Simulation of Additive Manufacturing using a Mechanism Based Constitutive Model

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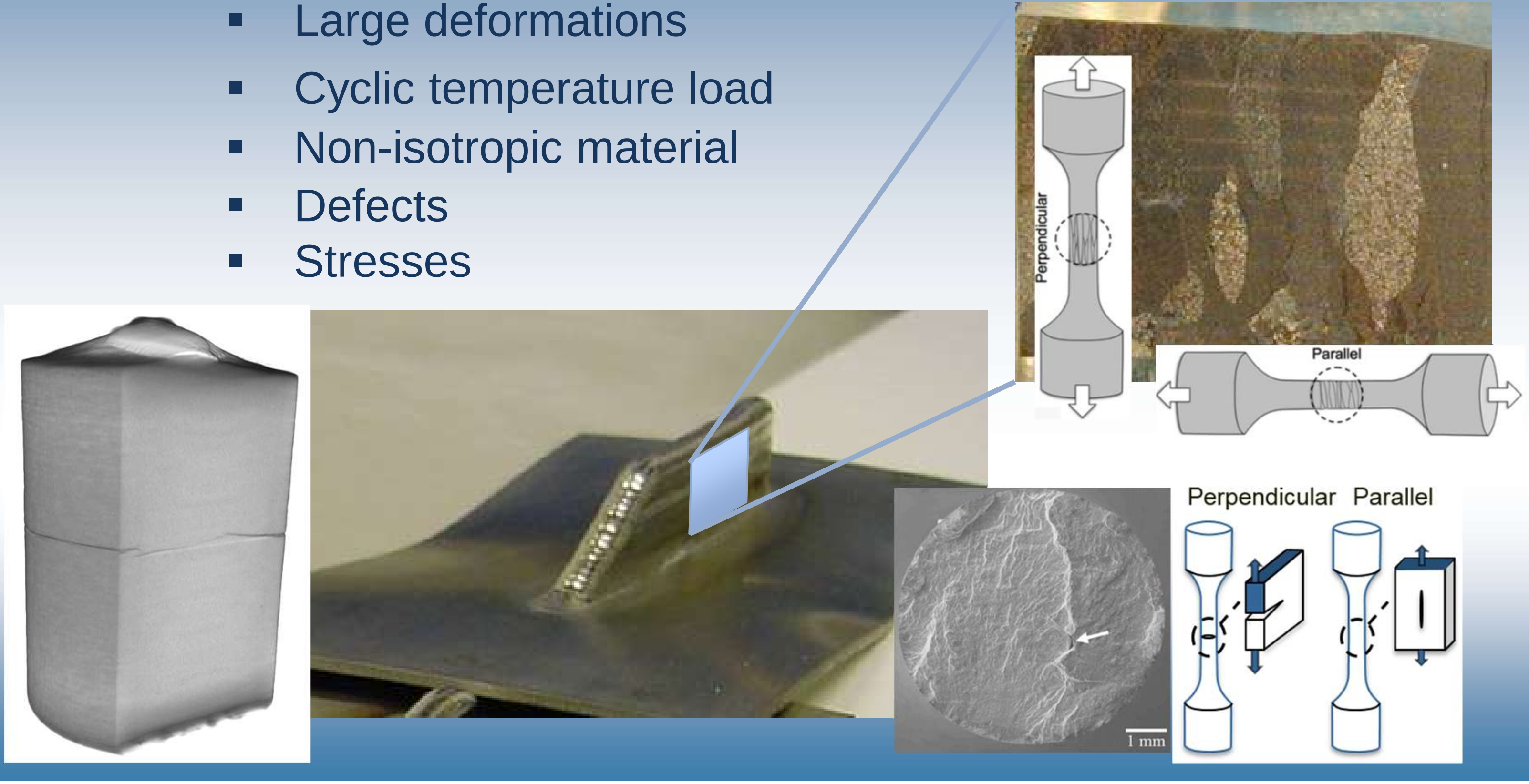
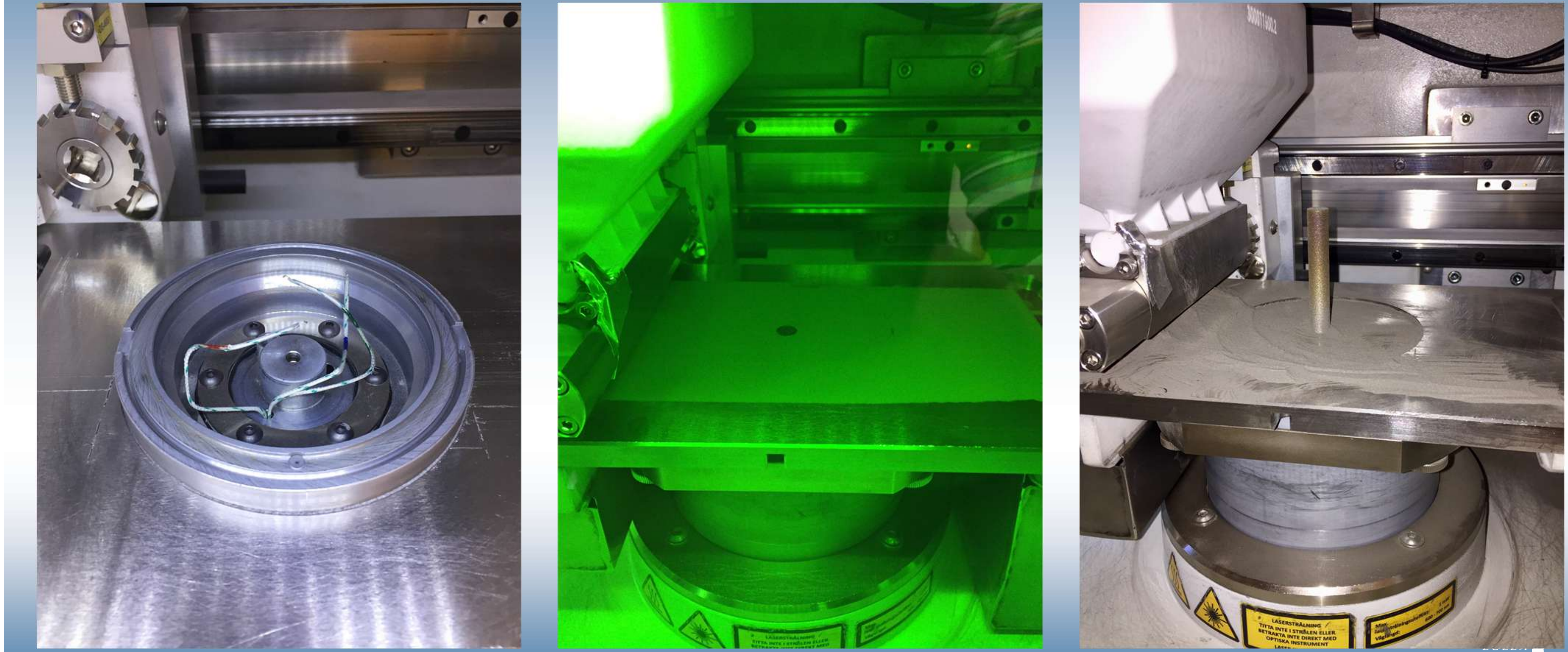
Challenges

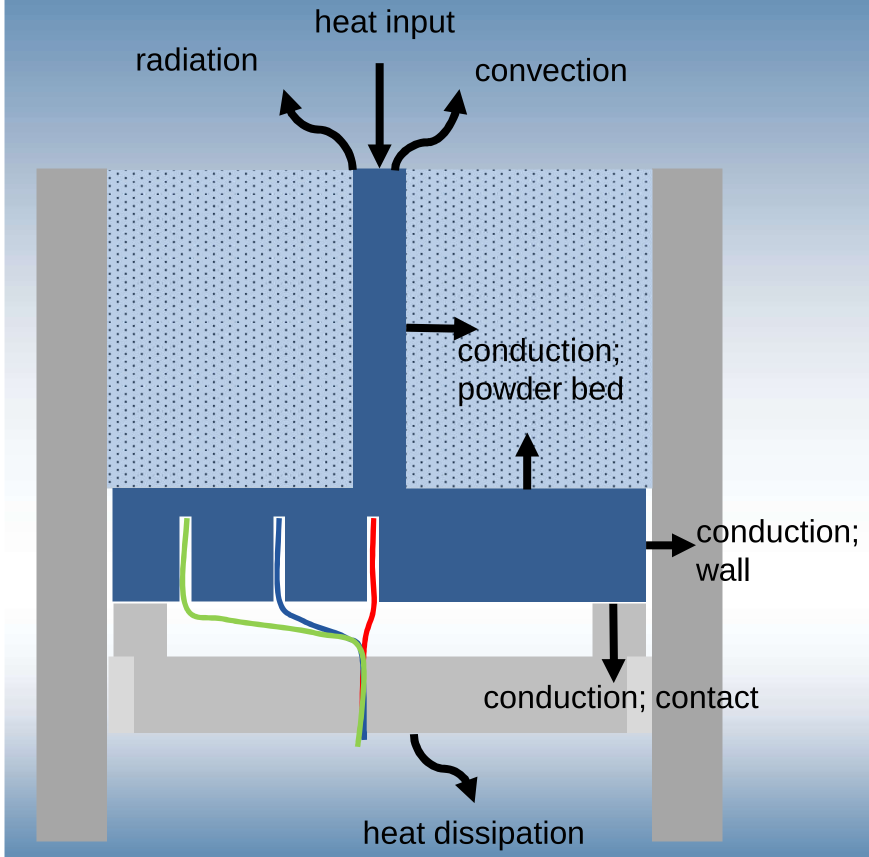
- Large deformations
- Cyclic temperature load
- Non-isotropic material
- Defects
- Stresses



Measurements on an EOS M100



Thermal model and measurements



heat input

radiation

convection

conduction; powder bed

conduction; wall

conduction; contact

heat dissipation

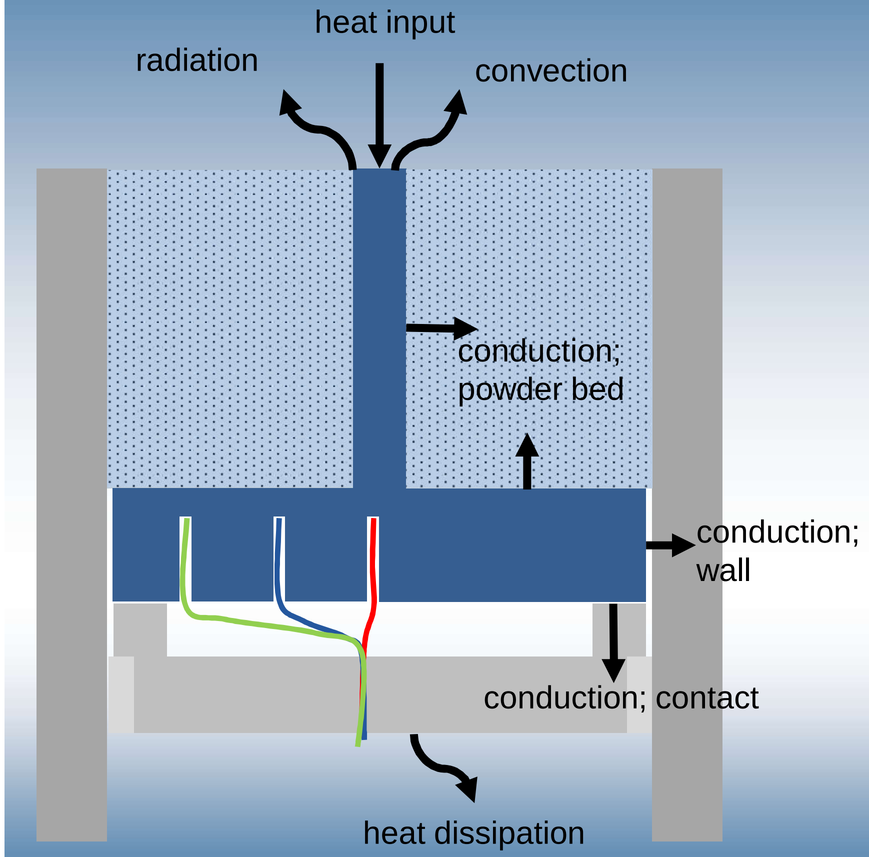
$$q_{inp} = \frac{2\sqrt{3}\eta Q}{\sqrt{\pi}ch^2} e^{\frac{-3z^2}{c^2}}$$

$$q_{rad} = \sigma\epsilon(T^4 - T_s^4)$$

$$q_{powder} = h_{pb}(T - T_s)$$

$$q_{sys} = h_s(T - T_s)$$

Thermal model and measurements



heat input

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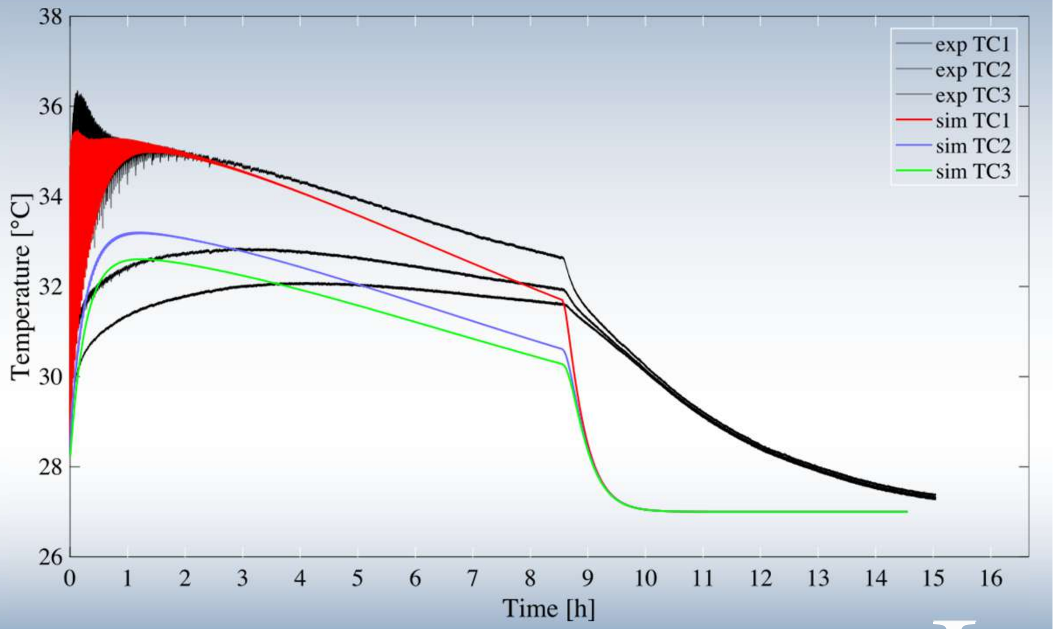

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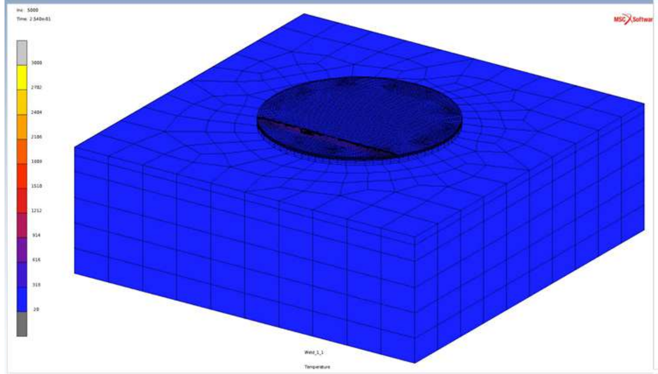
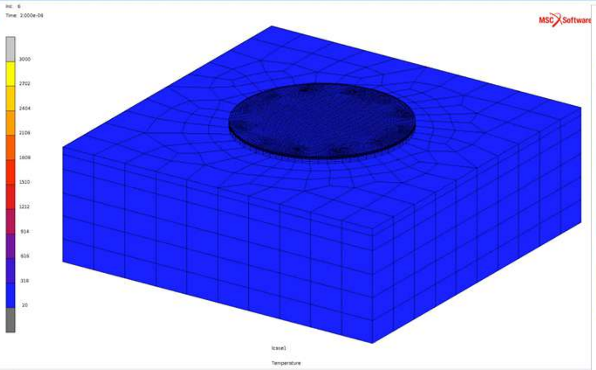
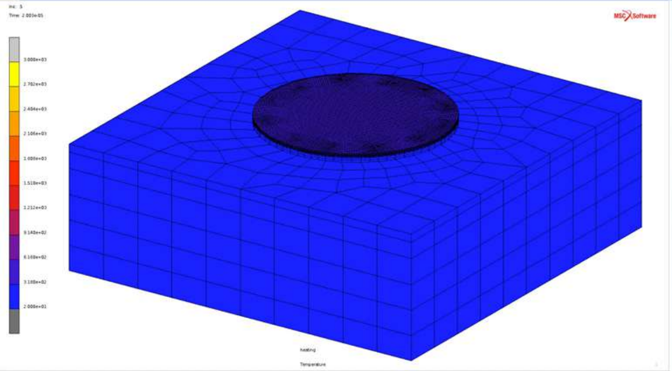
Temporal reduction



Individual hatch



Sweeping of hatches



Entire layer

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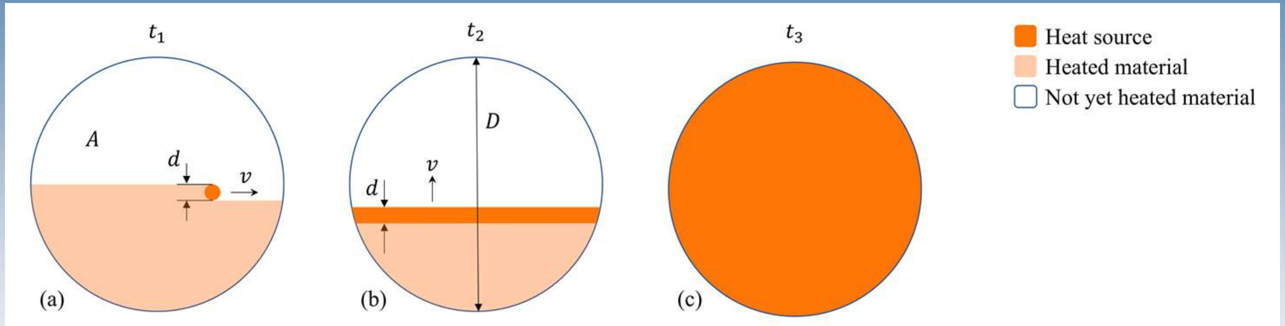
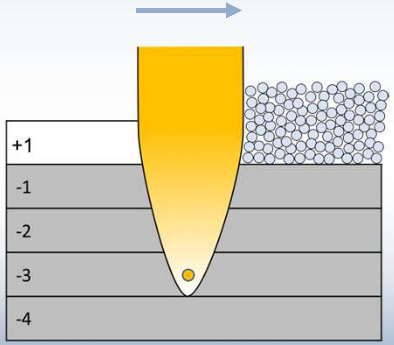
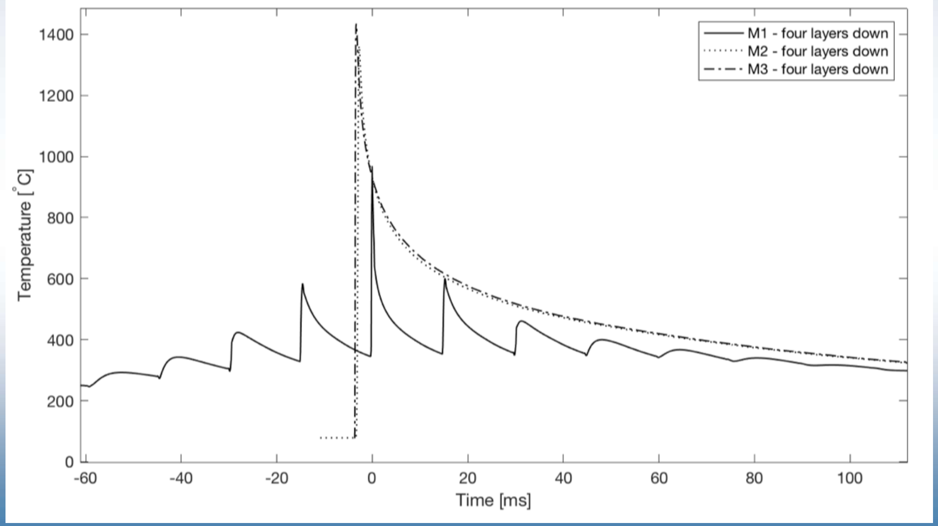
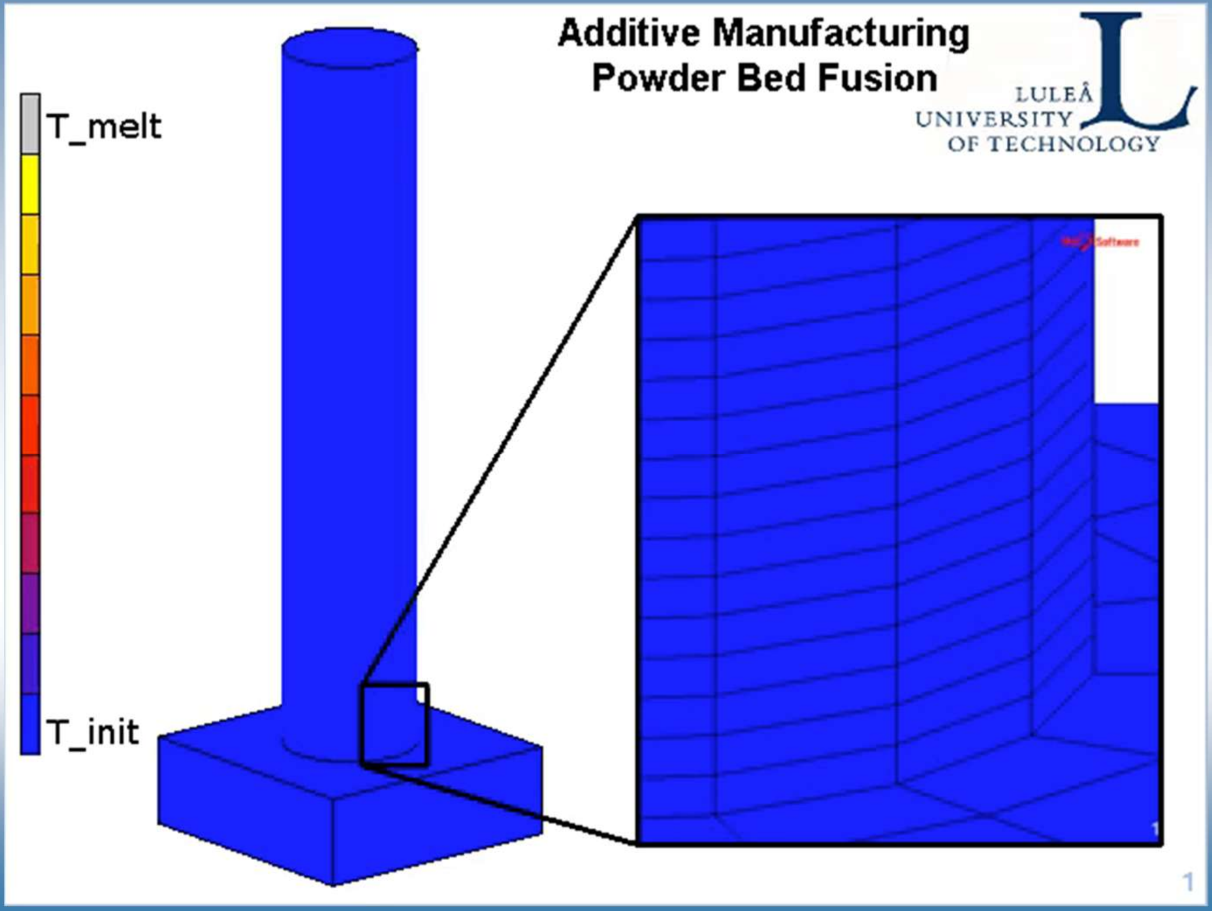
Temporal reduction





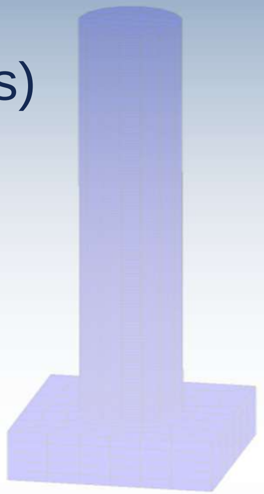


Simulation of Powder Bed Fusion

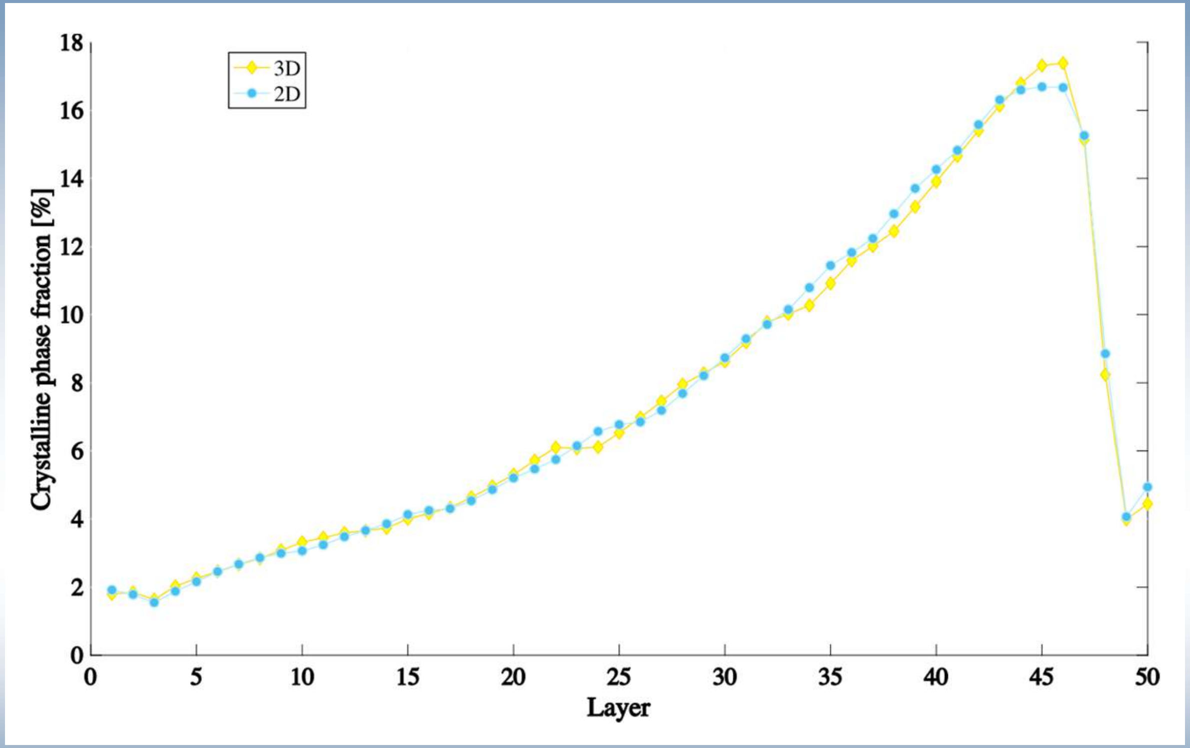


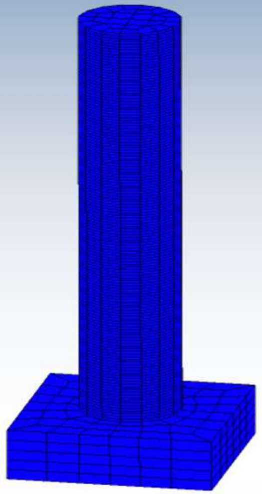
Simulation of Powder Bed Fusion

- More than 1100 layers
- Local adaptive meshing, refinement and coarsening (3 levels)
  - 11000 to 14000 elements in average during the process
  - Without coarsening >2 million elements at the end
- Adaptive time stepping
  - Cooling from T_m to T_g, BMG
- 1-D Gaussian distribution of heat source



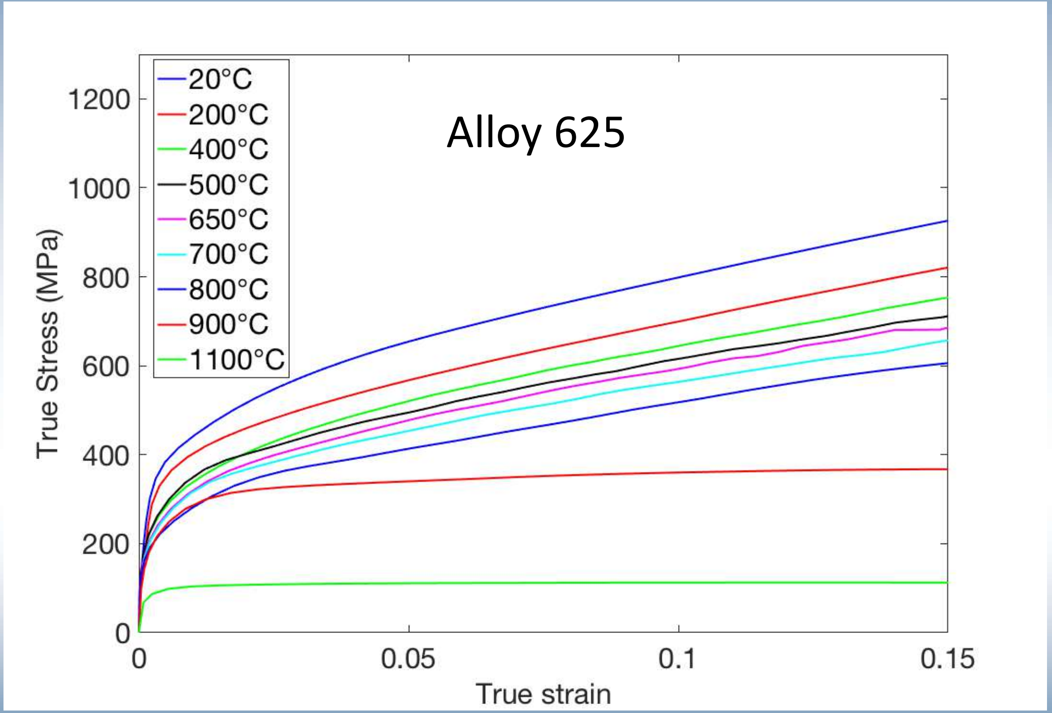
Axisymmetric vs. 3D model



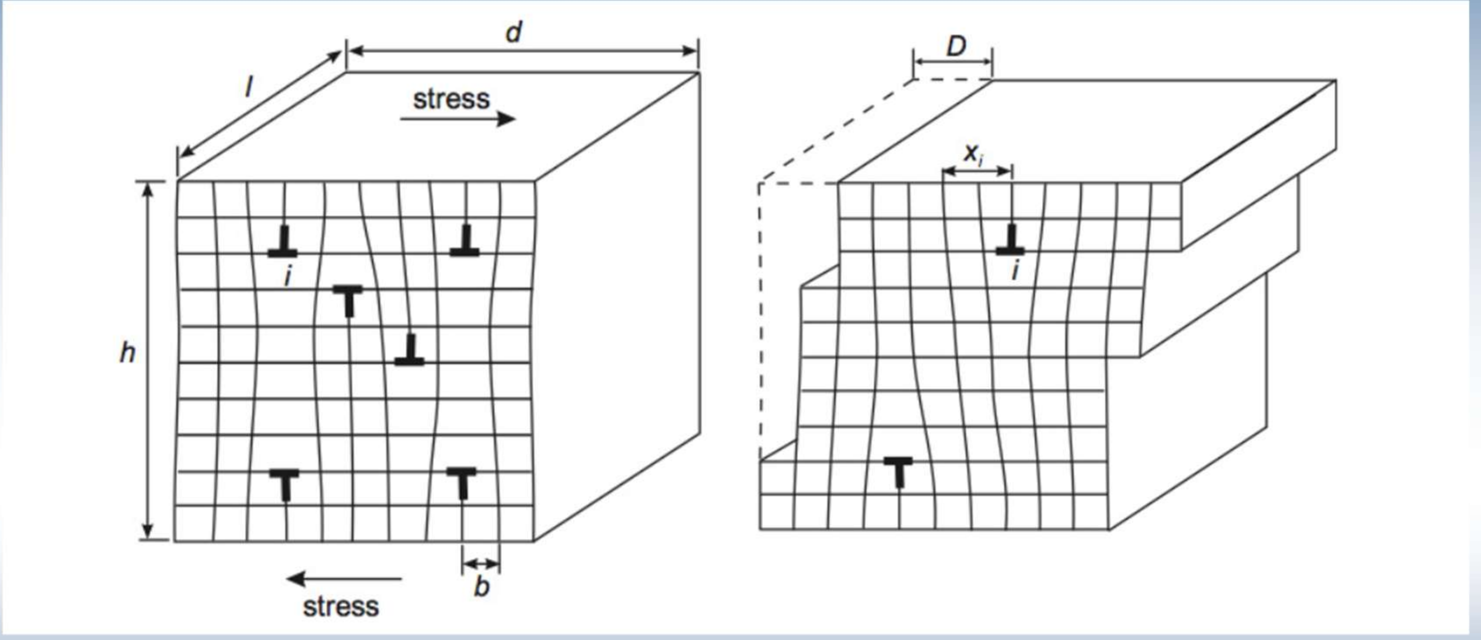


Material modelling approach

Tensile or compressive tests at different temperatures



Dislocation density based material model



Dislocation density based material model

$$\sigma_y = \sigma_G + \sigma^* + \sigma_{HP} + \sigma_s + \sigma_p$$

σ_G - disturbances in the lattice caused by immobile dislocations

σ^* - stress needed to move dislocations through short range obstacles

σ_{HP} - Hall-Petch effect (grain size dependency)

σ_s - solid solution strengthening

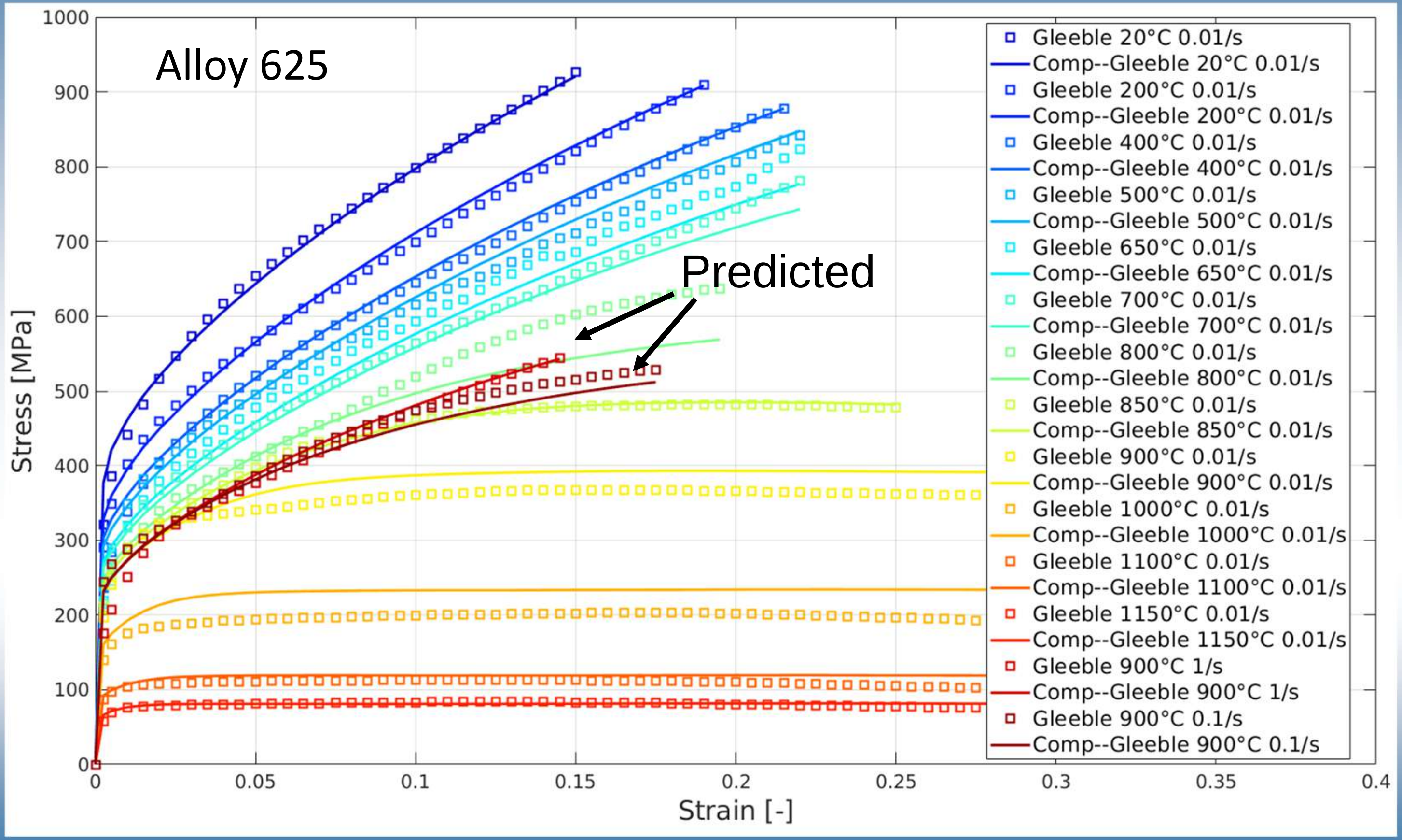
σ_p - strengthening due to precipitates

*Bergström, Y. Dislocation model for the stress-strain behaviour of polycrystalline alpha-iron with special emphasis on the variation of the densities of mobile and immobile dislocations. *Materials Science & Engineering* **1969**, *5*, 193–200.

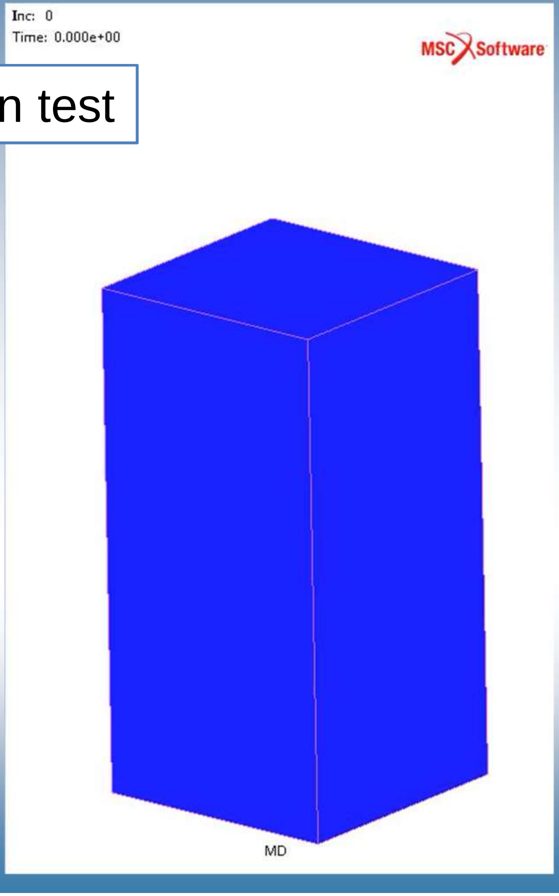
*Lindgren, L-E., Domkin K., Hansson S., Dislocations, vacancies and solute diffusion in physical based plasticity model for AISI 316L, Mechanics of Materials, **2008,** 40(11), 907-919.

*Babu B., Lundbäck A. and Lindgren L-E., Simulation of additive manufacturing of Ti-6Al-4V using a coupled physically-based flow stress and metallurgical model, submitted to *Materials, **2019.***

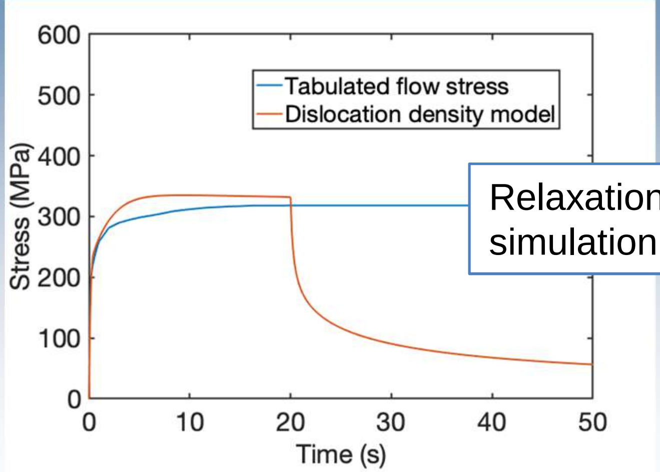
Calibration of material model



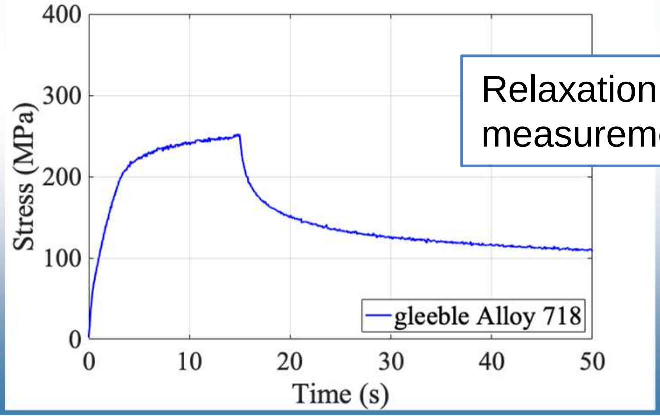
Relaxation test



Relaxation test



Relaxation test @930°C, simulation, Alloy 625



Relaxation test @930°C, measurement, Alloy 718

AM-Bench case (NIST)

AMB2018-01-PD

AMB2018-01-RS

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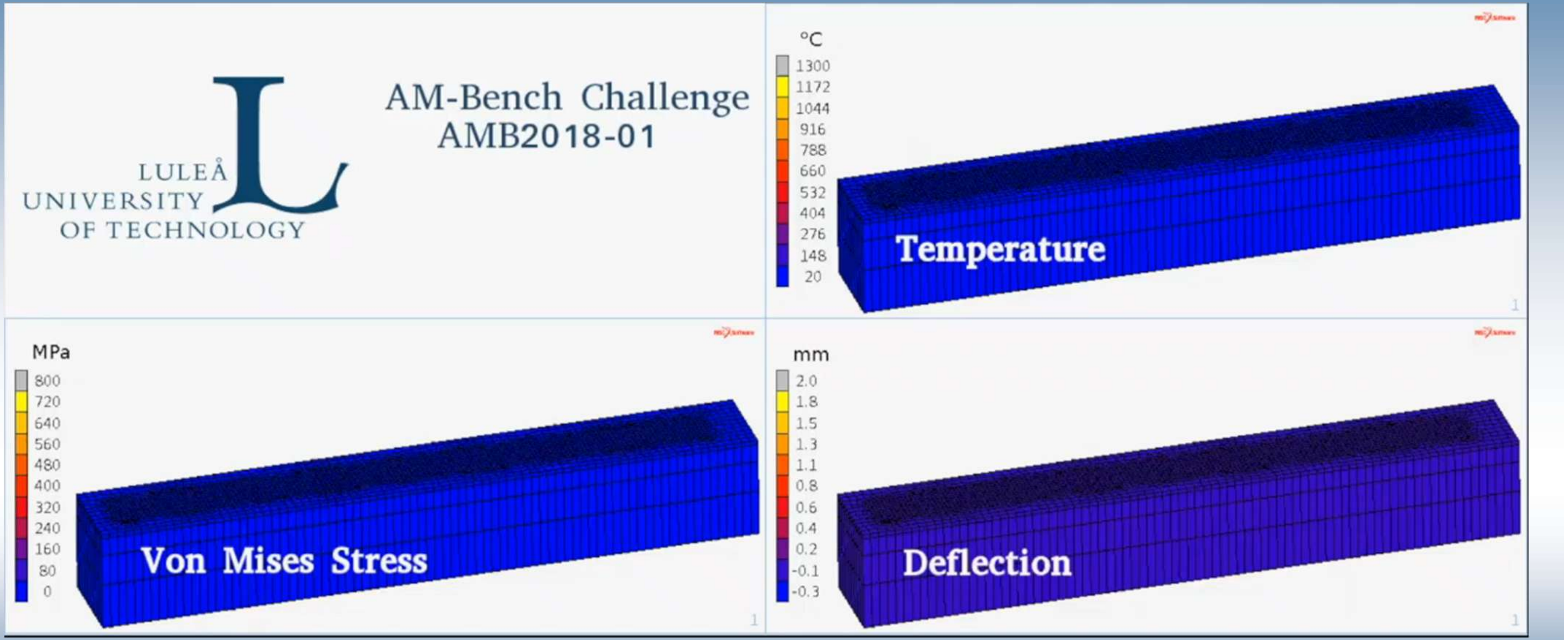
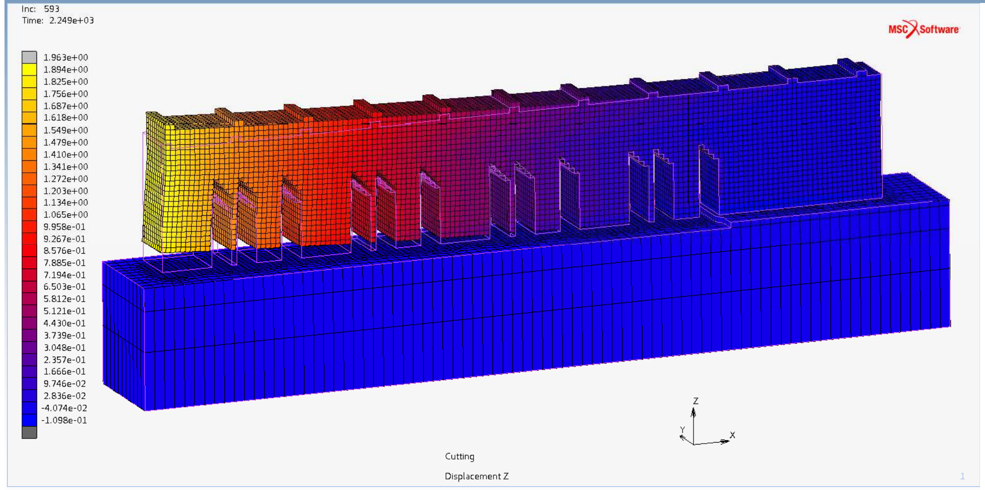
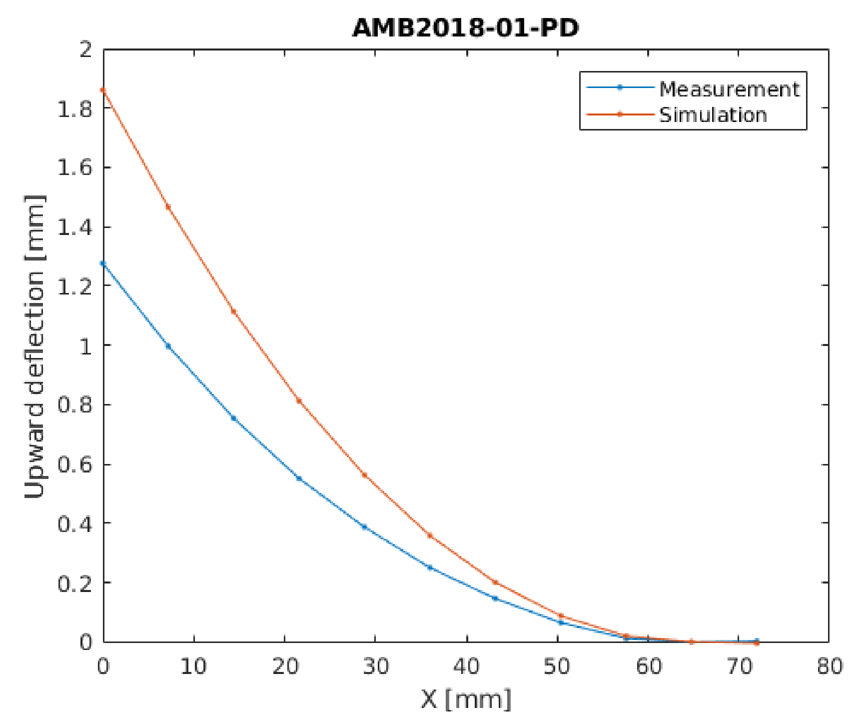
AM-Bench case



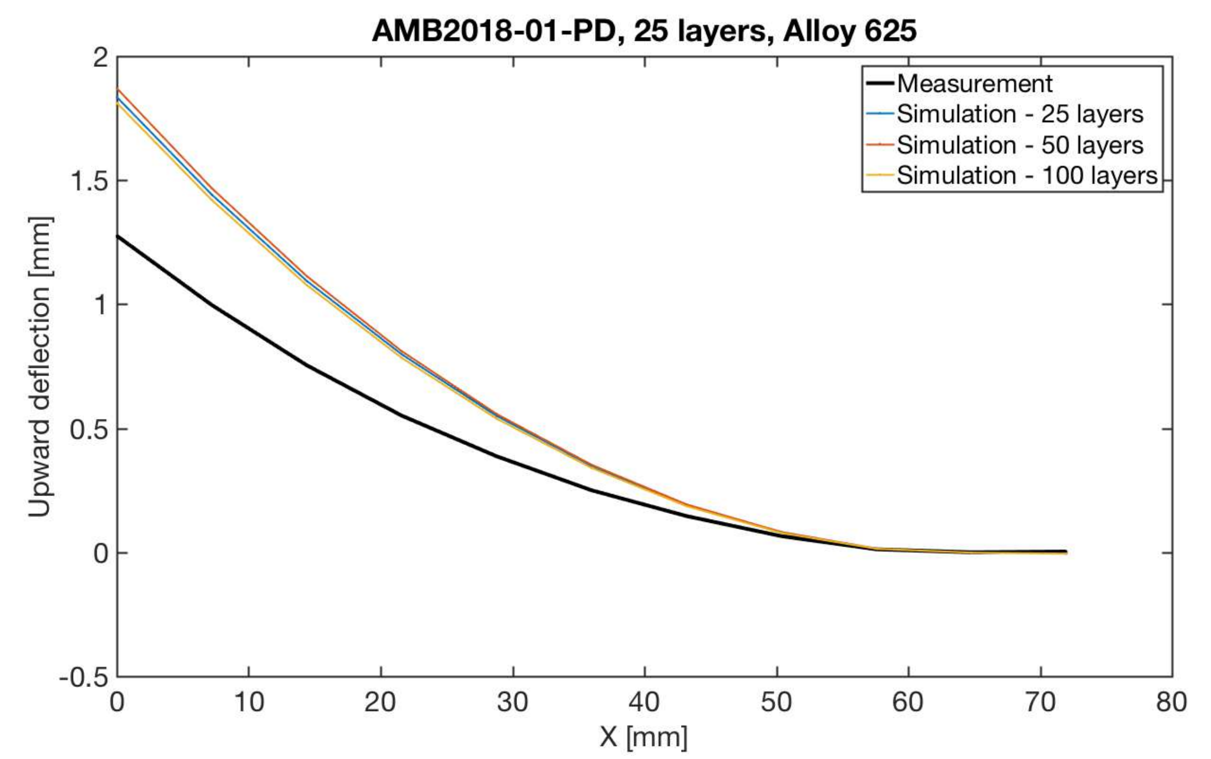
AM-Bench case, deformations



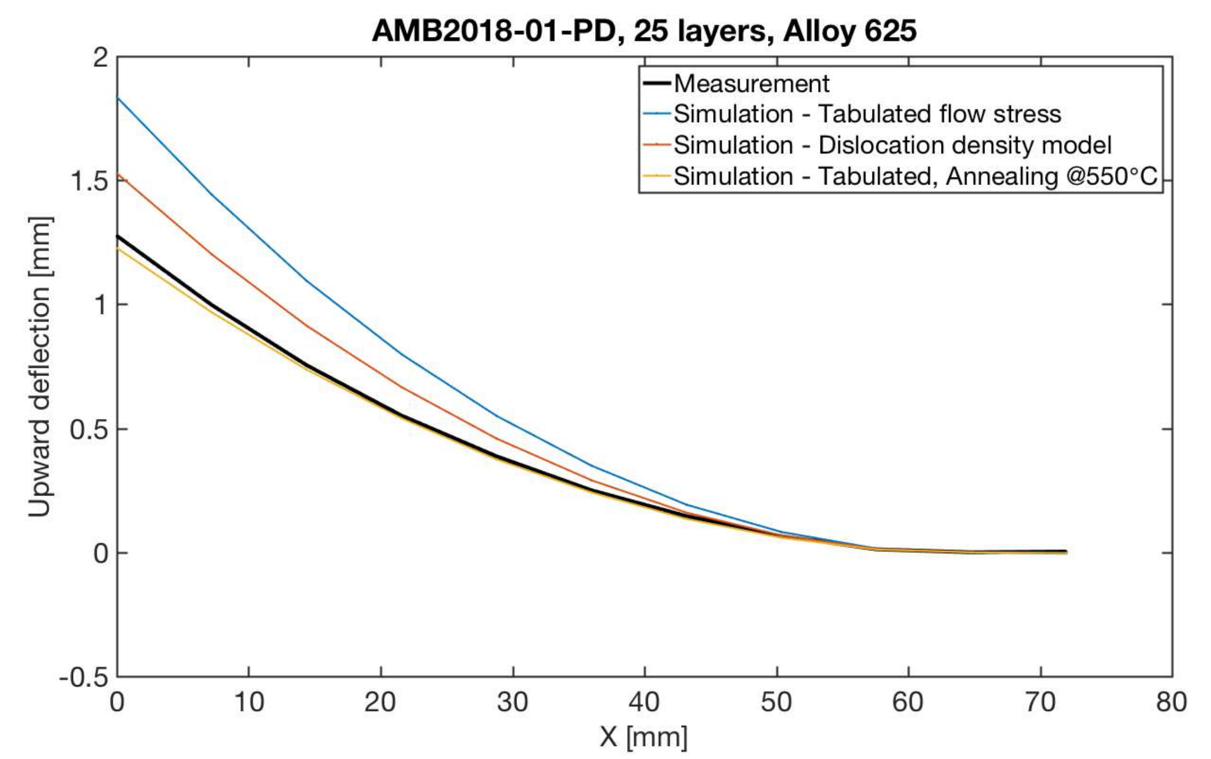


PBF, Alloy 625
600 layers, lumped into 25 layers
EDM cutting → residual deformations

Increase the number of simulated layers - Spatial discretization



Mechanism based material model



Summary

- Additive manufacturing is a disruptive technique wrt design and manufacturing, but there are a number of challenges yet to solve
- Multi-physics, length scales and time scales poses great challenges
- Reducing the simulation time with maintained/adequate accuracy is vital
- Mechanism based material model for Alloy 625 with coupled microstructure model
- Sub-model
  - Detailed study, e.g. mictrostructure
  - Predict fitting parameters, e.g. inherent strains