5th International Conference on
Light Materials

LightMAT 2023

TU Graz

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Heterogeneous microstructural evolution of AA6082 during plastic deformation

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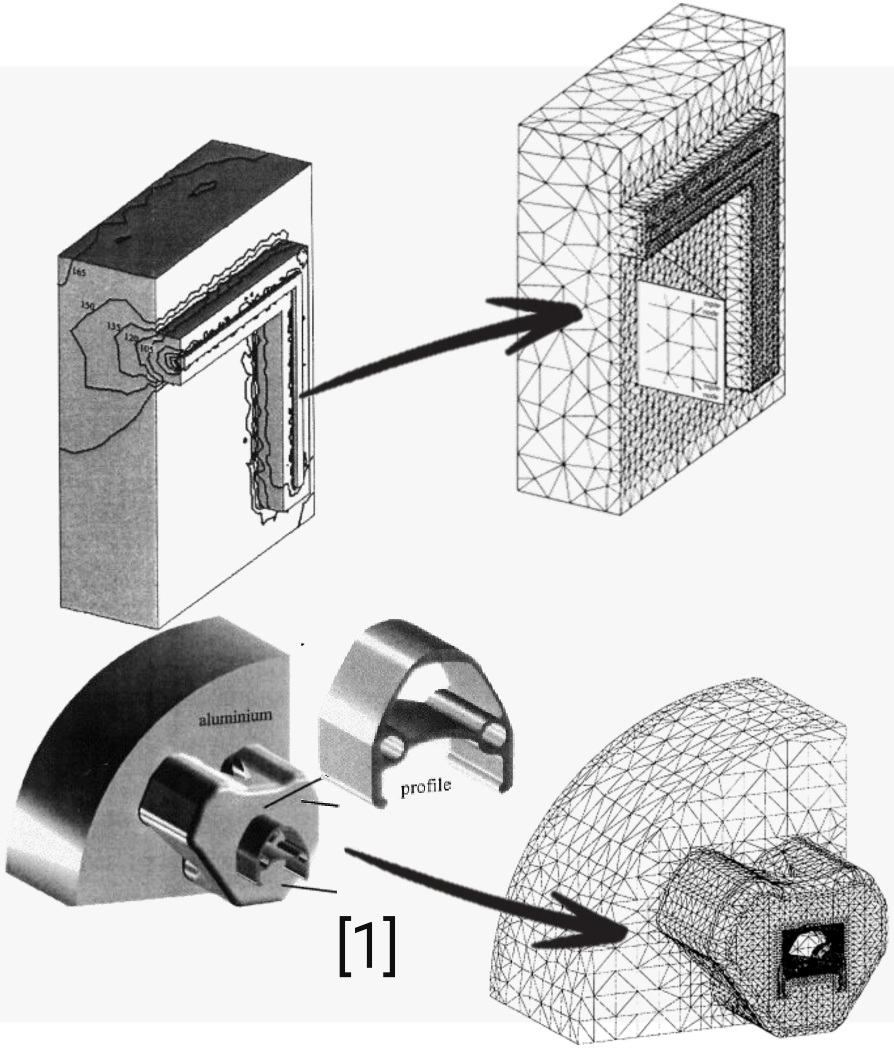
21 of June 2023

Christian Doppler Forschungsgesellschaft

NEUMAN ALUMINIUM

IMAT

MOTIVATION



[1]

Simulations of industrial processes

- Improvement of processing parameters
- Desired mechanical properties in final components
- Reduction of costs

OBJECTIVES

- To study **heterogeneous microstructural evolution** during hot deformation of **AA6082**, representative of **hot extrusion** processes
  - To generate heterogeneous deformation conditions at the lab-scale by compressing **hat-shaped samples**
  - To model and simulate compression tests using a **phyics-based model** implemented in **DEFORM** (FEM software)

FOCUS

FEM APPROACHES

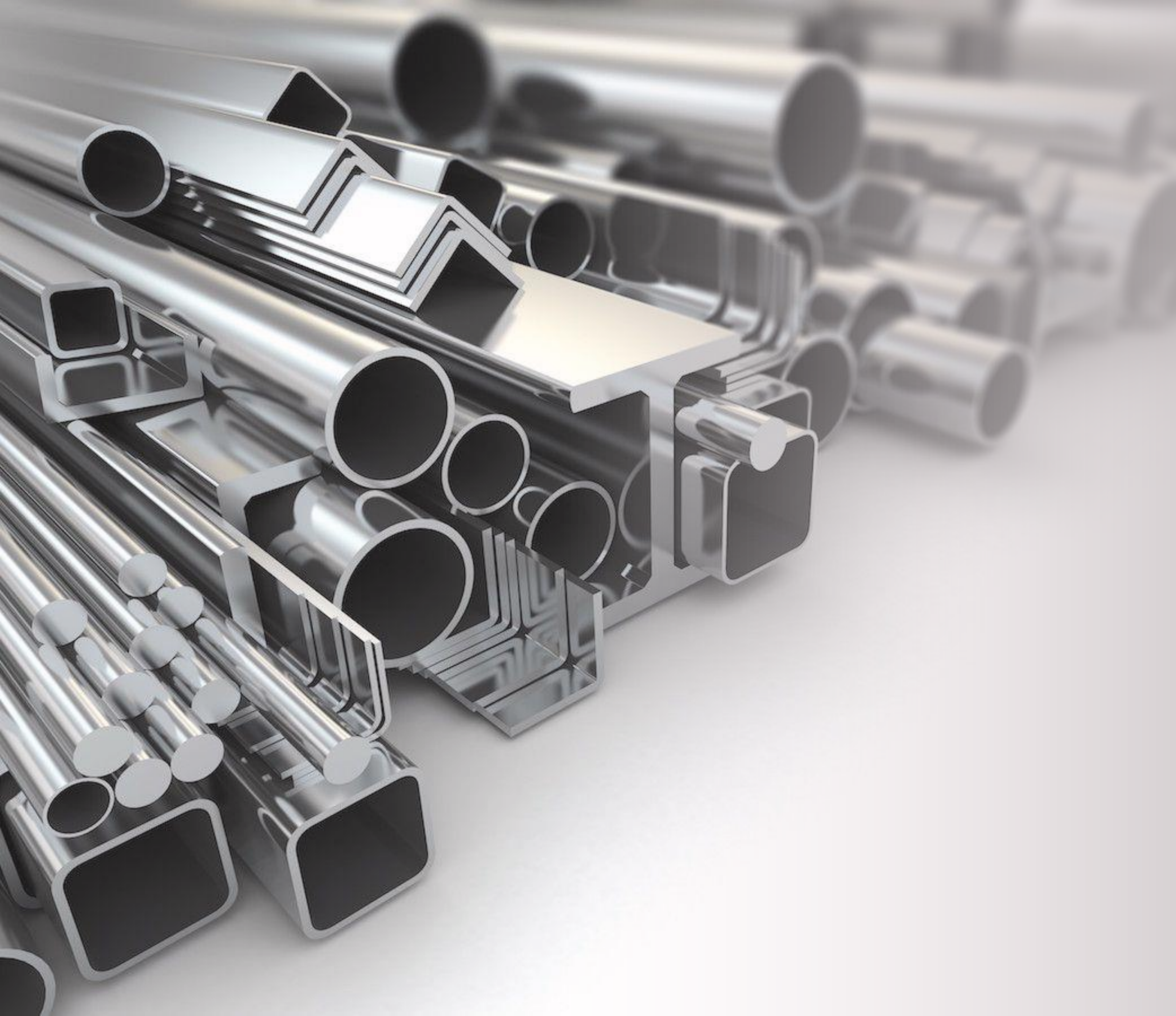
Phenomenological modelling

Physical modelling

Processing parameters
+
Formulations with **empirical parameters**

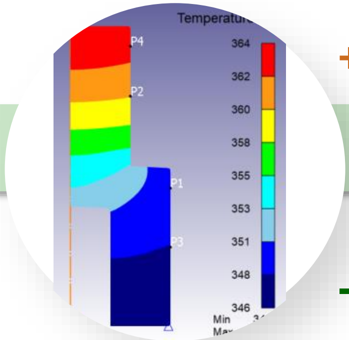
Processing parameters
+
Physics–based model (microstructure evolution)

Flow stress (σ) during deformation



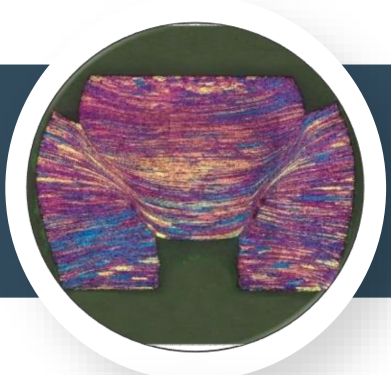
Methodology

WORKFLOW

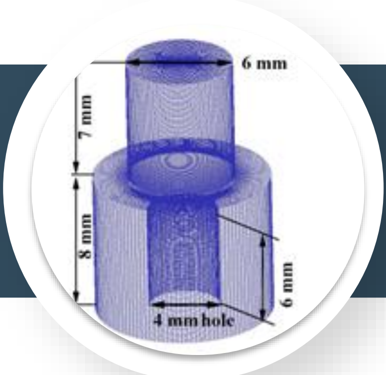


+ Ohmic heating
- Q. convection
- Q. conduction
- Q. emission

Hat shaped sample



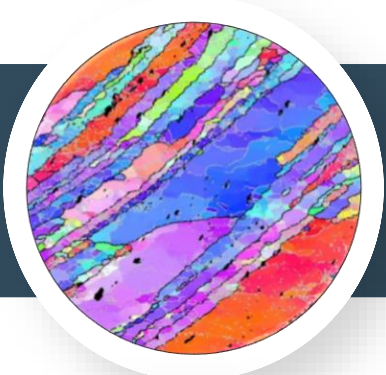
Hot deformation



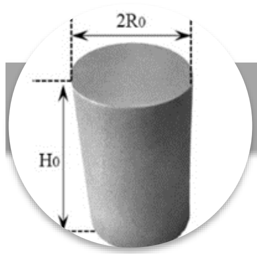
FEM

?

Microstructure prediction

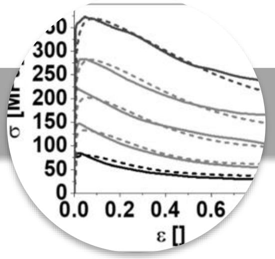


Microstructure validation

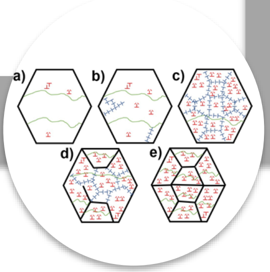


Compression sample

Hot deformation



Microstructure and flow curves

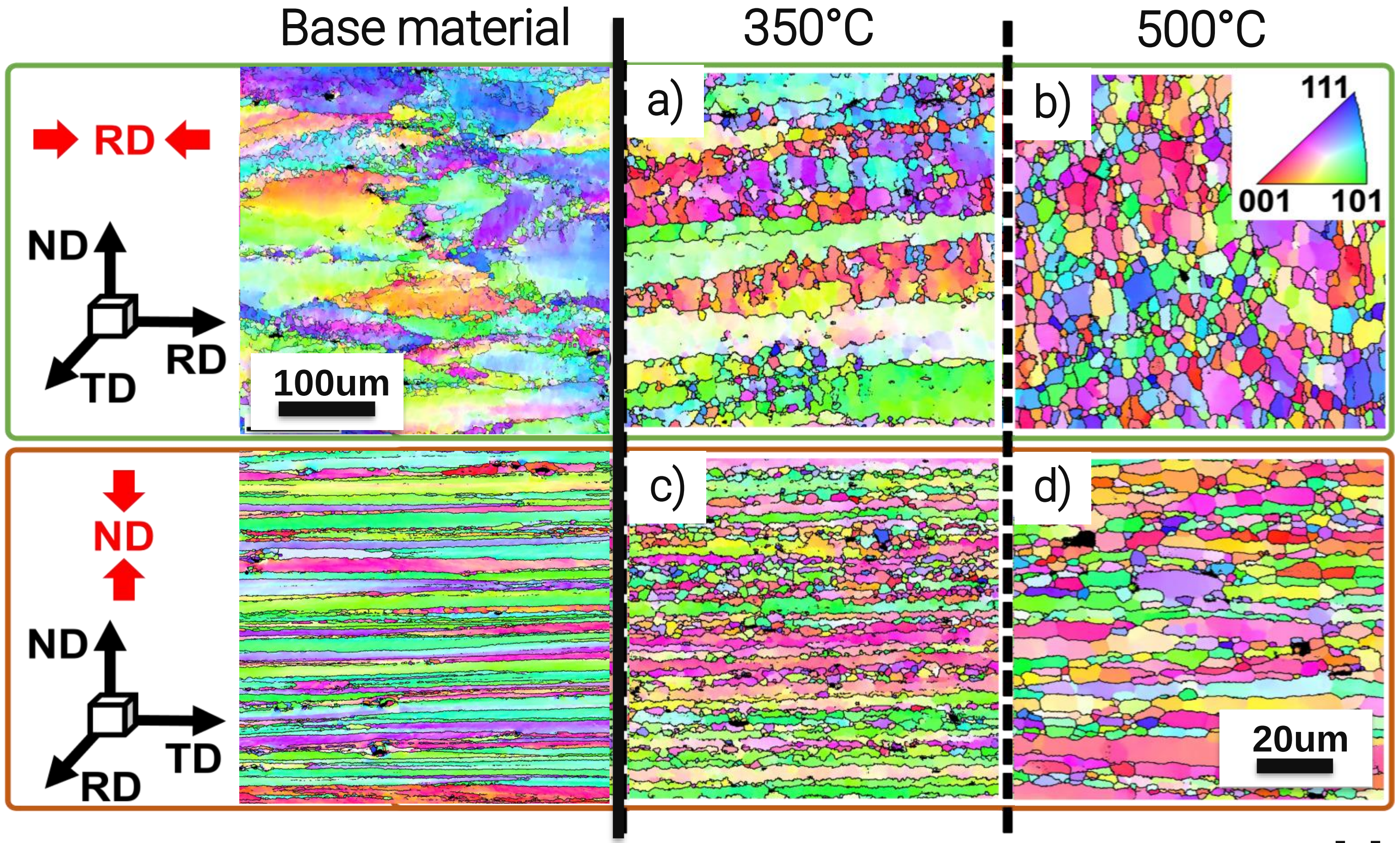


Mean field model

Model Optimization

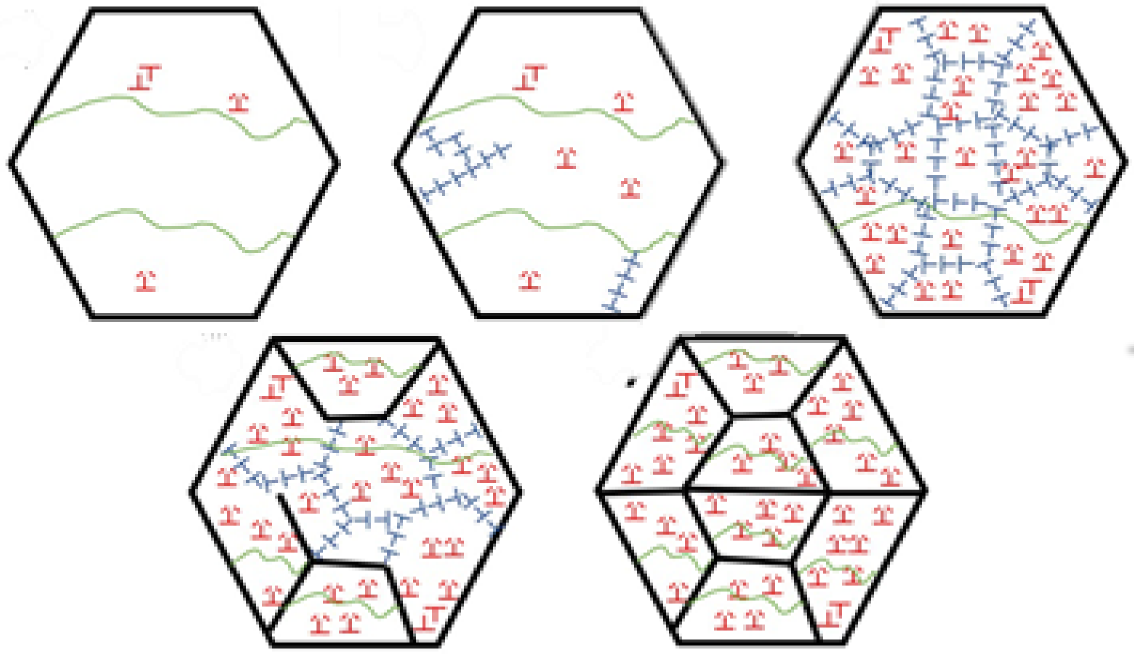
DEFORMATION IN ALUMINIUM

- **High stalking fault energy material**
- **Dynamic Recovery (DRV)**
  Cell formation followed by subgrain formation
- **Continuous Dynamic Recrystallization (CDRX)**
  Progressive formation and rotation of subgrains into grains
- **Geometric Dynamic Recrystallization (GDRX)**
  Migration and pinching off of original HAGB
- **Intermetallics**
  Effect on dislocation motion, pinning of boundaries or PSN
- **Texture**



[2]

MICROSTRUCTURE DESCRIPTION – AA6082



Fully recrystallized microstructure

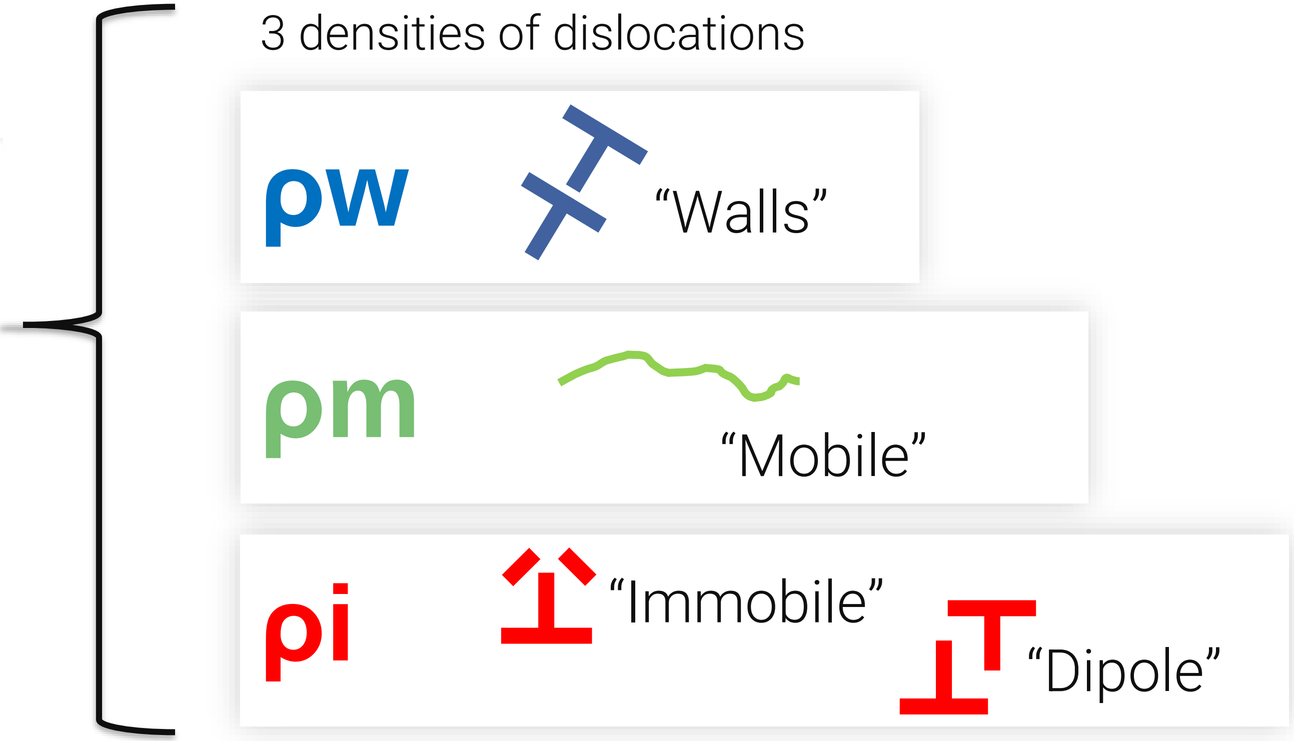
Initial stages of deformation

Formation of the substructure

Transformation of LAGBs into HAGBs

Fully recrystallized steady state

3 densities of dislocations



CDRX MODEL

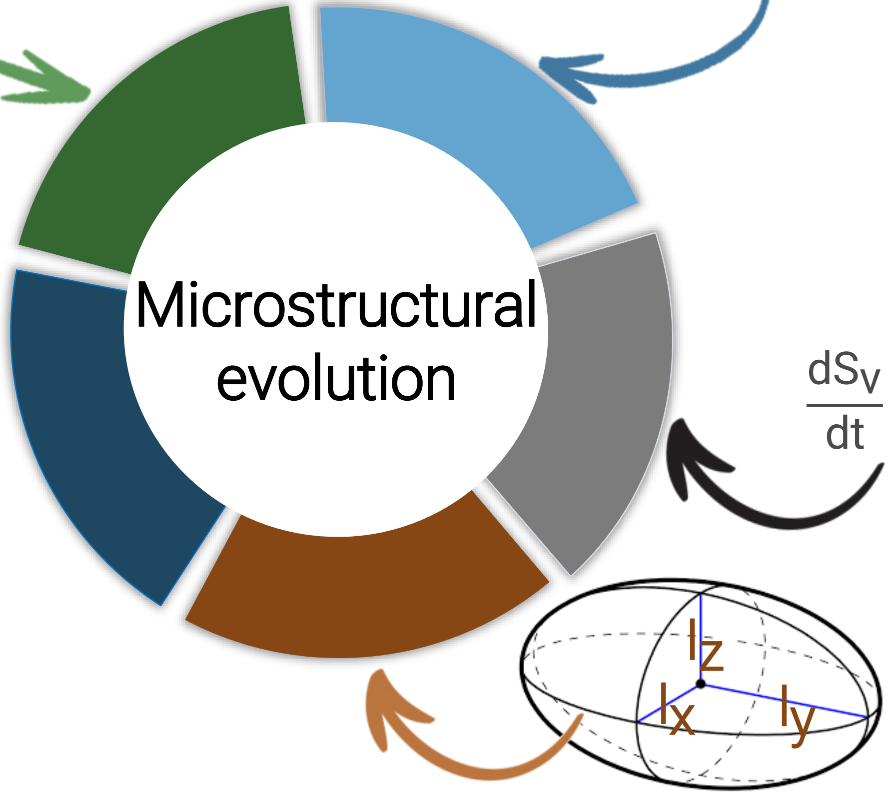
$$\sigma_{YS} = \frac{1}{\alpha_{YS}} \ln\left\{\left(\frac{\dot\varepsilon \exp\left(\frac{Q_{YS}}{RT}\right)}{A_{YS}}\right)^{\frac{1}{n_{YS}}} + \left[\left(\frac{\dot\varepsilon \exp\left(\frac{Q_{YS}}{RT}\right)}{A_{YS}}\right)^{\frac{1}{2n_{YS}}} + 1\right]^{1/2}\right\}$$

Yield stress formulation

Rate equations

$$\frac{d\rho_m}{dt} = \rho_m^{3/2} v_{eff} + \frac{\delta_{SG}\rho_m \phi_{sg} v_{eff}}{\lambda^2} - \frac{\rho_m v_{eff}}{\phi_{sg}} - 8\frac{\rho_m v_c}{\lambda} - \overline{\delta_{DRV}\rho_m(\rho_m+\rho_i)v_{eff}} - f_{sv} S_{Interface} v_{eff}\rho_m - \frac{2\rho_m f_{HAGB} v_{HAGB}}{\phi_{sg}}$$

$$\frac{d\rho_i}{dt} = \frac{\rho_m v_{eff}}{\phi_{sg}} - 8\frac{\rho_i v_c}{\lambda} - \delta_{DRV}\rho_m\rho_i v_{eff} - \frac{2\rho_m f_{HAGB} v_{HAGB}}{\phi_{sg}}$$



$$\frac{dl_i}{dt} \text{ for } i = x,z,y$$

CDRX

$$\frac{dS_V}{dt} = \alpha_{CDRX}\frac{b}{n\theta_0}\Delta\rho_{CDRX}\dot\varepsilon_p - S_V^2 f_{HAGB} v_{HAGB}$$

$$\frac{d\overline{\theta}_R}{dt} = (1-\alpha_{CDRX})\frac{b}{nS_V}\Delta\rho_{CDRX}\dot\varepsilon_p$$

[2,3,4]

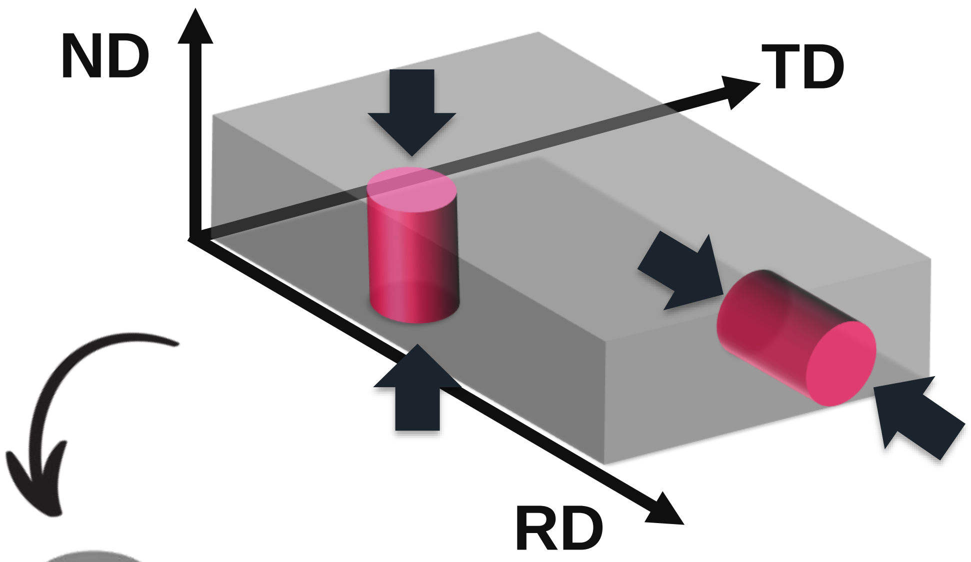
$$\sigma = \sigma_{th} + \sigma_{ath}$$

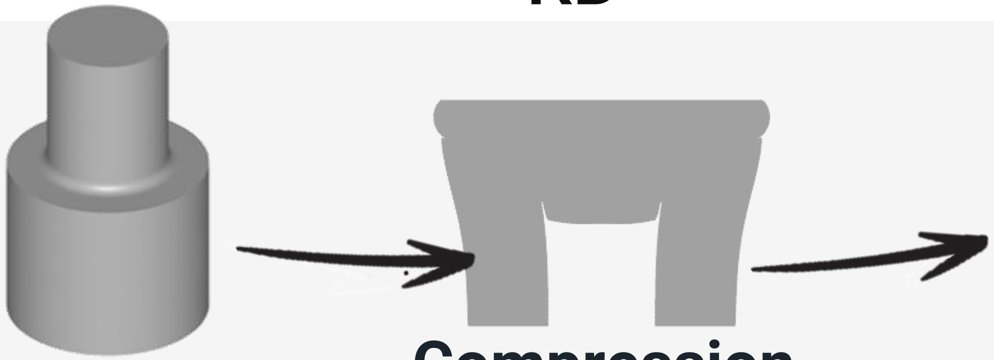
$$\sigma_{th} = \sigma_{YS} - \sigma_{ath}^0$$

$$\sigma_{ath} = \alpha b G M\sqrt{\rho_m+\rho_i+F_w\rho_w}$$

Constitutive equations

HAT-SHAPED SAMPLES





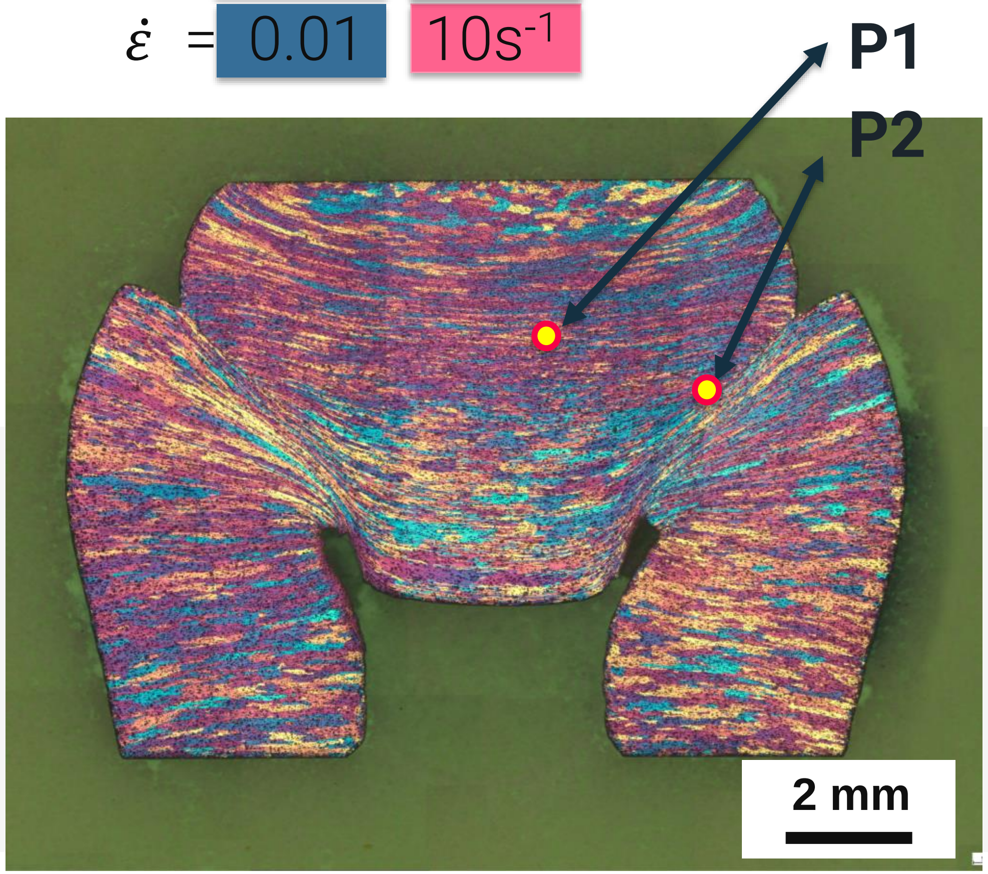
Compression
Gleeble3800

LOM
EBSD

Tested conditions:

T = 350 | 500°C

$\dot{\varepsilon}$ = 0.01 | 10s^{-1}

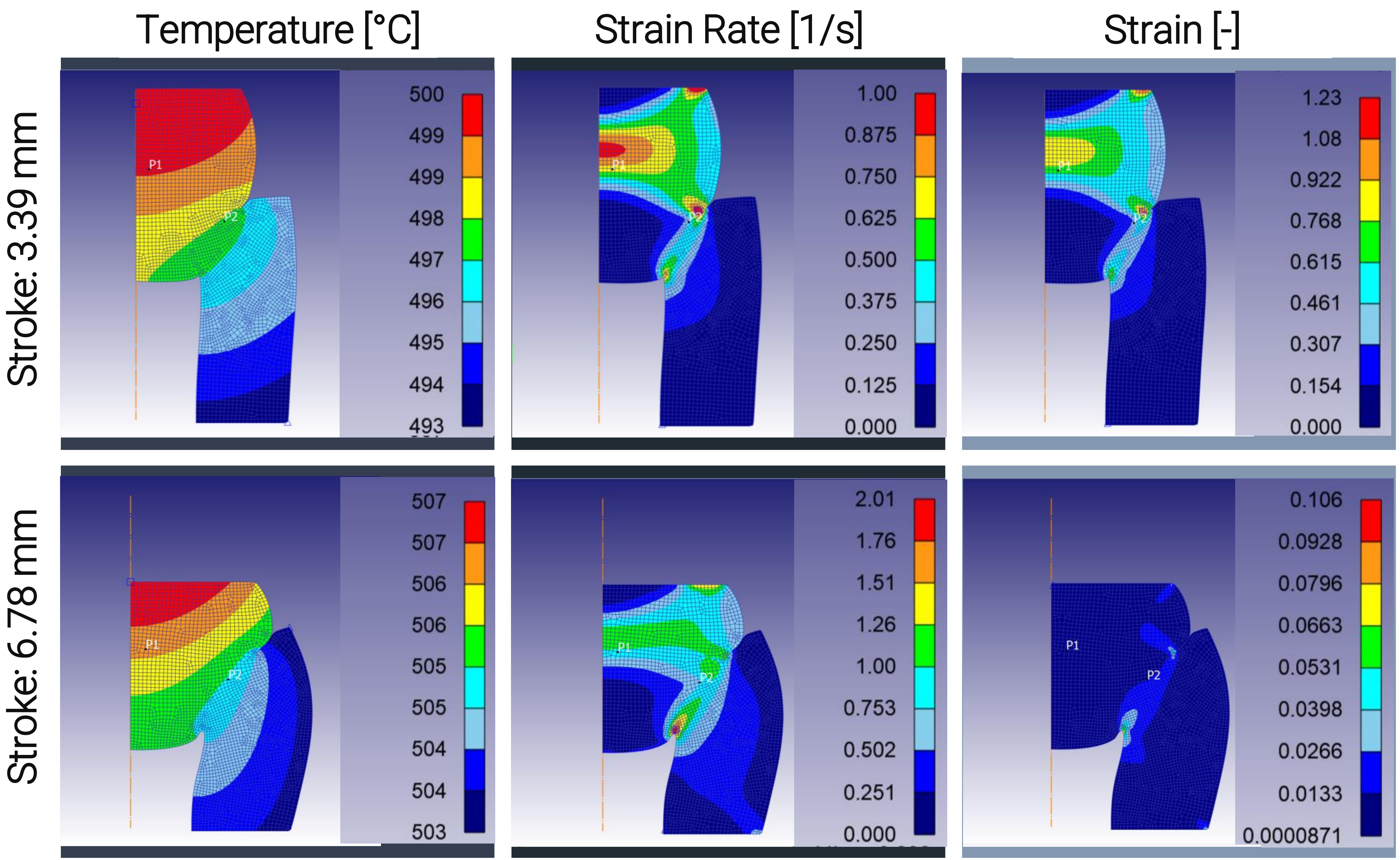


HAT-SHAPED SAMPLES

Why is this geometry interesting?

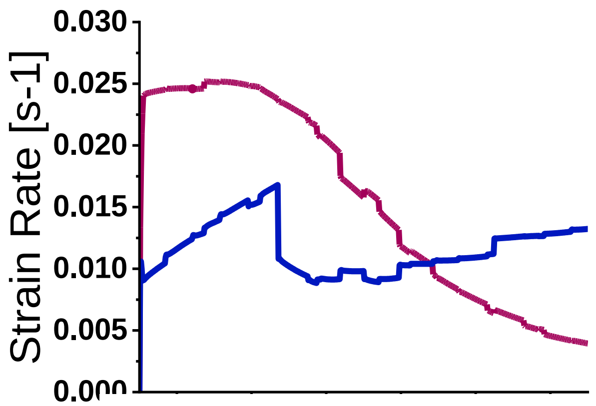
- Flow curves?
- Local T, ε, $\dot{\varepsilon}$ gradients

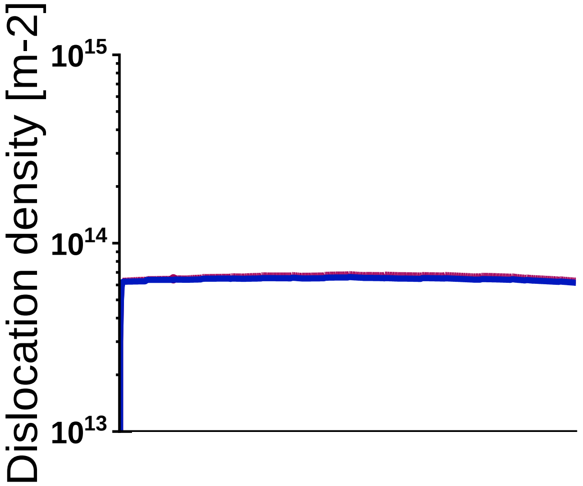
- **Representative of HOT EXTRUSION**



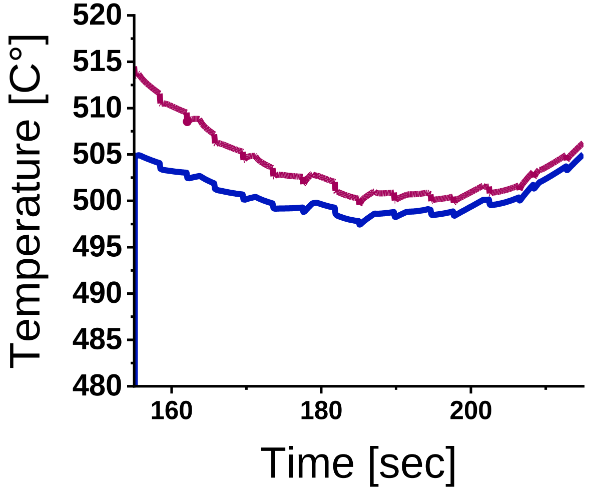
Selected results

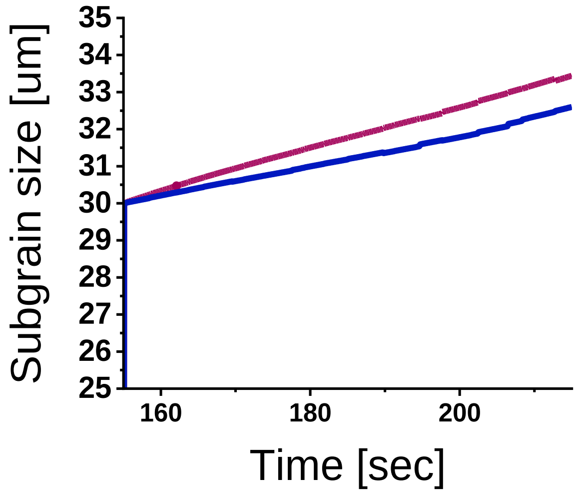
MICROSTRUCTURE EVOLUTION
500°C, 0.01s^{-1}, ND

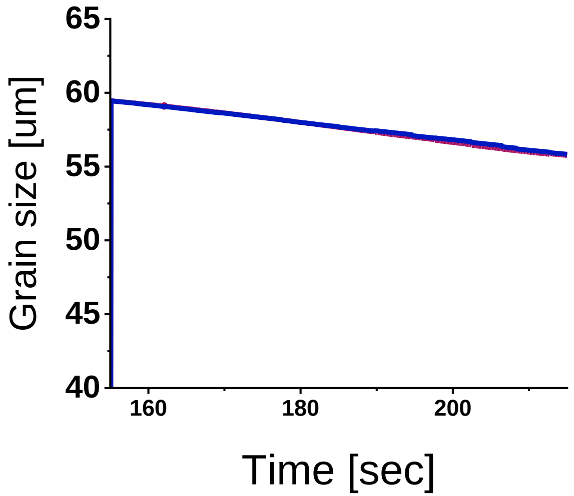


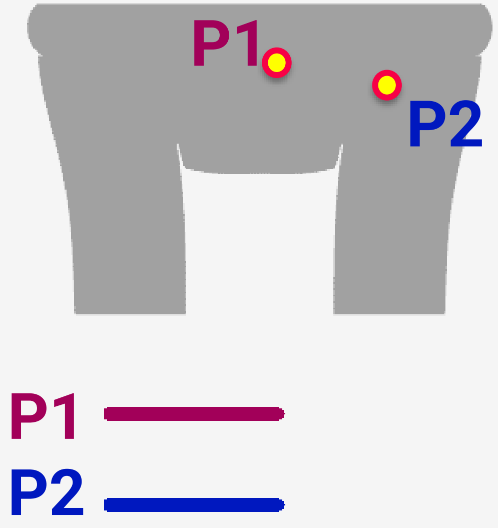


- Subgrains become larger
- Grains become smaller
- Homogenous grain/subgrain structure in P1 and P2





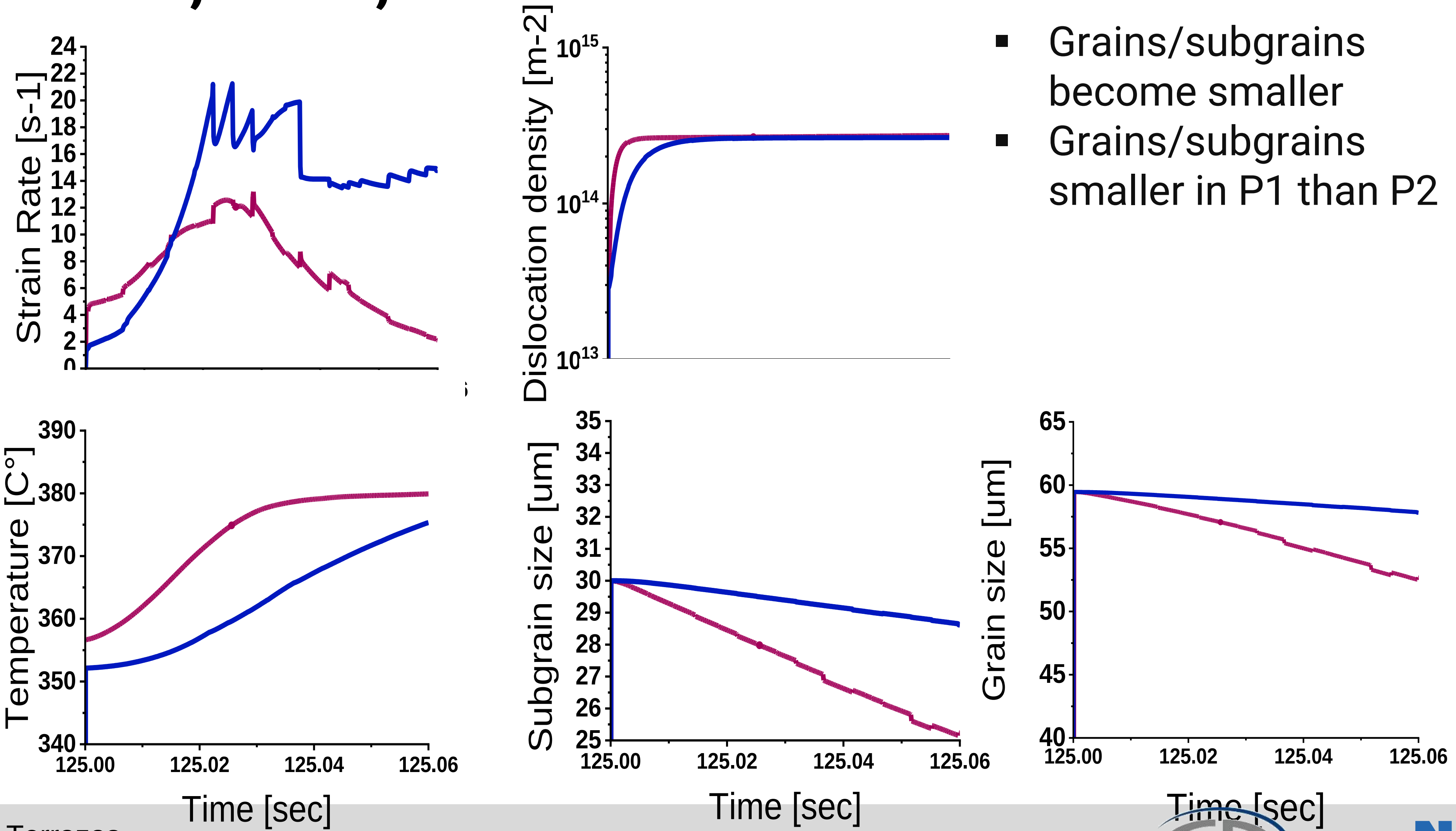




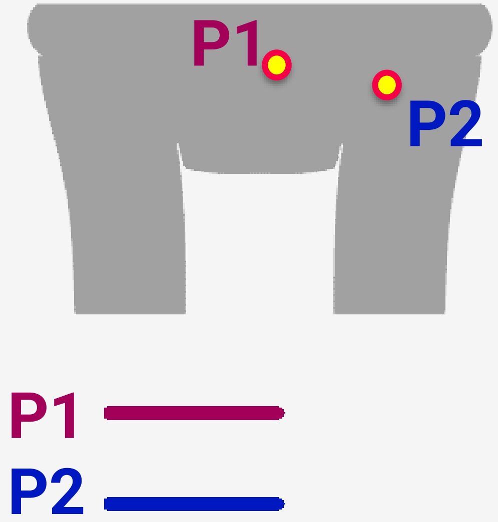
Selected results- Model predictions

MICROSTRUCTURE EVOLUTION

350°C, $10s^{-1}$, ND

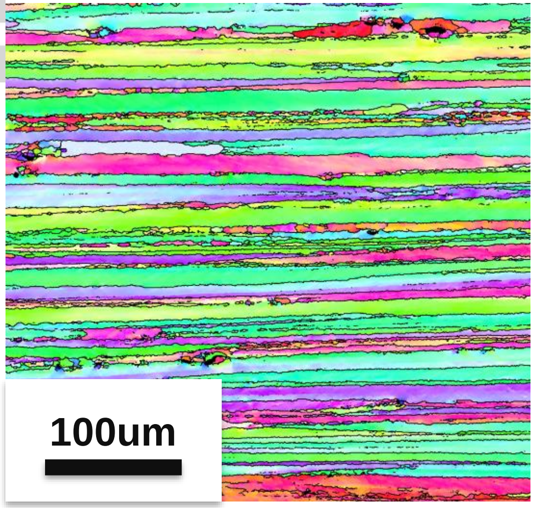


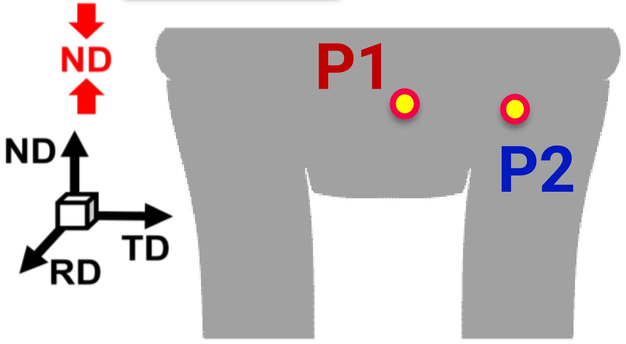
- Grains/subgrains become smaller
- Grains/subgrains smaller in P1 than P2

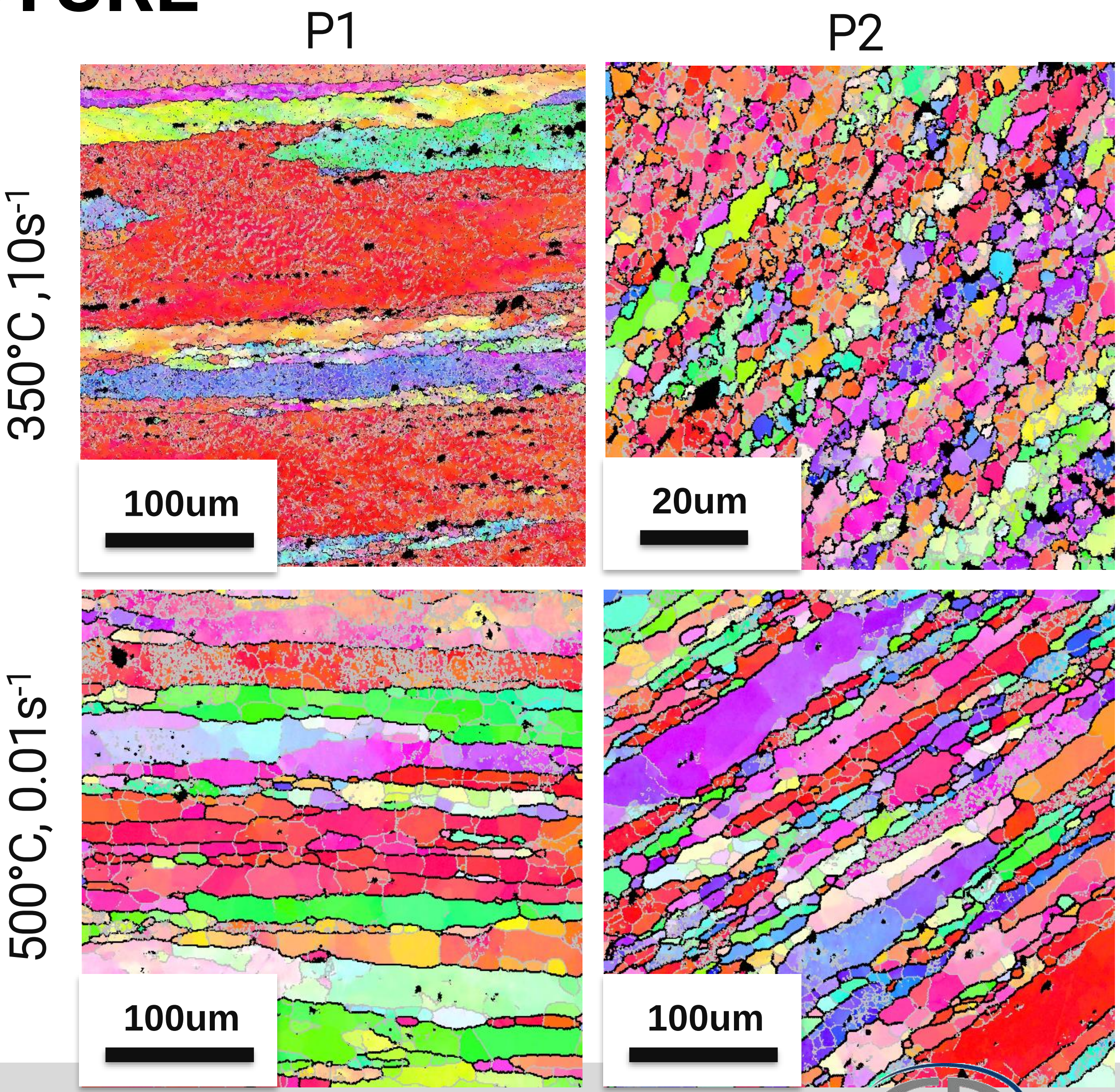


MICROSTRUCTURE EVOLUTION

Base material



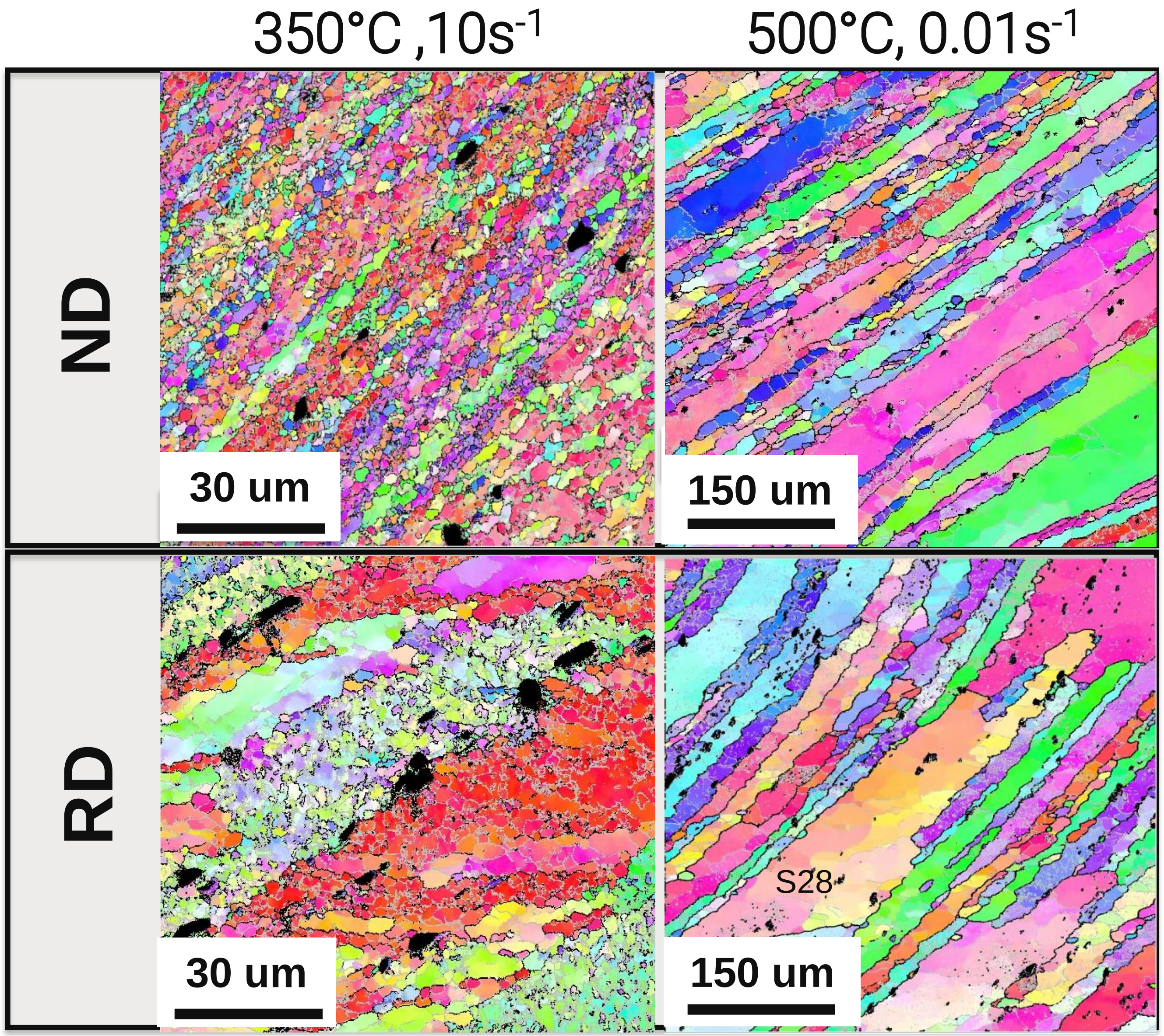




- Subgrains smaller in P1 than P2
- Grain sizes?

- Subgrains become larger than for 300°C 10s-1
- Homogenous grain/subgrain structure in P1 and P2

MICROSTRUCTURE EVOLUTION DURING SHEAR DEFORMATION



CONCLUSIONS

- Substructure becomes coarser for higher temperatures and lower strain rates
- For analyzed areas, higher temperatures and lower strain rates produce homogeneous grain and subgrain formation
- For low temperatures and high strain rates further analysis is required to assess grain/subgrain sizes
- Grain/subgrain formation is not influenced significantly by compression direction, but by the deformation conditions (T, $\dot{\varepsilon}$)

SUMMARY AND ACKNOWLEDGEMENTS

- We generated heterogeneous deformation conditions using by hot compressing **hat-shaped samples** to represent **hot extrusion** processes
- The compression tests were modeled and simulated using a **phyics-based model** implemented in **DEFORM** (FEM software)
- The **heterogeneous microstructural evolution** during hot deformation was studied

Funding

CHRISTIAN DOPPLER SOCIETY

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Thank you for your attention!

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