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Integrated experimental-numerical analysis of "2D" dual-phase steel microstructures

project s17012a - UNFAIL

J. Wijnen, T. Vermeij

R.H.J. Peerlings, J.P.M. Hoefnagels, M.G.D. Geers

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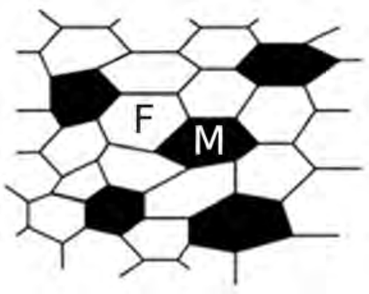
Dual-phase steels



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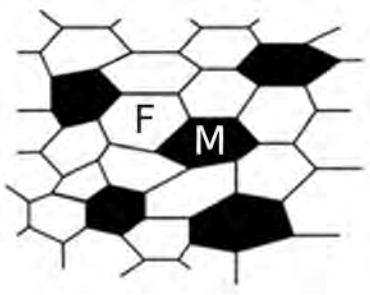

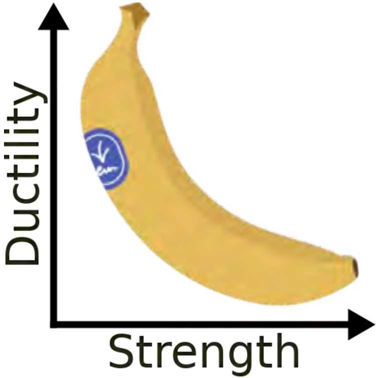

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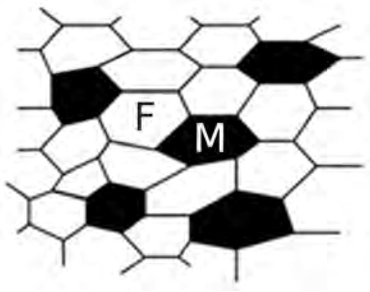

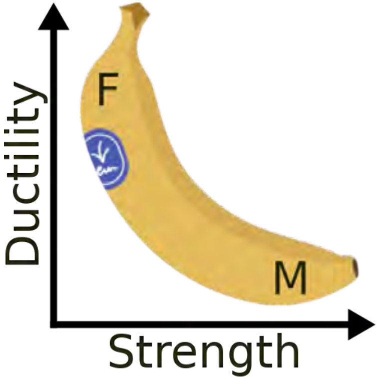

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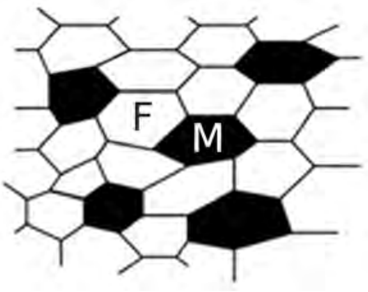

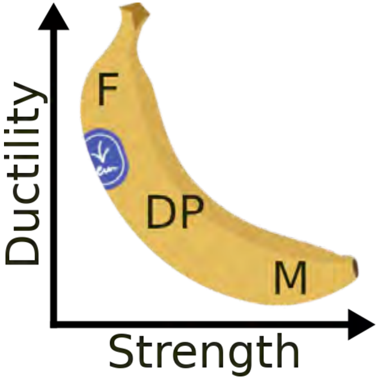

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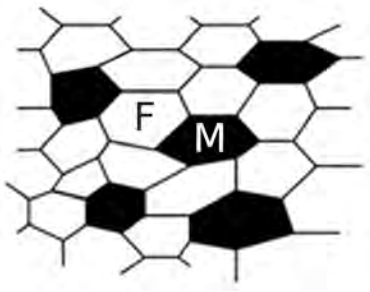
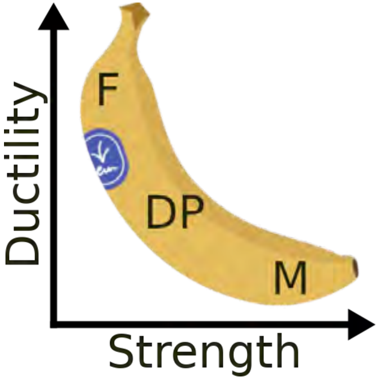
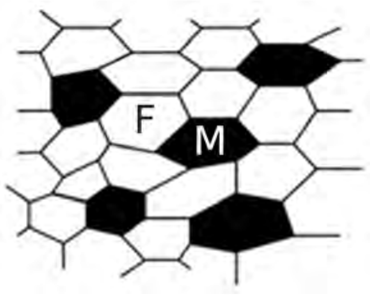
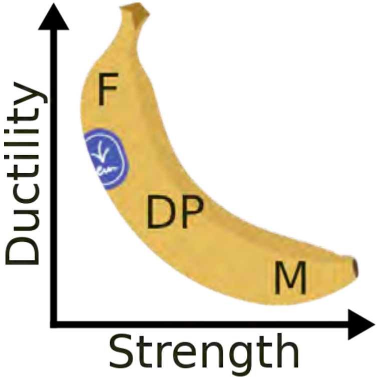




- Good strength-ductility trade-off

Dual-phase steels





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- Low production cost

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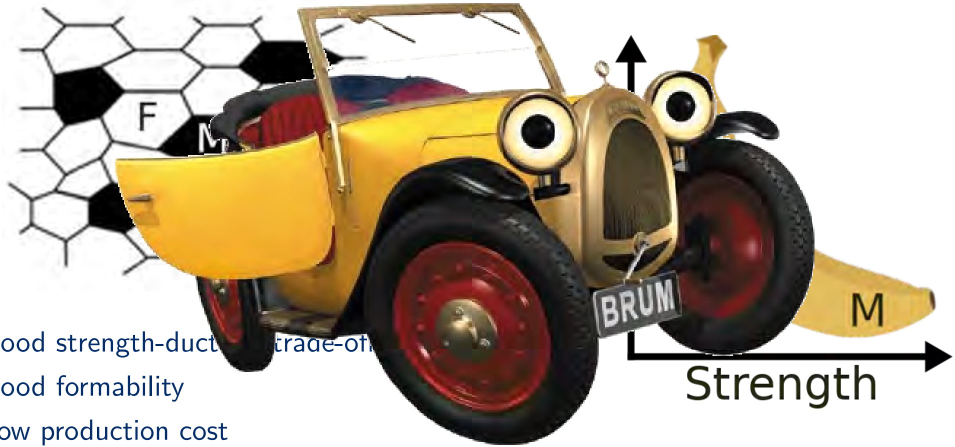

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Experimental-numerical analysis

Combining experiments and simulations

- Calibrate models
- Fully controlled
- Easily repeatable
- Additional information

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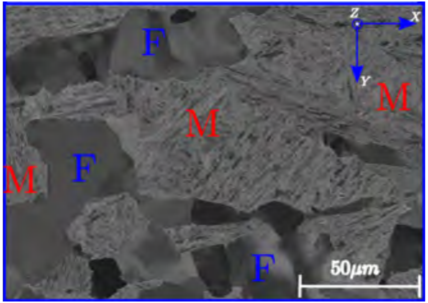
Study influence of certain "ingredients"

Experimental-numerical analysis



(R. Kerkhof)

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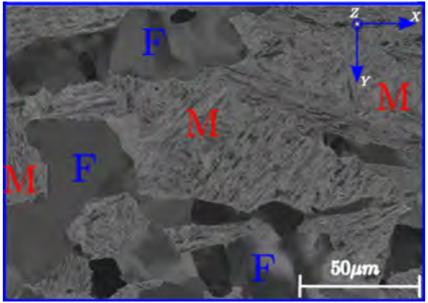

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Unknown sub-surface microstructure?

- Limits the analysis to 2D
- Influence of 2 to 3 sub-surface grains (Zheghadi et al. 2008, Diehl et al. 2016)

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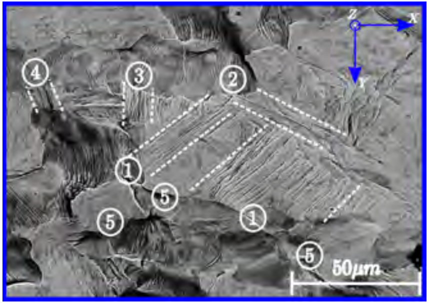

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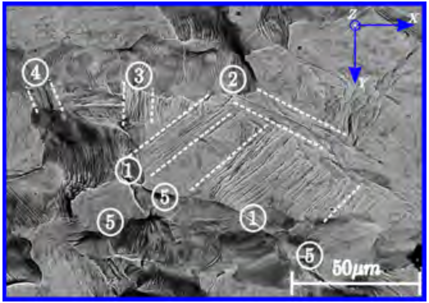

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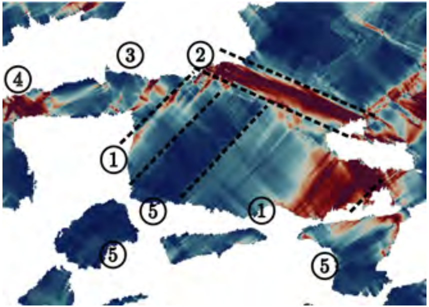

(Rezazadeh et al. 2022)

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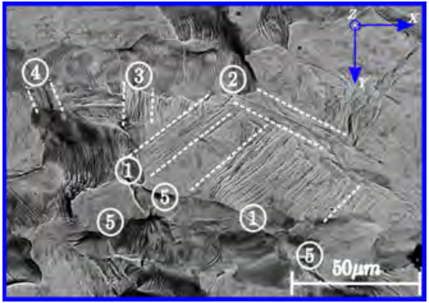

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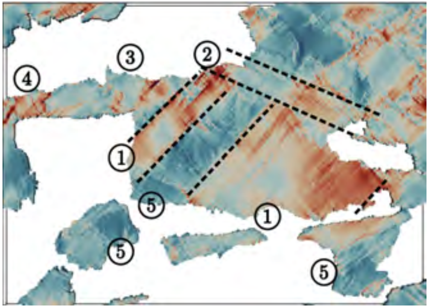

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Experimental-numerical analysis

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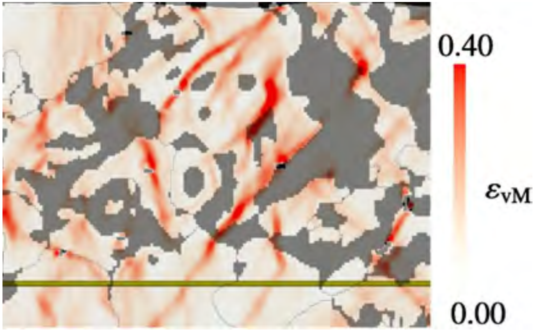
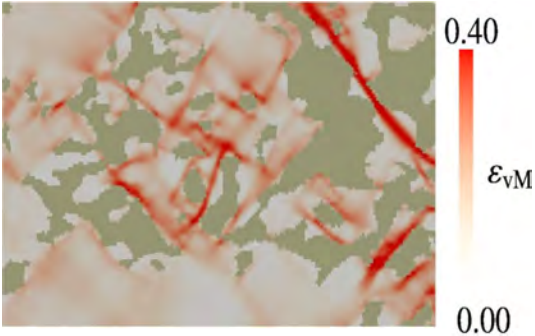


CP simulation



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Our goal is to look at more specific features of the microstructure

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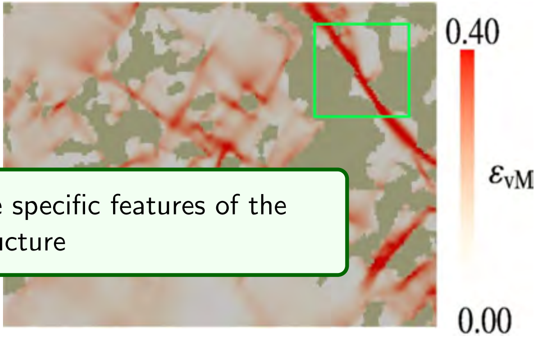

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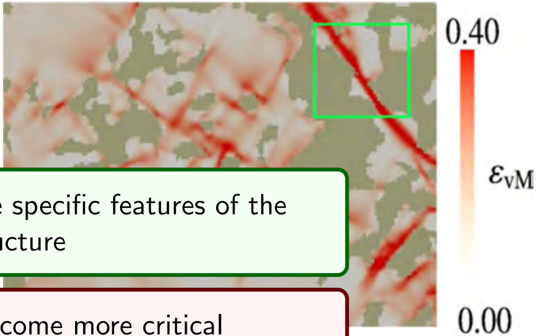

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Sub-surface effects become more critical

(Tasan et al. 2014)

Experimental framework

Remove sub-surface structure?

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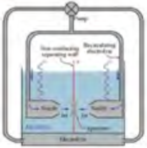

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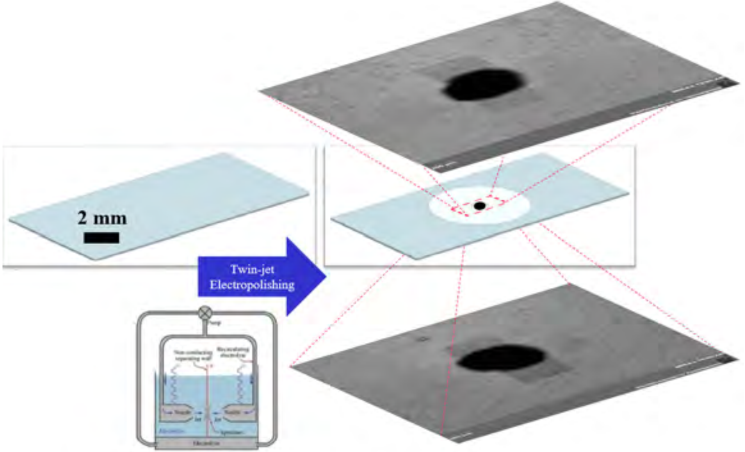

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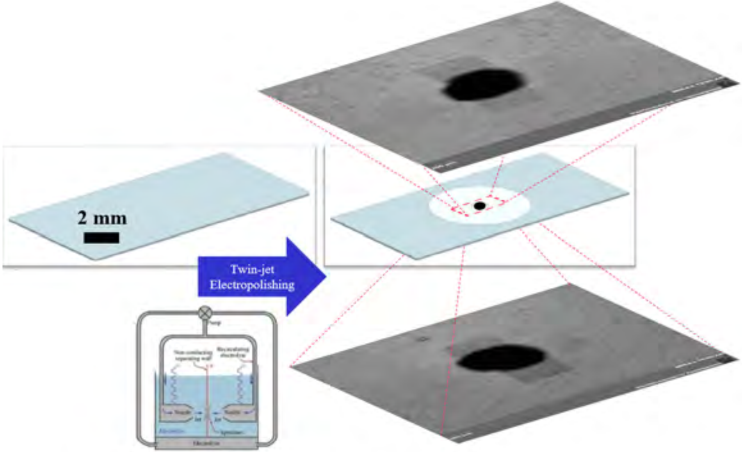
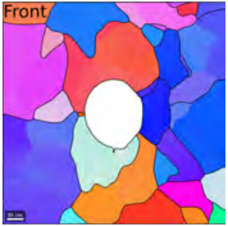
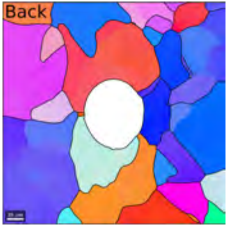
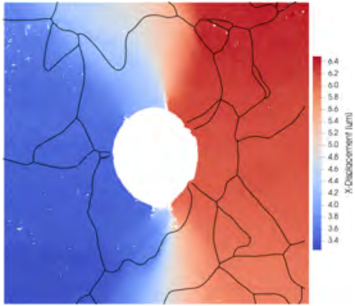






Measured deformation in experiment on ferrite

x-displacement



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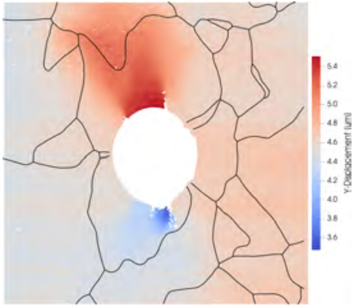

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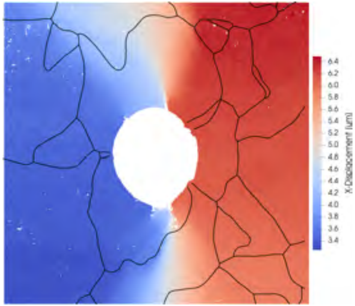

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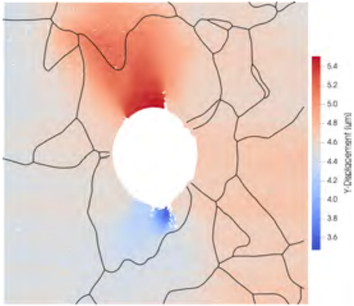
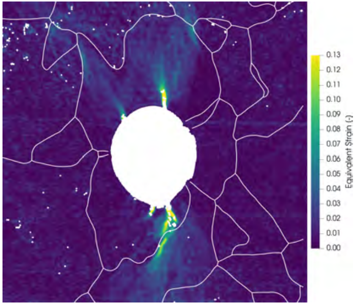
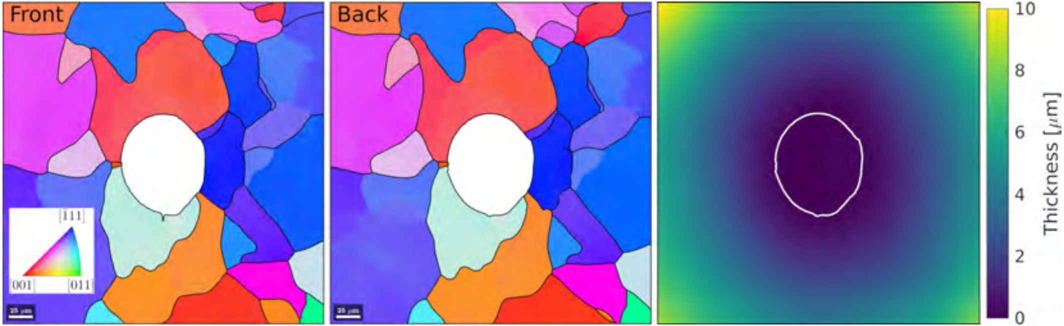


Equivalent strain



Geometry and mesh of ferrite microstructure



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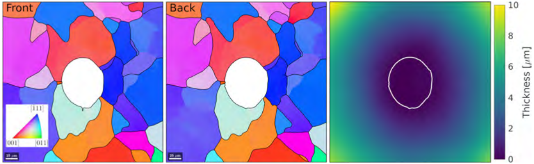

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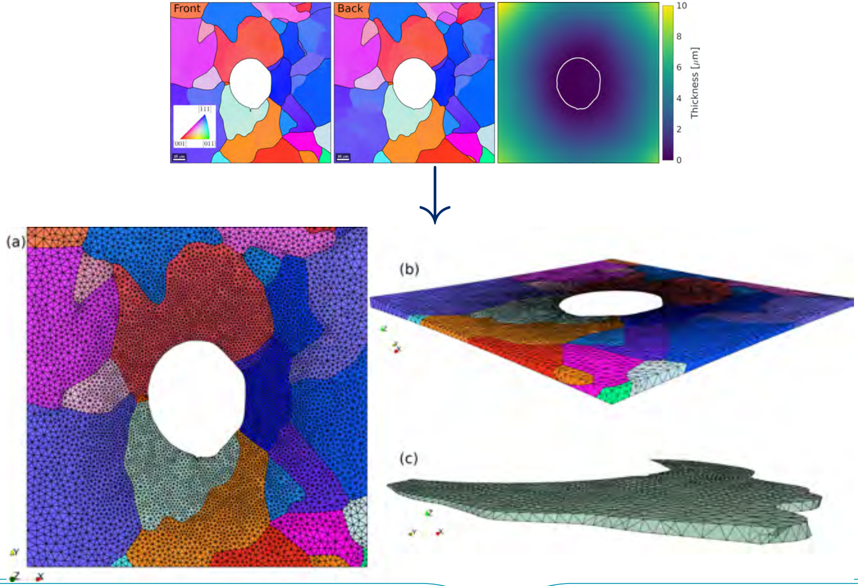


Simulation of ferrite

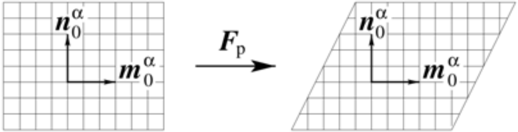
Crystal Plasticity FEM

Multiplicative split

$$\mathbf{F} = \mathbf{F}_e \cdot \mathbf{F}_p$$

Plastic velocity gradient

$$\mathbf{L}_p = \dot{\mathbf{F}}_p \cdot \mathbf{F}_p^{-1} = \sum_{\alpha=1}^{N} \dot{\gamma}^{\alpha} \, \vec{m}_0^{\alpha} \otimes \vec{n}_0^{\alpha}$$



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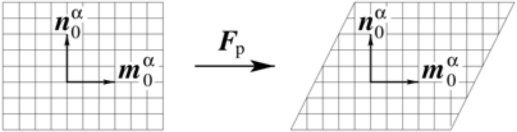

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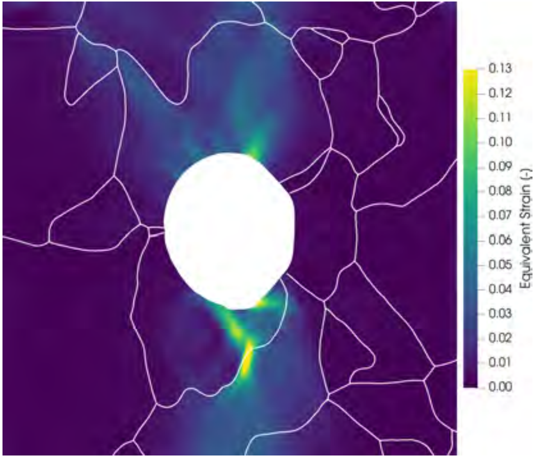

Simulation of ferrite

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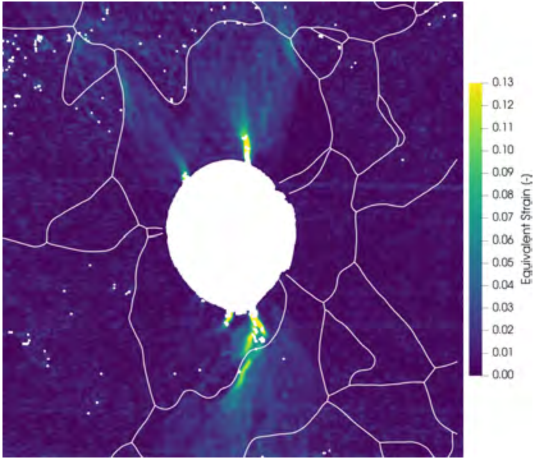

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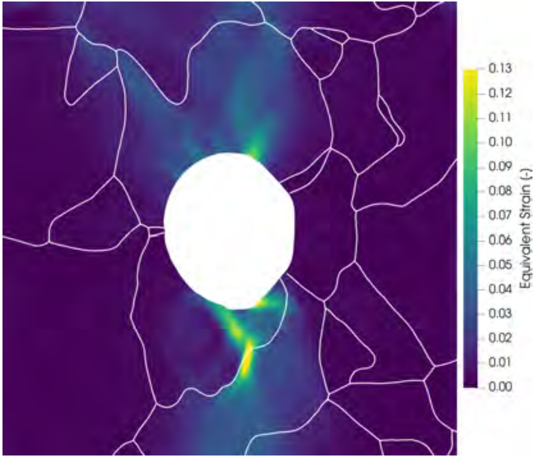

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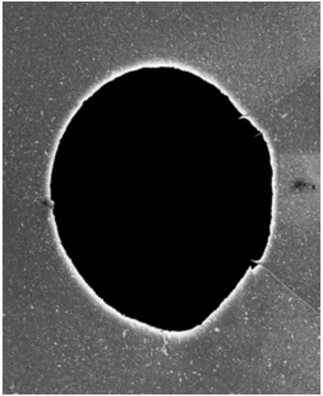

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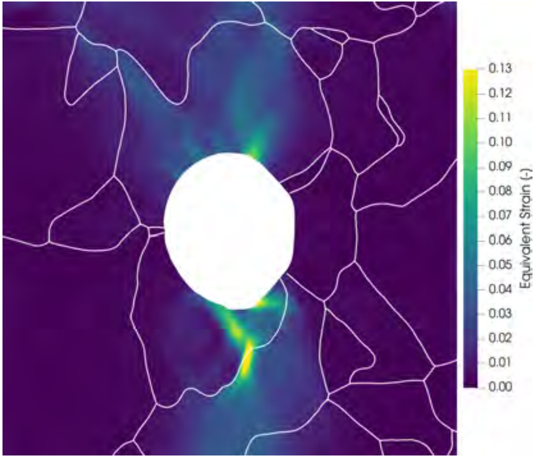

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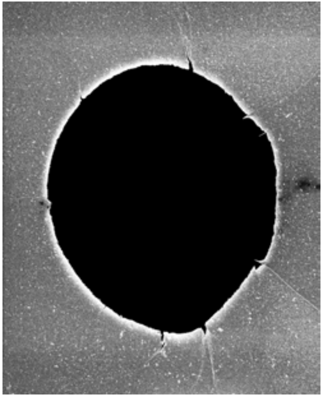

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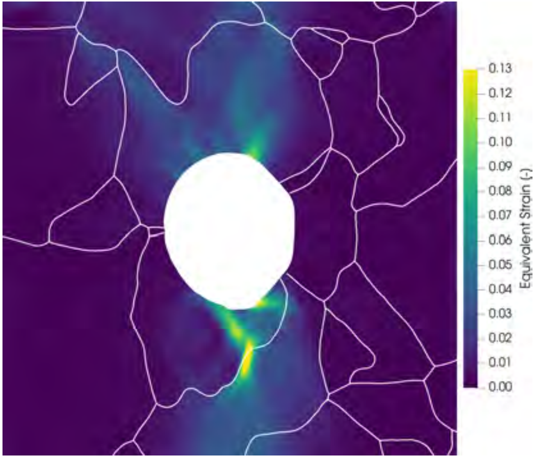

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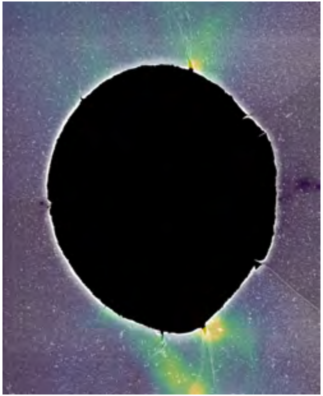

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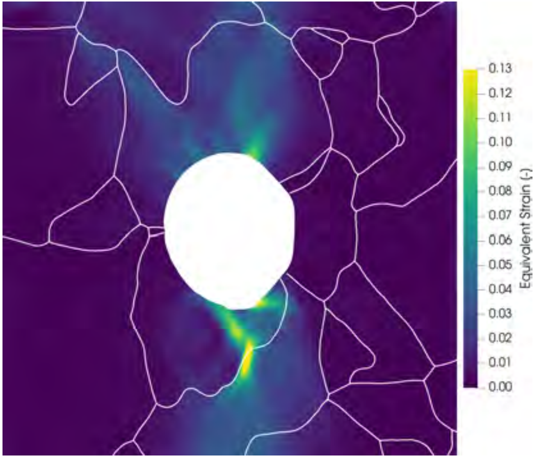
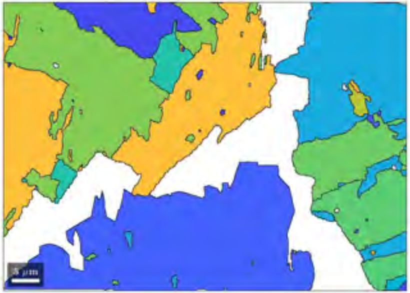


Dual-phase steel area



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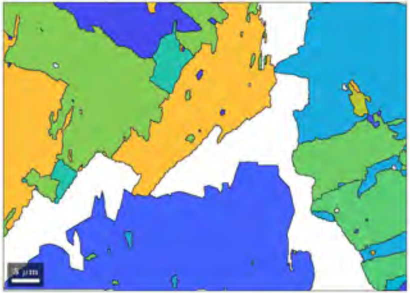

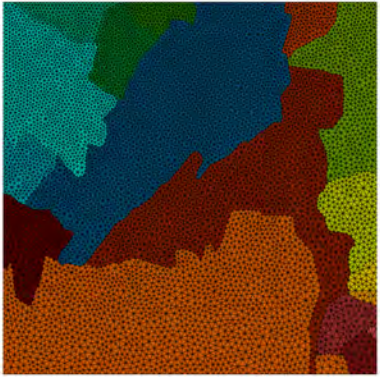

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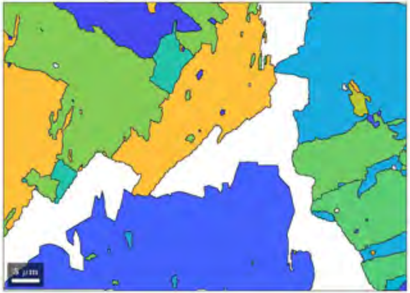
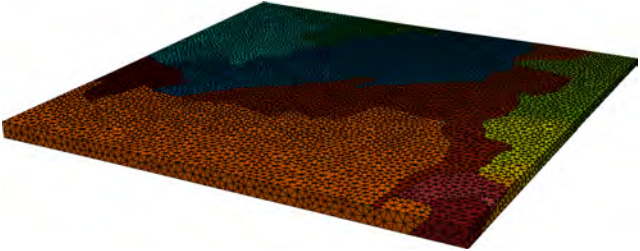
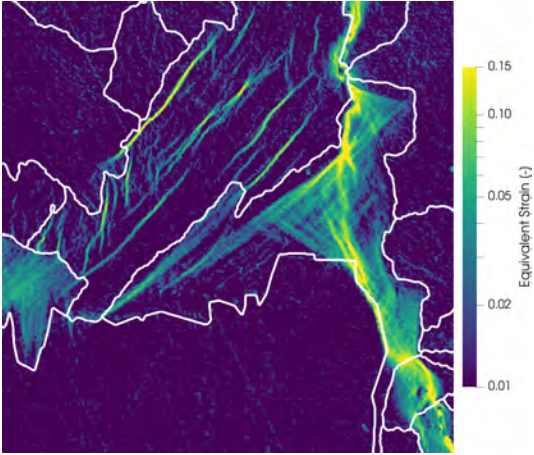




Crystal Plasticity Simulation

Experiment



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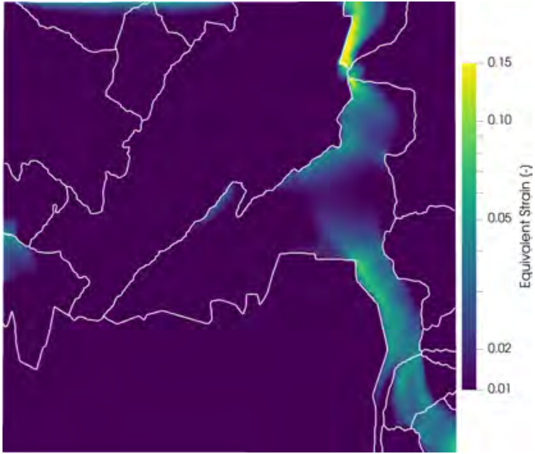

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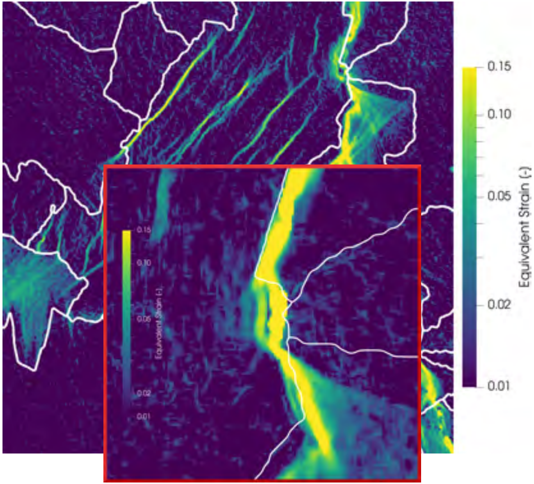

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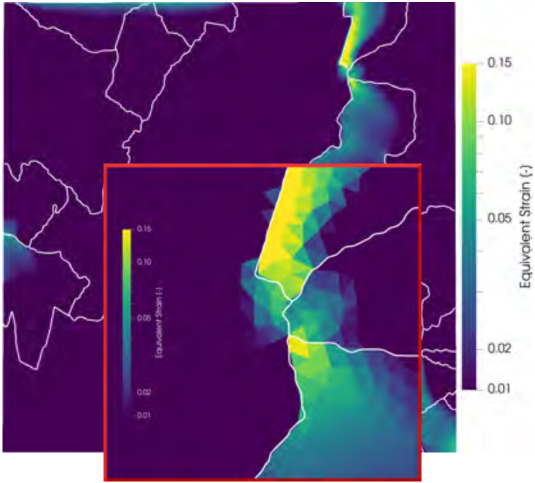

Mechanical Behavior of Martensite

Not that brittle after all?

- Strains over 100% in DP (Ghadbeigi et al. 2010)

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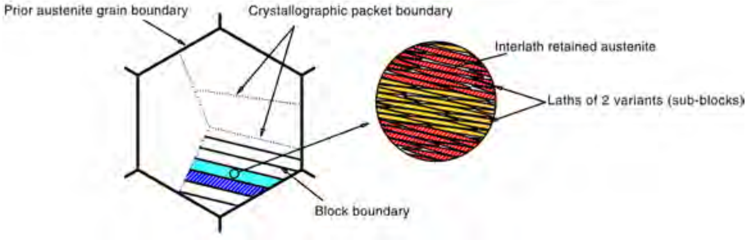

(Maresca et al. 2014)

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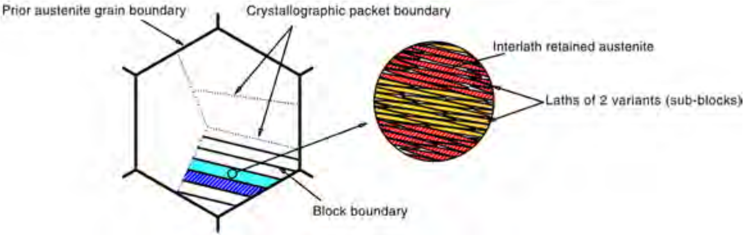

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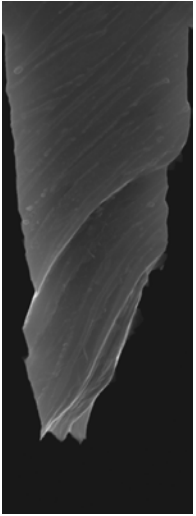

(Du et al. 2016, 2019)

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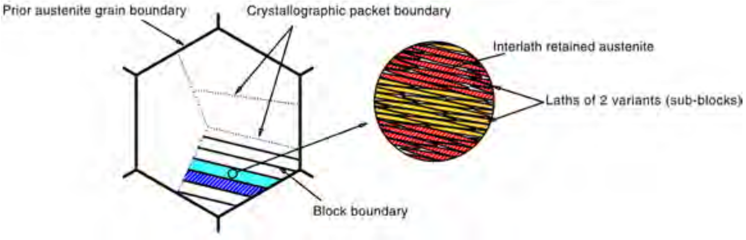
- Possible explanation: softer retained austenite (Maresca et al. 2014)



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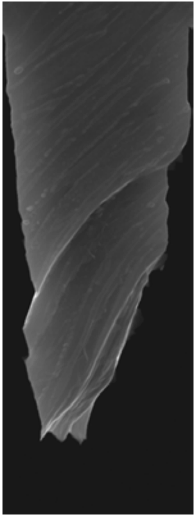

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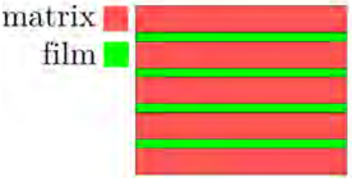
Modeling substructure boundary sliding



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Austenite to martensite transformation

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- KS orientation relationship
- 3 austenite slip systems aligned with habit plane

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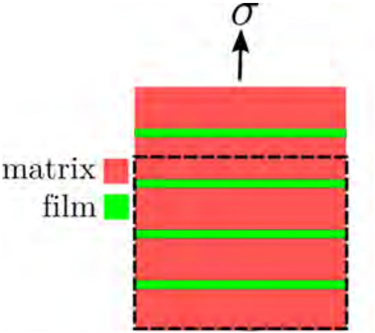

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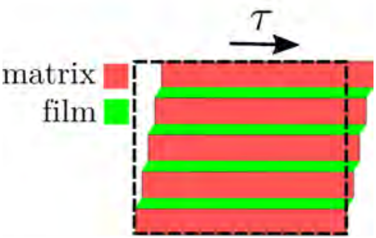

(Rezazadeh et al. 2022)

Austenite to martensite transformation

- Not all austenite transforms
- KS orientation relationship
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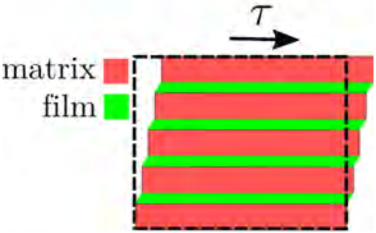

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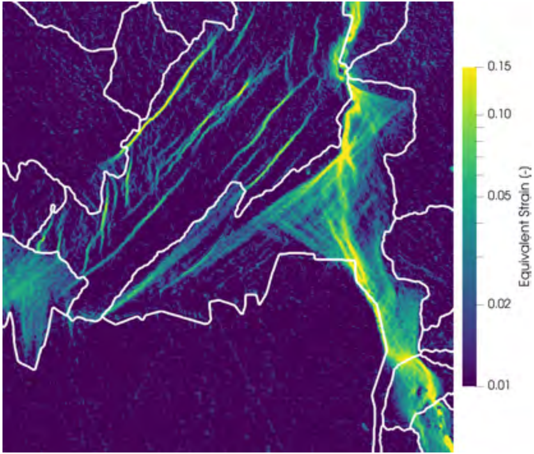
Plastic velocity gradient

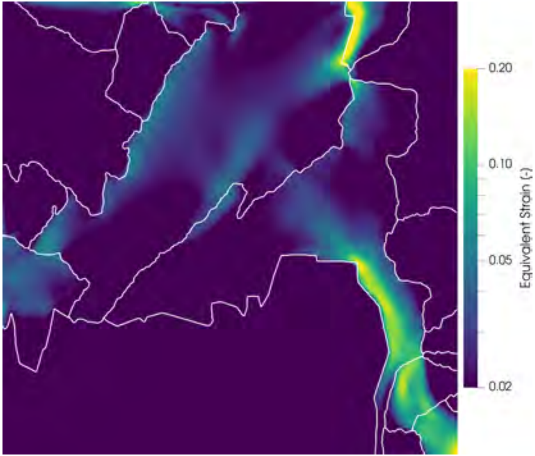
$$\mathbf{L}_p = \sum_{\alpha_\mathrm{M}=1}^{12} \dot{\gamma}^{\alpha_\mathrm{M}}\, \vec{m}_0^{\alpha_\mathrm{M}} \otimes \vec{n}_0^{\alpha_\mathrm{M}} + \phi_\mathrm{A} \sum_{\alpha_\mathrm{A}=1}^{3} \dot{\gamma}^{\alpha_\mathrm{A}}\, \vec{m}_0^{\alpha_\mathrm{A}} \otimes \vec{n}_0^{\alpha_\mathrm{A}}$$

Dual-phase steel including habit plane slip

Experiment



Simulation



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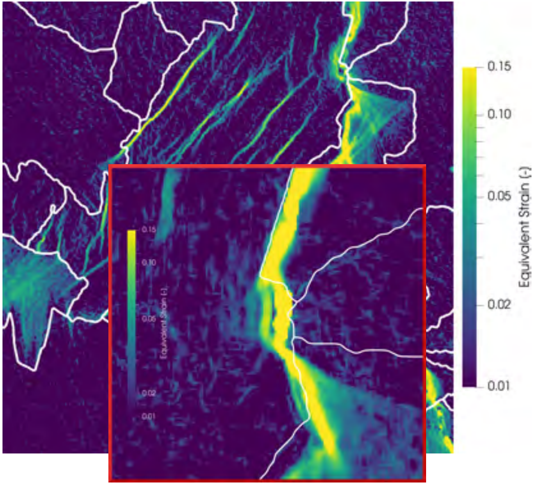
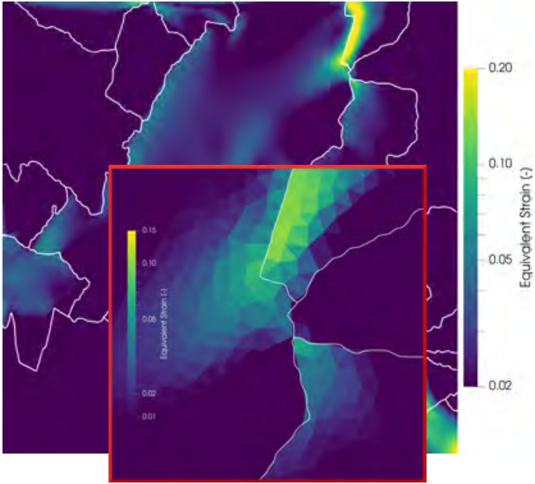
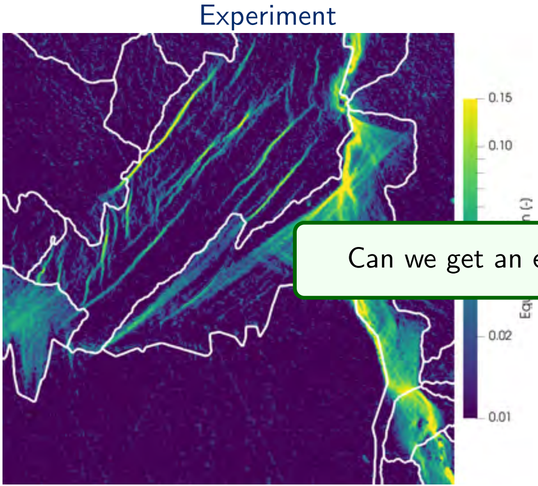
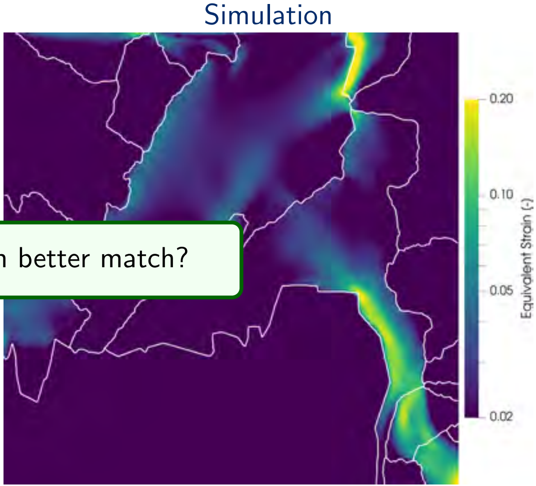


Simulation



Dual-phase steel including habit plane slip





Can we get an even better match?

The discrete slip plane model for ferrite

Crystal plasticity model with properties that are (Wijnen et al. 2021)

- Heterogeneous
- Stochastic

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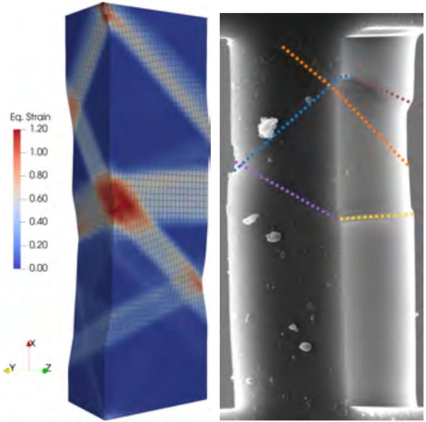

The discrete slip plane model for ferrite

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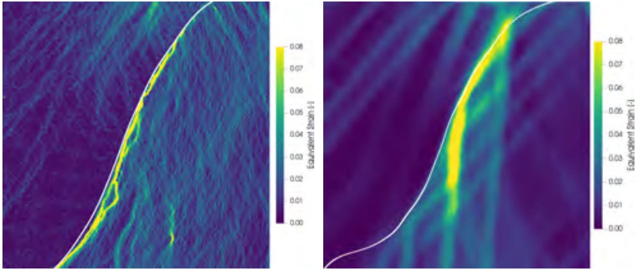
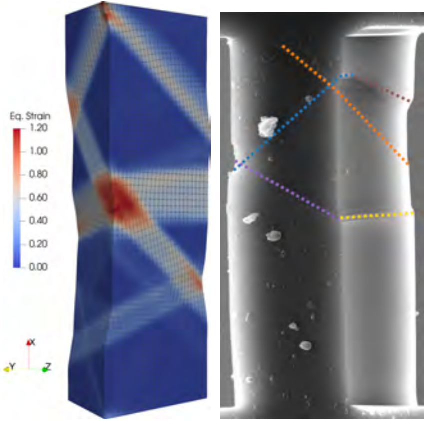
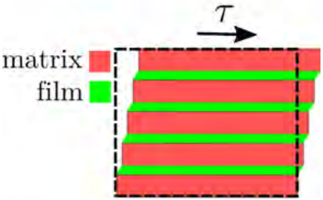
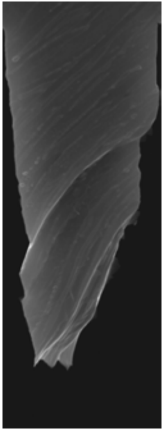
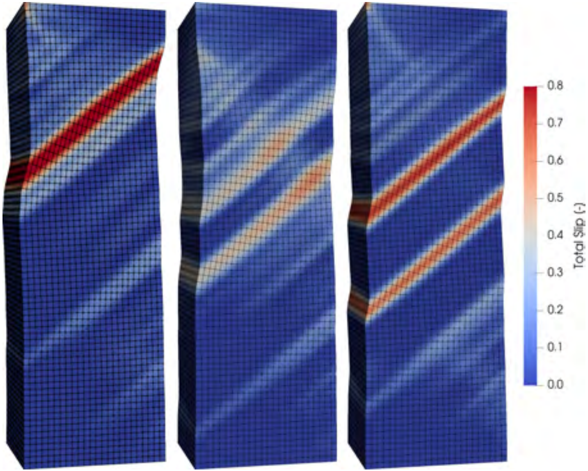




The discrete slip plane model for martensite







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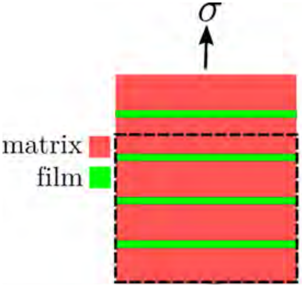
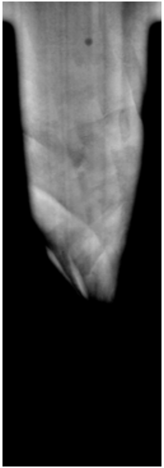
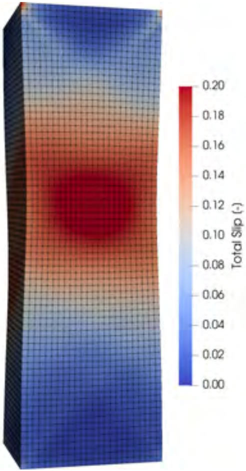
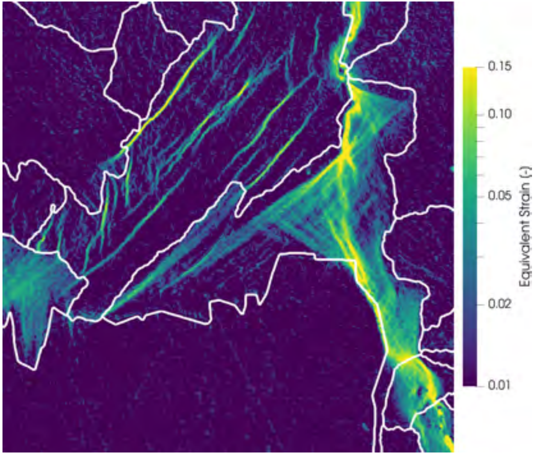




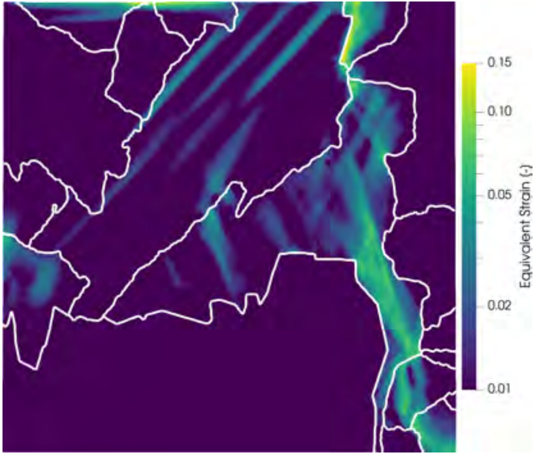


The final result

Experiment



Simulation



Summary

Integrated experimental-numerical framework

- Removes sub-surface effects
- One-to-one comparisons of simulations and experiments

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Takeaway points

- Softer substructure boundary sliding mechanism in martensite
- Stochastic effects needed for small scales

Thank you

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