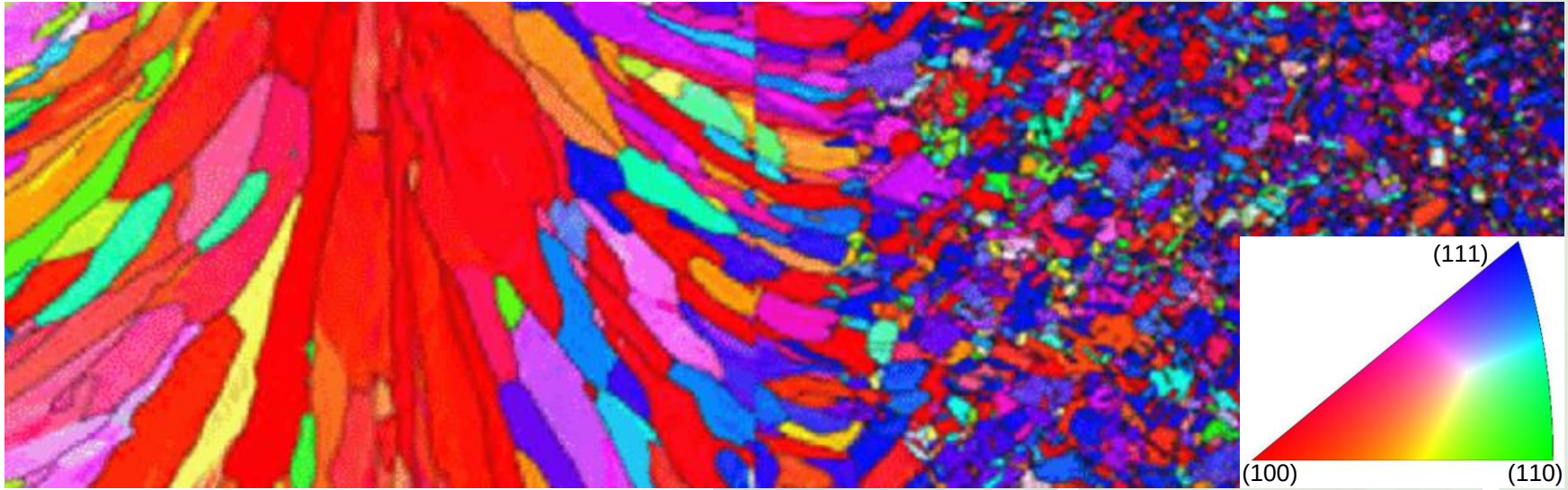
Electron Back Scattered Diffraction (EBSD)



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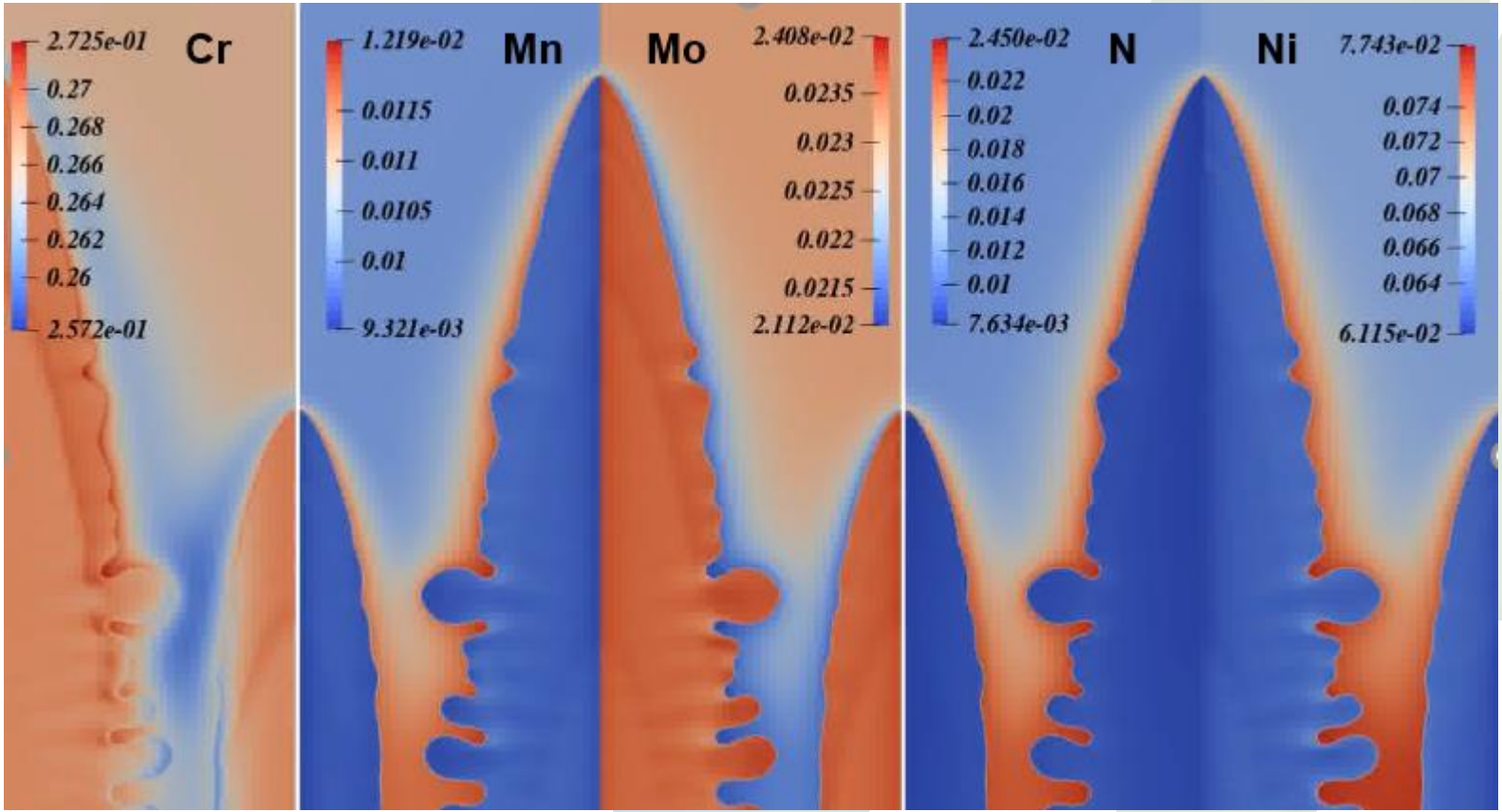
Phase Field simulations for ferritic solidification



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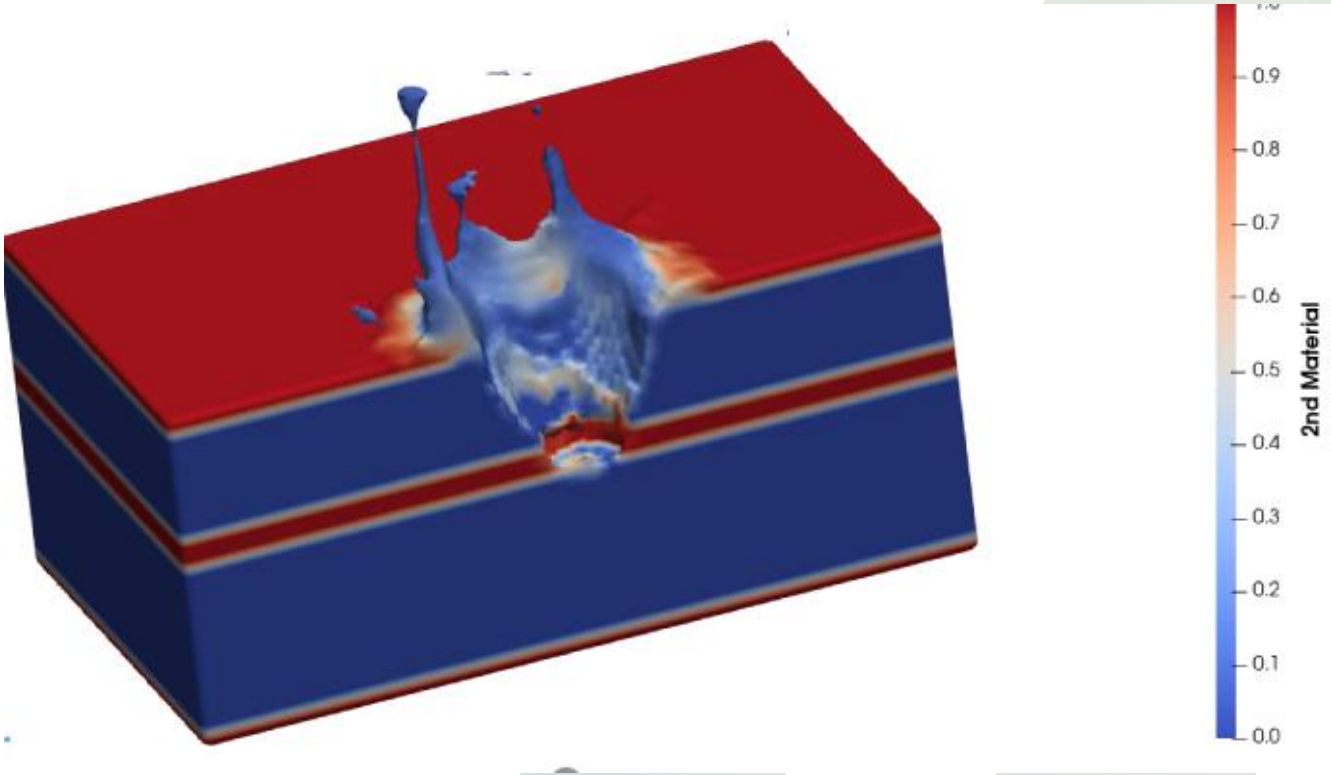
Computational Fluid Dynamics (CFD) simulations



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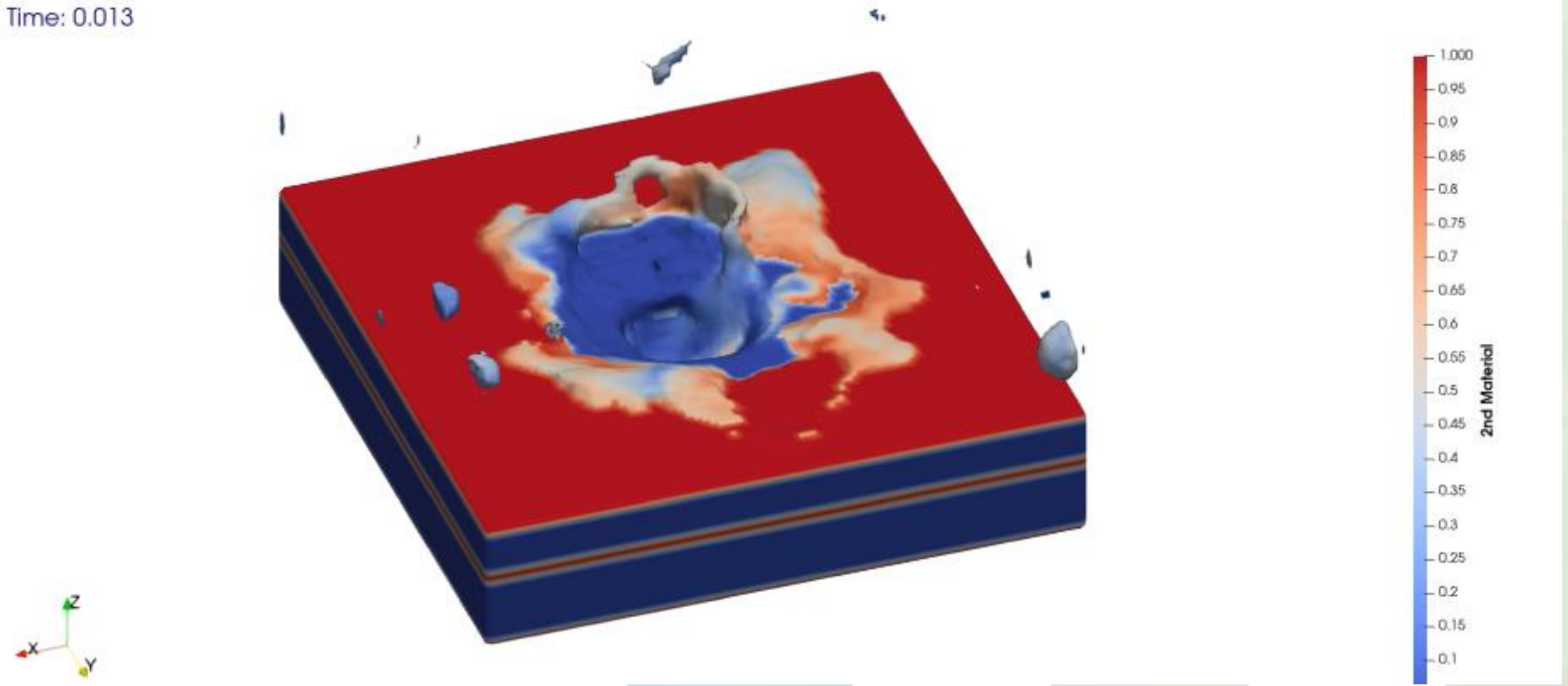

Conclusion

- Possibilities are numerous.

- Trend: coupling
  - of different software packages
  - at different length scale
  - with different physics

- Necessary
  - reliable temperature dependent material properties
  - calibration of heat source

- Non-trivial simulations require a lot of background preparation.


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