Simulating the recrystallization kinetics of ultrafine grained aluminum using a multiphase field model, and the evolution of the structure and properties

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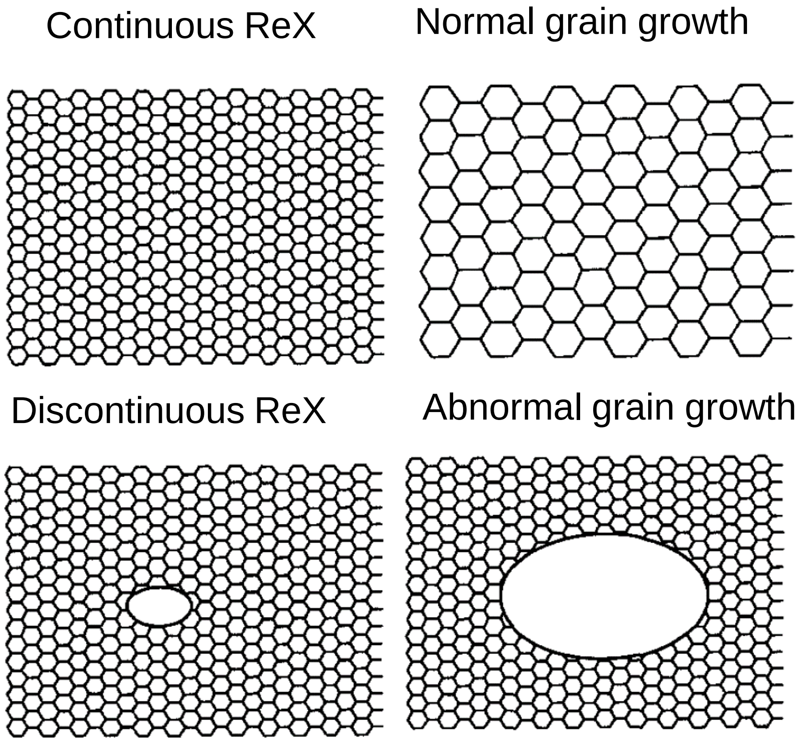
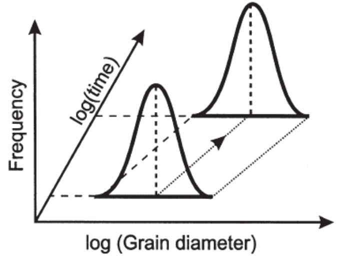
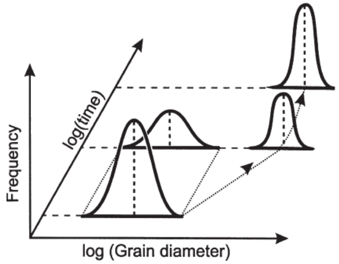
Introduction



- Normal grain growth



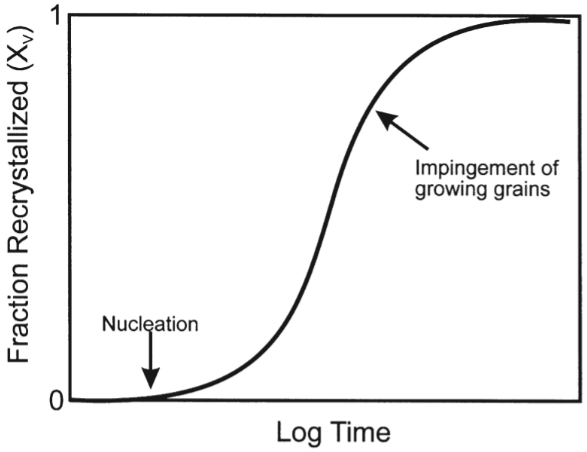
- Abnormal grain growth

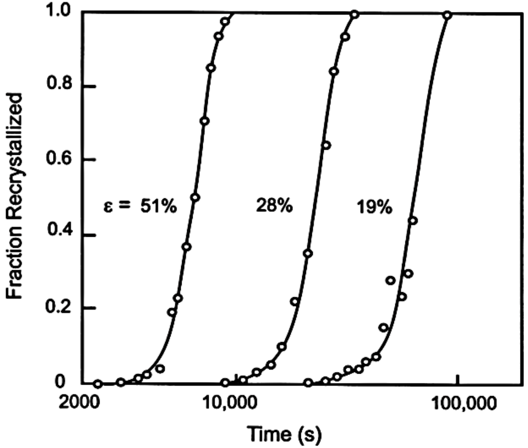


Schematic representation of the change in grain size distribution (After Detert 1978).

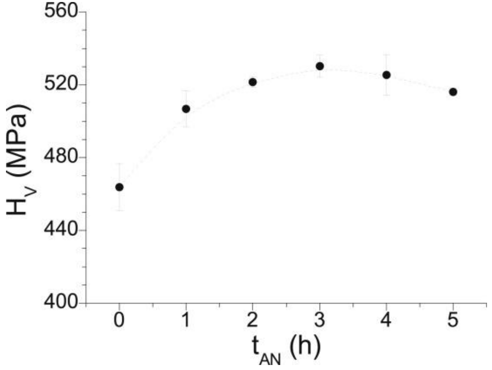
Introduction. ReX kinetics after conventional deformation and SPD-processed material.

Typical recrystallization kinetics during isothermal annealing of an coarse grain deformed material





Microhardness recover during ReX of pure Al after SPD by HPT*



Avrami-Johnson-Mehl-Kolmogorov equation

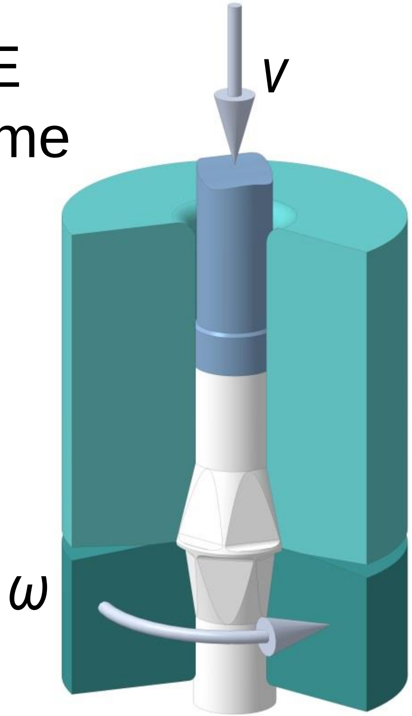
$$X_v = 1 - \exp(-Bt^n)$$

*T.S.Orlova, et al., J.Al.Com., vol. 784, pp. 41–48, 2019

- Additional hardening and strengthening after short-time annealing in pure Al
- Low angle boundaries (2°<Θ<15°) are characterized higher thermal stability than high angle boundaries (Θ>15°)

Experimental part. High pressure torsion extrusion In cooper. with J. Ivanisenko group, INT

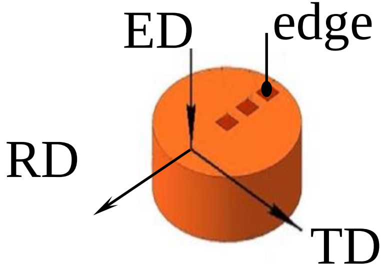
HPTE scheme



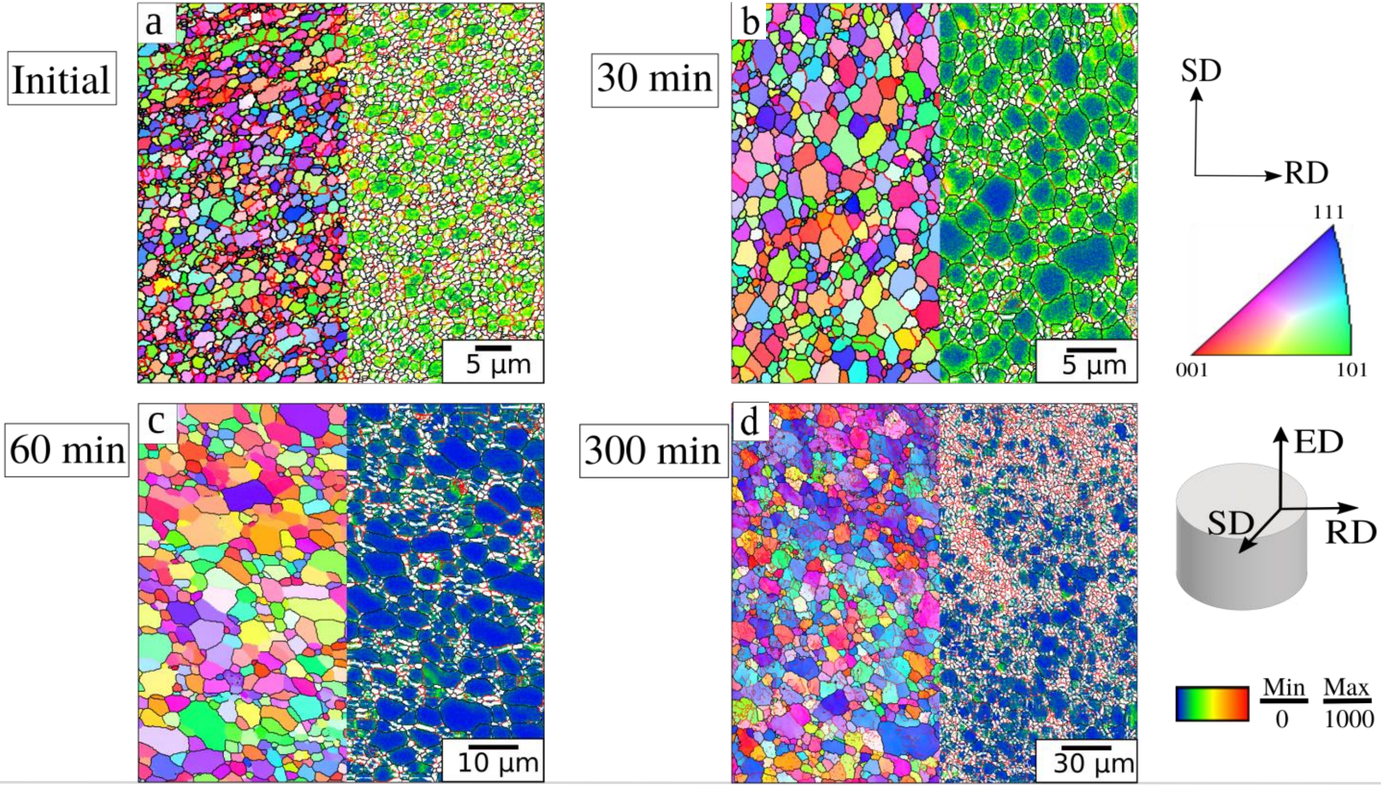
- **Material**: HPTE- processed pure Al
- **HPTE regime: $v1w1$** at RT
- υ- translation velocity, υ =1 mm/min
- ω – rotation velocity, ω =1 rot/min
- **Static recrystallization:** isothermal, annealing at **300°C** during **10, 30, 60** and **300** min. Quenching to water.
- **Material characterization:**
  SEM EBSD, X-ray diffraction, Microhardness

Controlling parameters

- (Sub)grain size
- Misorientation angles
- Dislocation density



Experimentally obtained microstructure of pure Al



Distribution of D15 parameter with respect to the specific area s_i/S

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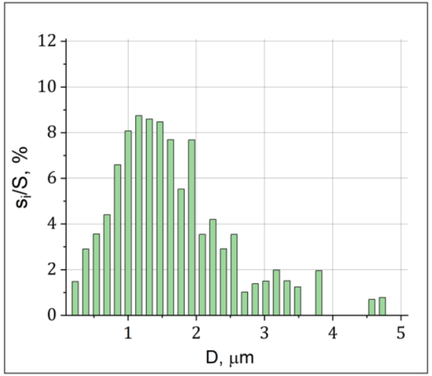
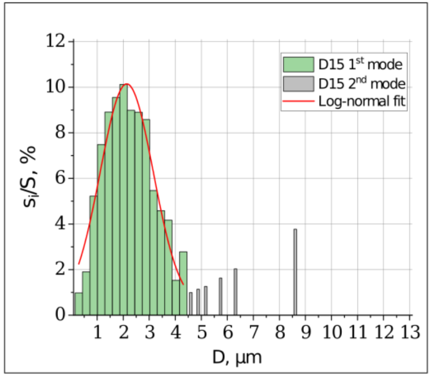
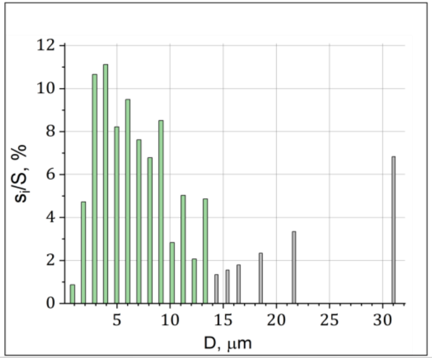
initial



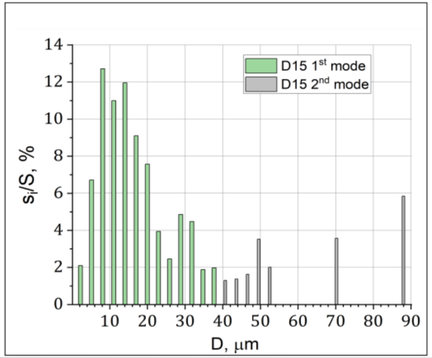
30 min



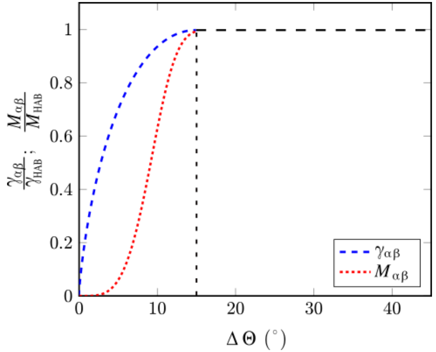
60 min



300 min



Surface energy and mobility as a function of misorientation in Al at 300°C



Phase-field model simulation of the recrystallization kinetic in pure aluminum structure

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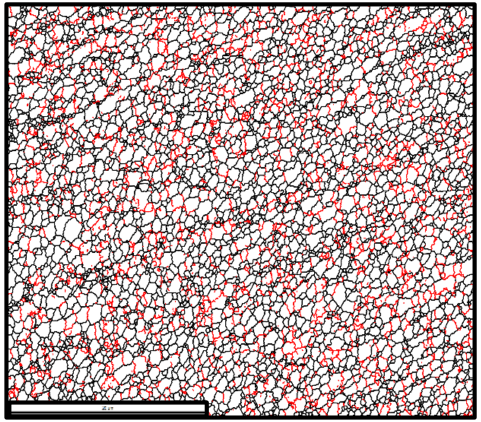
Distribution of the stored energy is defined from GND density distribution and from GB curves

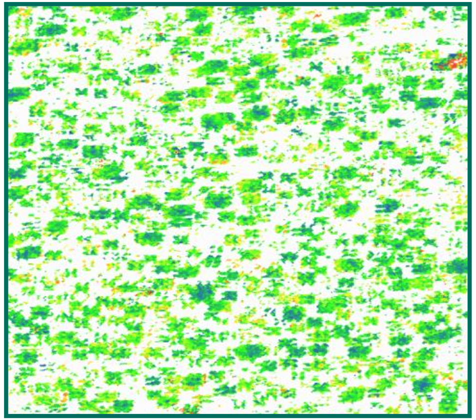
Initial GB



Initial places of the high SE match with the initial grains with high GND density.

+

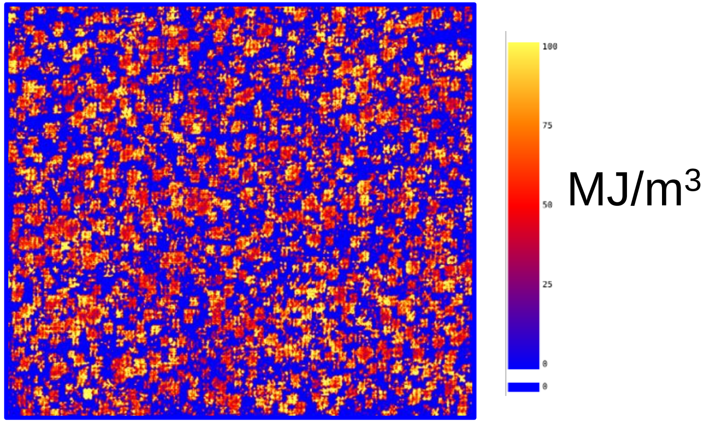
GND



Min	Max	Total Fraction	Partition Fraction
0	300	0.415	0.415

=

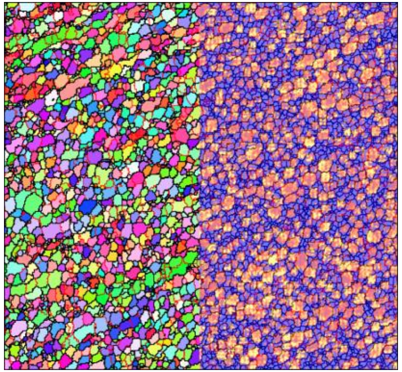
Stored energy



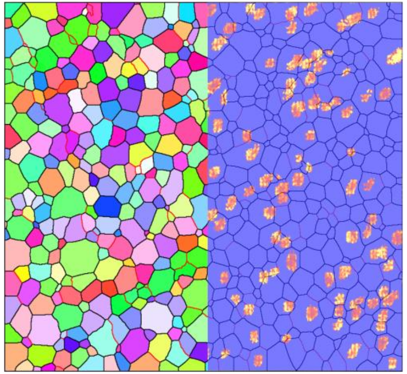
$$W_{\text{bulk}}(\rho_d) = \frac{1}{2}\rho_d G b^2$$

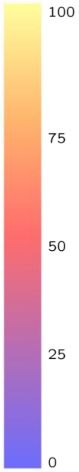
PFM simulation in PACE 2D. Oriented image maps and stored energy distribution during the ReX simulation

Imported structure



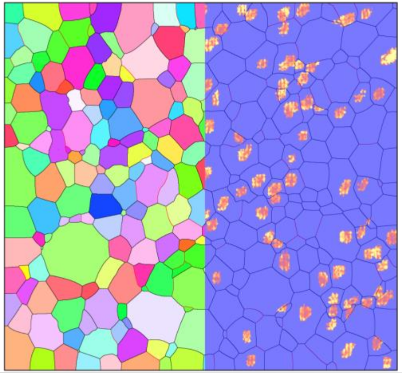
400(x100)



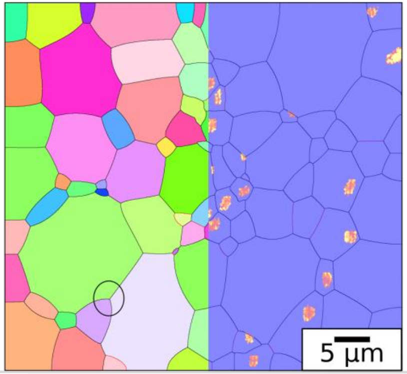


SE full down very quickly:
after first simulated steps the number of the places with high SE became in three times smaller

564(x100)



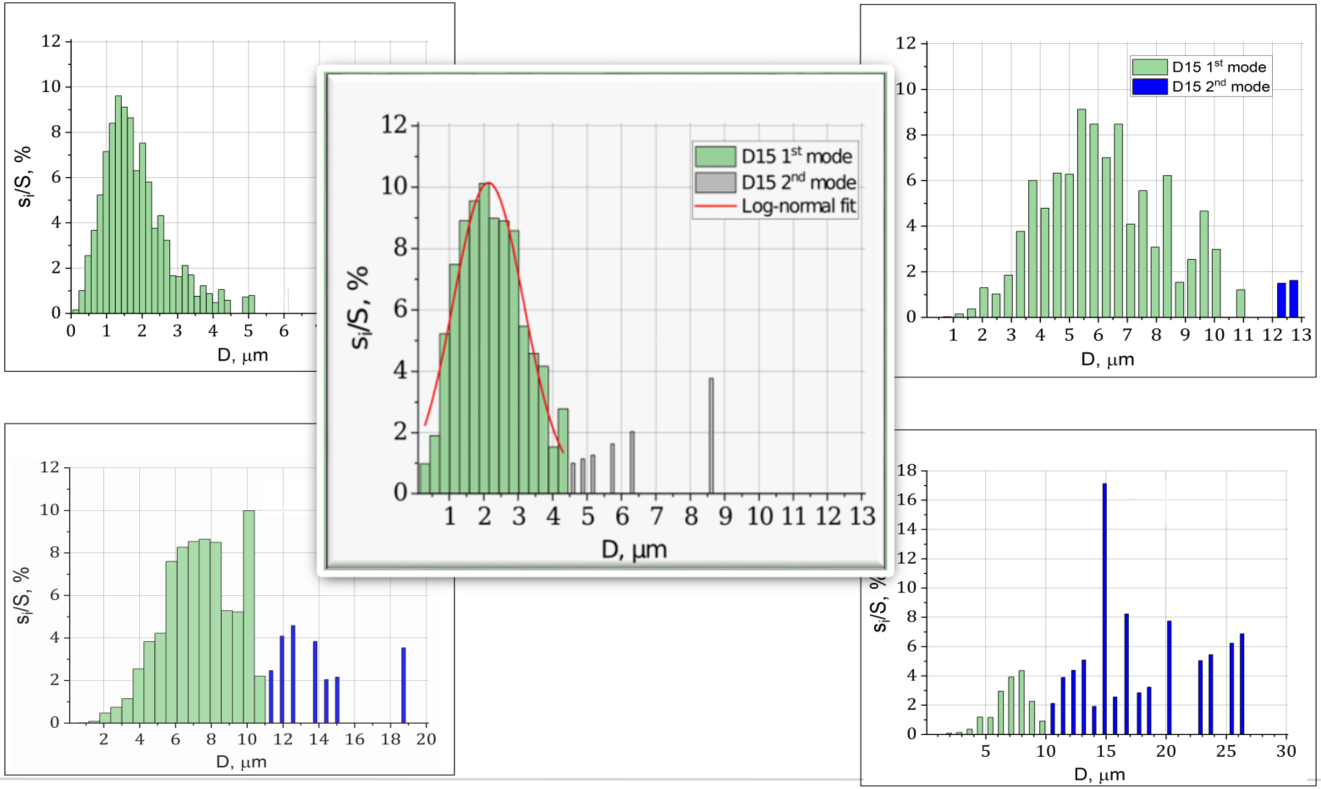
1212(x100)



PFM simulation in PACE 2D. Distribution of D15 parameter with respect to the specific area s_i/S

9(x100) step

564(x100)



Combination of the crystal plasticity with MPFM simulation to calculation of the stress-strain curves of the pure Al under the simple stress conditions

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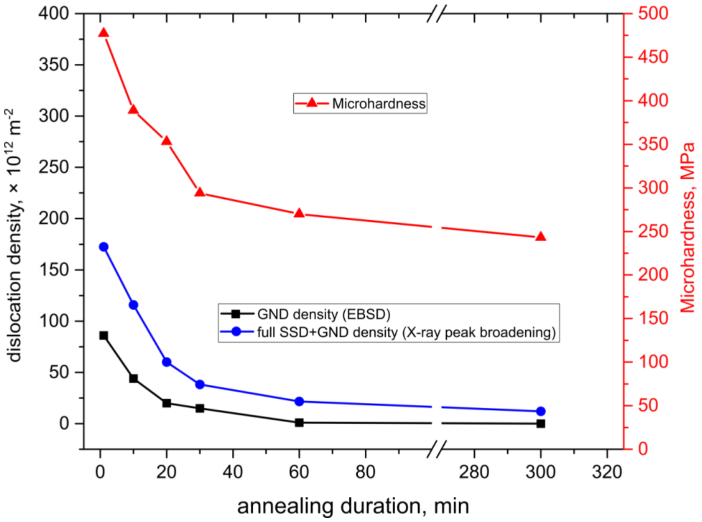
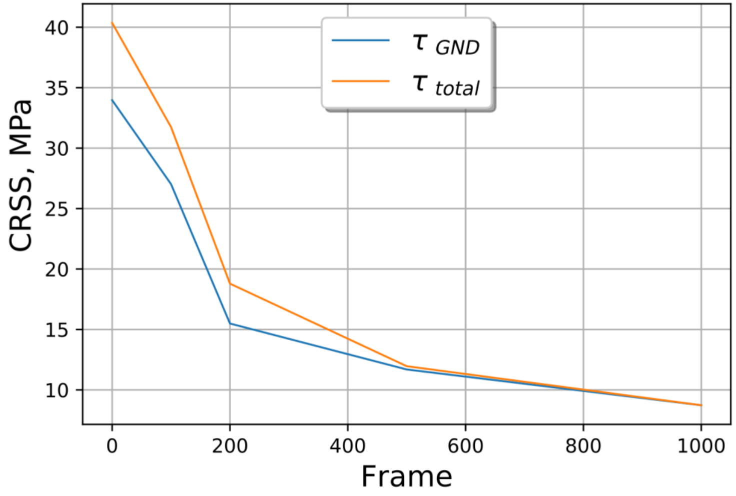
ReX kinetic



$$\tau_1 = C_1 M G b \sqrt{\rho_{GND}} \qquad \tau_2 = C_2 M G b \sqrt{\rho_{total}}$$

$$\rho_{total} = \rho_{GND} + \rho_{SSD}$$

CRSS for <111>(111) slip system is defined:*,**



*R. Honeycomb, Plastic Deformation of Metals. 1968.
**U.F. Kocks, J. of Engin. Mater. and Techn. 1976

Simulated true strain-true stress curves for compression in ED direction

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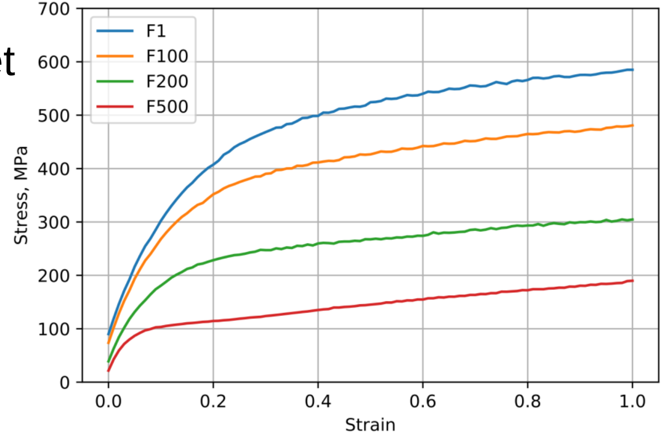
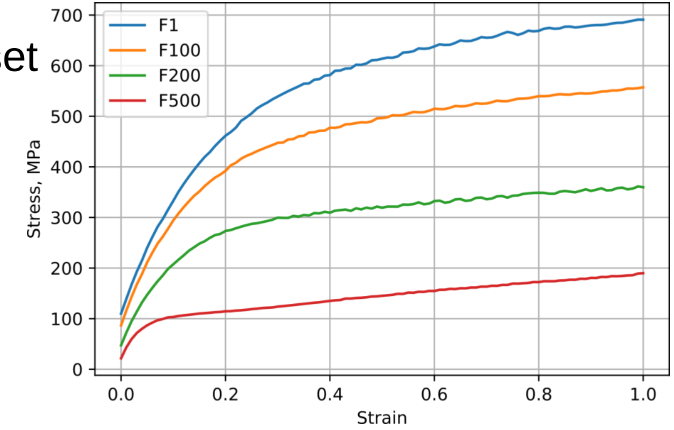
τ_{01} set



τ_{02} set



Simul. frame	ρ_{GND}		$\rho_{GND} + \rho_{SSD}$		State	HV_{exp}, MPa	YS_{exp}~$0.3HV_{exp}$, MPa
	τ_{01}, MPa	YS_{simul_1}, MPa	τ_{02}, MPa	YS_{simul_2}, MPa			
initial	33,97	119,10	40,36	138,60	initial	477	143.1
F100	27,02	102,20	31,74	115,60	10 min	389	116.7
F200	11,69	63,08	18,79	72,10	30 min	353	105.6**
F500	8,73	42,96	8,73	42,96	60 min	270	81

Summary and outlook

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- ReX process replicated by digital twin using PFM Multistage grain growth: nucleation and growth in UFG structure Normal and abnormal grain growth predicted by some model
- The combination of PFM and crystal plasticity through VPSCM enables the creation of a database for stress-strain curves. It facilitates the assessment of how tensile properties change during recrystallization (ReX) and the subsequent recovery of strength to the non-deformed state.
- This approach offers a valuable opportunity to establish a database for stress-strain curves of structural metals and alloys that have undergone various deformation modes (tension, compression, torsion) and recrystallization processes at a wide range of temperatures.

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Thank you for your attention!