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Controlling recrystallization in austenite:
a competition between nucleation sites

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- Supervisors: Jilt Sietsma, Erik Offerman, Winfried Kranendonk, Kees Bos
- Project partners: Delft University of Technology, Tata Steel

- Project no. M2i: 557079

– December 2022 –

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CONTENTS

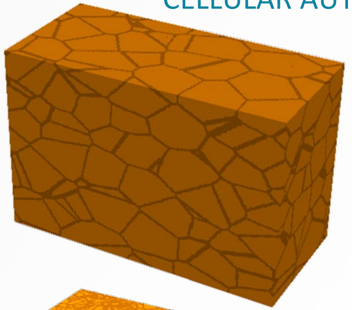
INDUSTRIAL AIM

STEEL PRODUCTION | APPLICATION

Hot Rolling mill:
Static Recrystallization (SRX)
occurs in-between passes

- Phase: austenite
- Temperature: 800-1200°C
- Reduction ≤ 20%

CELLULAR AUTOMATON (CASIPT)



Grain Size
Before SRX = 86 μm

Grain Size
After SRX = 15 μm

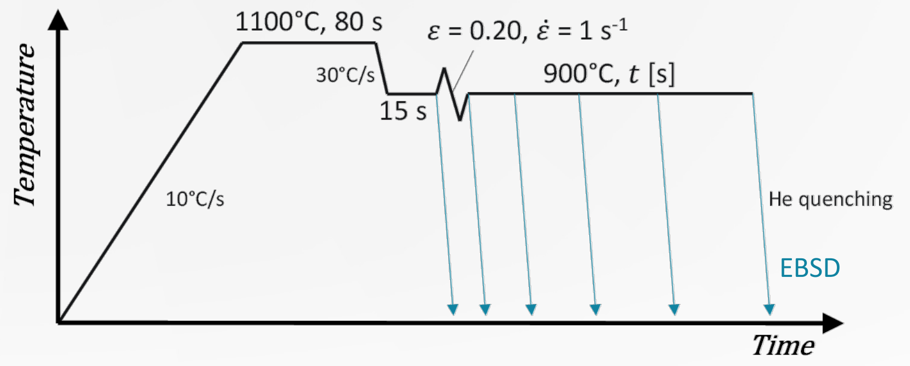
➢ Relevant outputs to predict in SRX of austenite:

- SRX kinetics
- Grain size after SRX
- Texture evolution during SRX

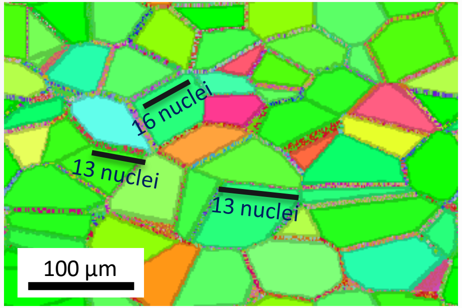
SCIENTIFIC AIM & APPROACH

- CASIPT greatly underestimates grain size after SRX: 10-15 µm (CASIPT) vs ~37 µm (exp.) (initial grain size = 86 µm)
  - Overestimation of no. nuclei per boundary: ~12-15 (CASIPT) vs ~3 (exp.)

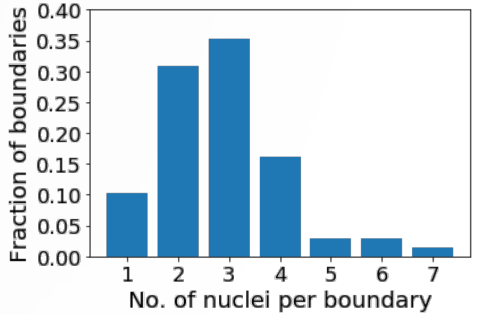
EBSD EXPERIMENTS



CASIPT



EXPERIMENTAL



- Aim of the project: develop and experimentally assess a model for SRX in austenite in CASIPT, with a focus on the prediction of nucleation rate/density

OVERVIEW OF CASIPT MODEL

GRAIN SIZE

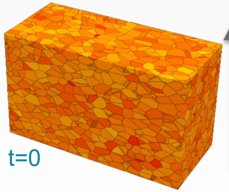
CRYSTALLOGRAPHIC ORIENTATION

DISLOCATION DENSITY

- *Grain-interior value* ρ_{grain}
- *Grain-boundary value* $\rho_{GB} = k_{GB} \cdot \rho_{grain}$

SUBGRAIN SIZE DISTRIBUTION
$\overline{D}_{SG}$, σ_{SG}

INPUTS (Grain values)



Red

Dislocation density

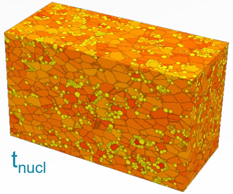
Yellow

SUBGRAIN GROWTH
$D_{SG}(t)$

NUCLEATION OF SRX GRAINS

$$D_c = \frac{\gamma_{GB}}{\Delta E_D}$$

GROWTH OF SRX GRAINS
$v_g(t)$

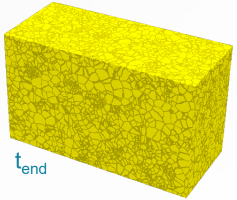


SRX KINETICS

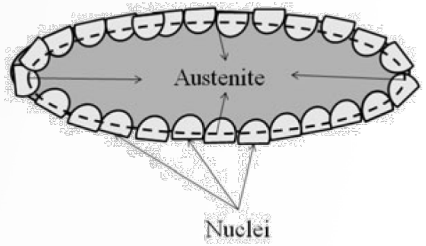
SRX GRAIN SIZE

SRX TEXTURE

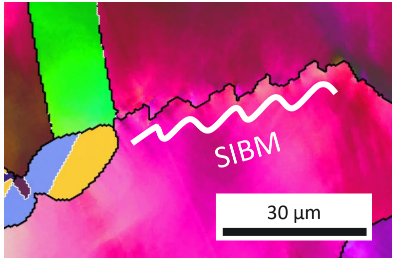
OUTPUTS



(Rehman and Zurob, *MMTA*, 2013)



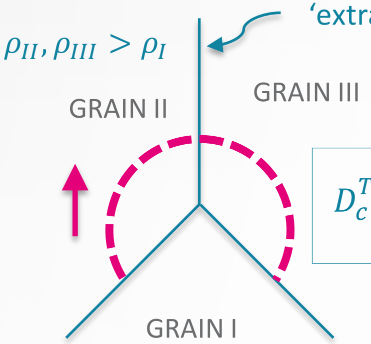
STRAIN-INDUCED BOUNDARY MIGRATION (SIBM)



Sensitivity: general

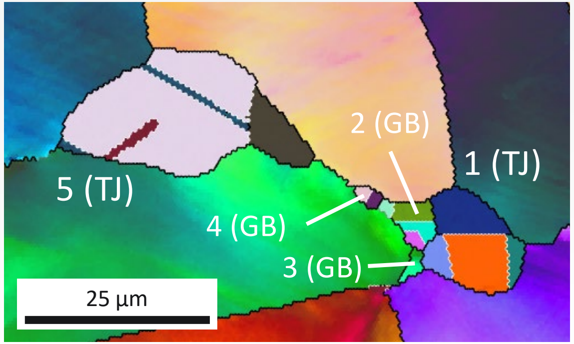
RESULTS: TRIPLE-JUNCTION NUCLEATION

- **Nuclei form first at triple junctions** (TJ), and grow to consume the boundary before many grain-boundary (GB) nuclei can form
- Earlier nucleation at triple junctions can be explained by (i) elimination of an 'extra' grain boundary energy, and (ii) higher dislocation density

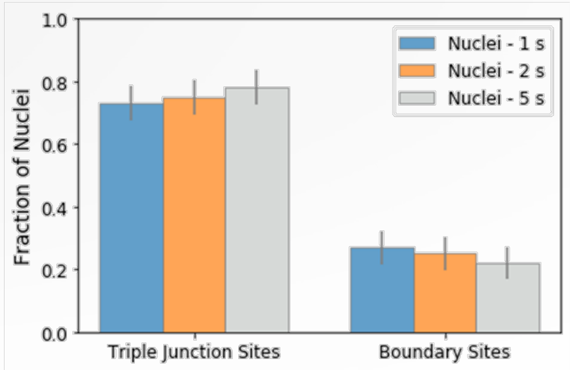


$$D_c^{TJ} = \frac{13\gamma_b}{8\Delta E_D^{TJ}} \approx \frac{1}{2} D_c^{GB}$$

ANNEALING TIME = 10 s

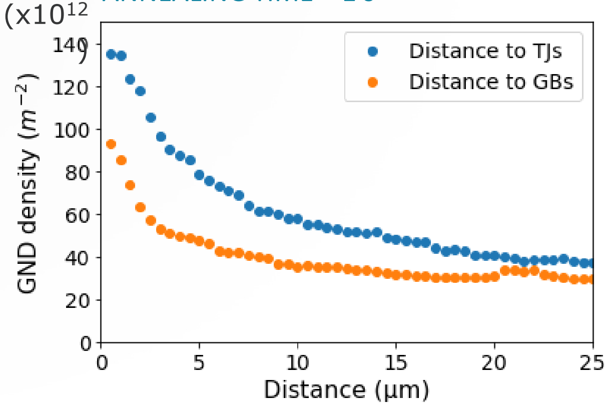


ISOLATED NUCLEI:



(Garcia-Chao *et al.*, submitted to *MMTA*)

ANNEALING TIME = 1 s

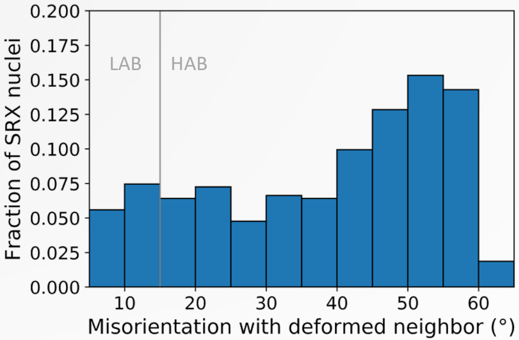


RESULTS: NUCLEI-PARENT MISORIENTATIONS

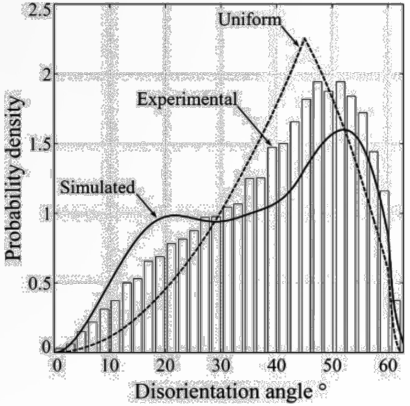
- Nuclei-parent misorientations predominantly display high-angle boundary (HAB) character – and not low-angle boundary (LAB) character, as previously thought

Annealing time (s)	% of LAB nuclei-parent misorientations
1	46,6
2	41,9
5	34,3
10	27,3

ANNEALING TIME = 10 s



MISORIENTATION DISTRIBUTION FOR FCC ROLLING TEXTURE



(Mason and Schuh, *Acta Mat.*, 2009)

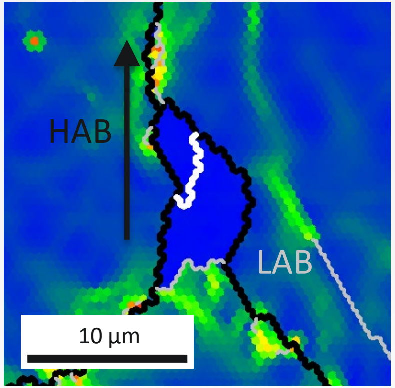
- Moreover, the fraction of LAB nuclei-parent misorientations decreases with time (!)

Sensitivity: general

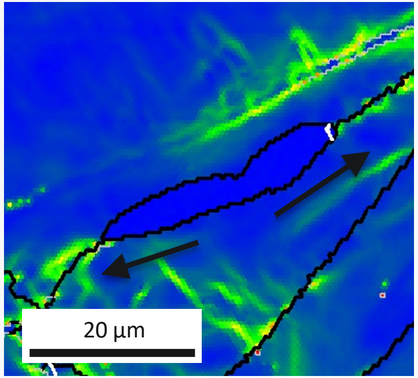
RESULTS: NUCLEATION MECHANISM

- SIBM represents a good explanation for nucleation at triple junctions…
- … However, is that also the case for grain-boundary nuclei?

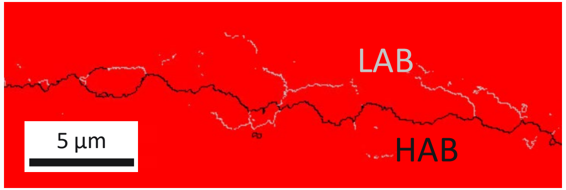
TRIPLE-JUNCTION NUCLEUS



GRAIN-BOUNDARY NUCLEUS



GRAIN-BOUNDARY NUCLEI



ANNEALING TIME = 1 s

RESULTS: NUCLEATION MECHANISM

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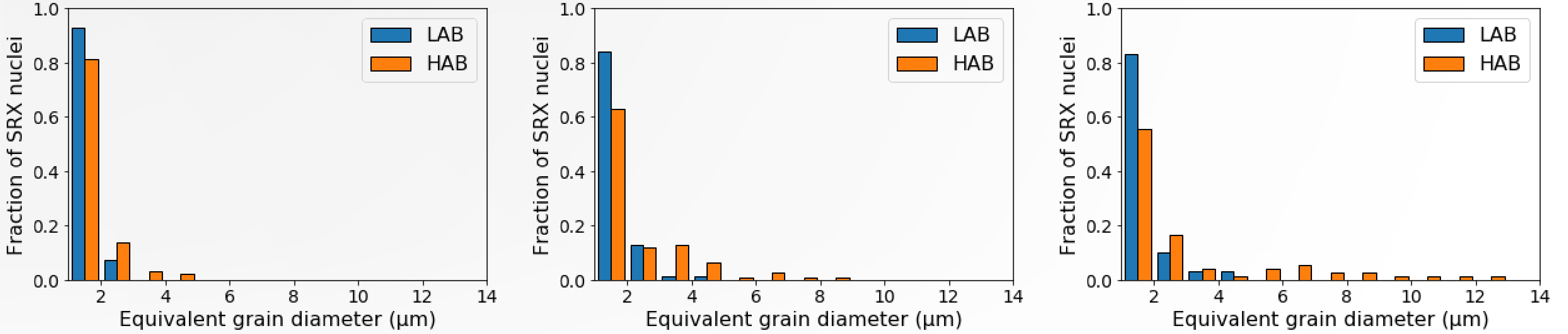
GRAIN-BOUNDARY NUCLEI:



ANNEALING TIME = 1 s

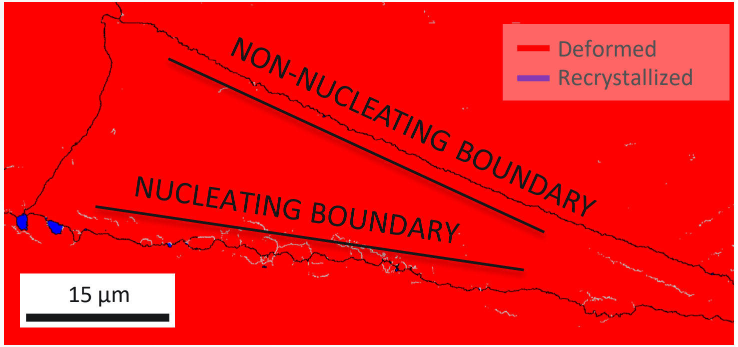
ANNEALING TIME = 2 s

ANNEALING TIME = 10 s

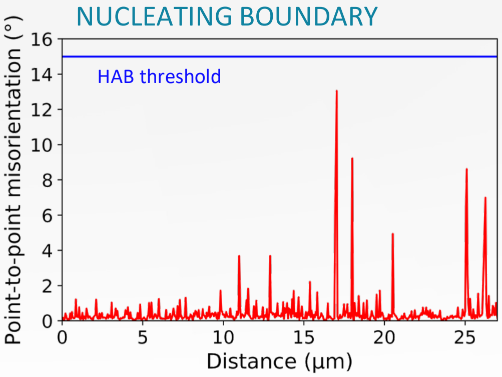
- For grain-boundary nuclei, the transformation from LAB to HAB may be a better nucleation predictor than SIBM

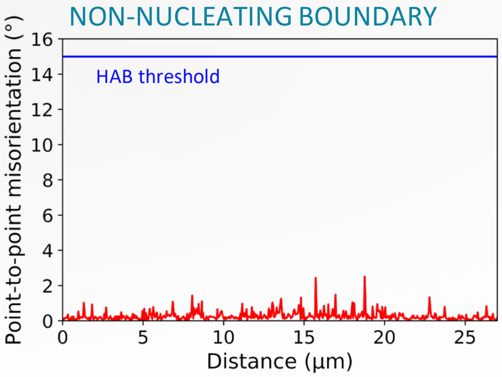
RESULTS: NUCLEATING BOUNDARIES

- Nucleating and non-nucleating boundaries exhibit a similar amount of relatively large subgrains
- Nucleating boundaries differ from non-nucleating boundaries in: (i) higher dislocation density, and (ii) a few relatively high subgrain misorientations (5-15°)



ANNEALING TIME = 1 s





	Nucleating	Non-nucleating
Dislocation density (m^{-2})	$1.9 \cdot 10^{15}$	$1.4 \cdot 10^{15}$
Subgrain size D_{SG-X} (µm)	0.43	0.62
$D_{SG-X} \geq \bar{D}_{SG-X} + 3\sigma_{SG-X}$ (fraction of subgrains)	0.03	0.04
$D_{SG-X} \geq \bar{D}_{SG-X} + 2\sigma_{SG-X}$ (fraction of subgrains)	0.05	0.06

CONCLUSIONS

- Application of a nucleation model based on strain-induced boundary migration (SIBM) at homogeneous grain-boundary sites to a realistic microstructure overestimates nucleation density

- For a given grain boundary, nucleation predominantly starts at the triple junctions (triple-junction nuclei grow and consume the adjacent grain-boundary sites)

- Nucleation at triple junctions starts via SIBM; however, nucleation at grain-boundary sites require further transformation of the parent-nucleus boundary from a low-angle (LAB) to a high-angle boundary (HAB)

- Nucleation-active boundaries are characterized by relatively high dislocation density and large subgrain misorientations

Thank you for your attention!!

Questions?

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