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Metallic Materials with High Structural Efficiency

DYNAMIC RECRYSTALLIZATION OF LOW STACKING FAULT ENERGY METALS

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Outline

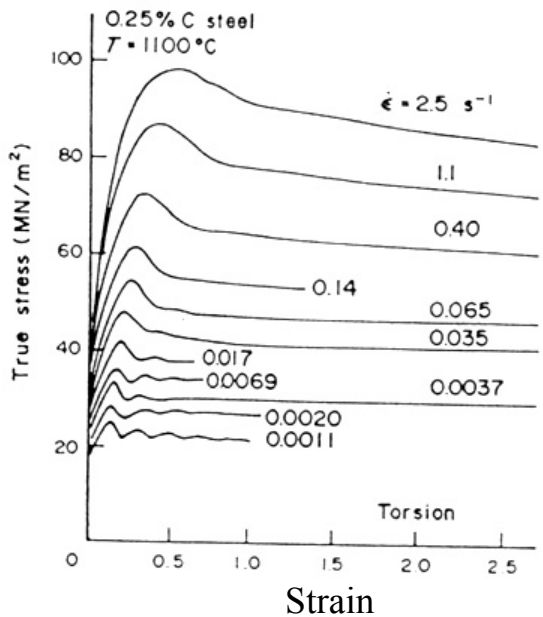
- Continuous and discontinuous dynamic recrystallization (DRX)
- DRX in a high purity base austenitic stainless steel
- DRX in a 718 grade nickel base superalloy. "Continuous nucleation"
- Conclusions

Continuous vs. discontinuous dynamic recrystallization

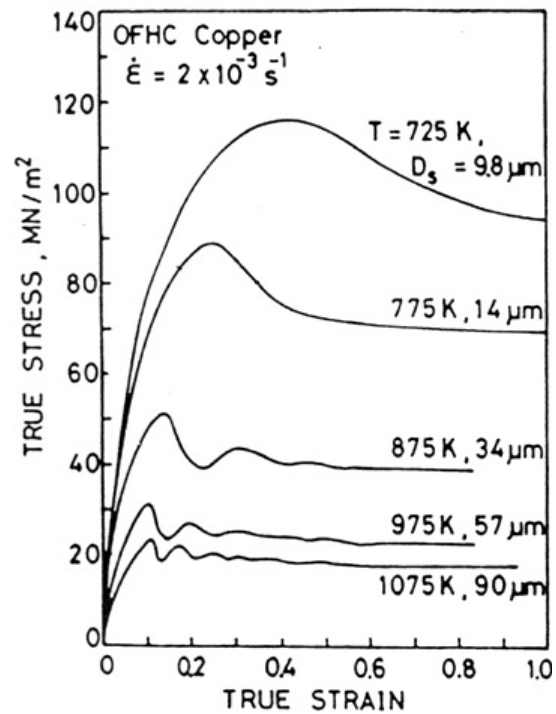
DDRX or "classical" DRX	**CDRX** or "rotation", "apparent", "*in situ*" DRX, or "extended dynamic recovery"
occurs by local (rapid) cycles of strain-hardening → nucleation → growth of new grains	occurs by progressive (slow) transformation of subgrain boundaries (LAGB) into grain boundaries (HAGB)
- dynamic recovery is weak	- dynamic recovery is strong (dislocation rearrangement and annihilation)
- dislocation densities are inhomogeneous (strong $\Delta\rho$)	- dislocation densities are homogeneous (weak $\Delta\rho$)
- the rate of grain boundary migration is high	- the rate of grain boundary migration is low
low stacking fault energy materials: Cu, γ-iron and austenitic steels, Ni-base superalloys, ...	high stacking fault energy materials: Al, α-iron and ferritic steels, β-titanium, ...

DDRX: transition from multiple peak (low Z) to single peak (high Z) DRX

$$Z = \dot{\varepsilon} \exp\left(\frac{Q}{RT}\right)$$



[Rossard & Blain, 1959]



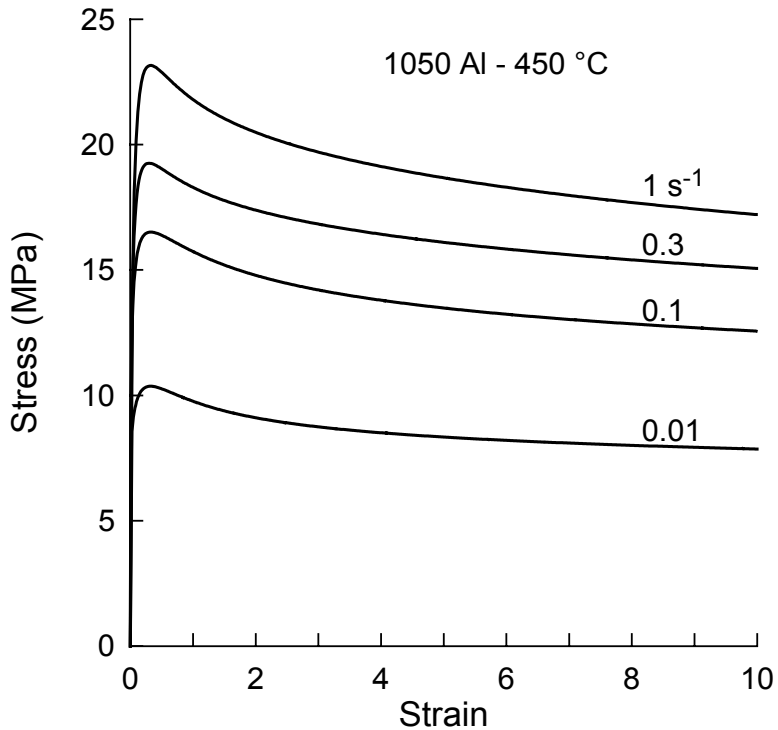
[Blaz et al., 1983]

Grain refinement

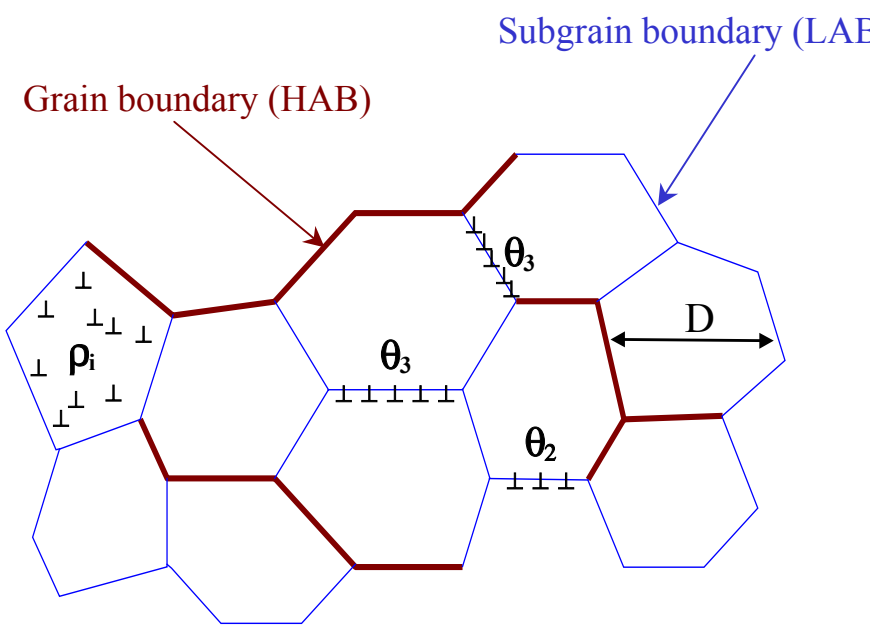
Increasing Z

Grain growth

CDRX: "Smooth" stress-strain curves

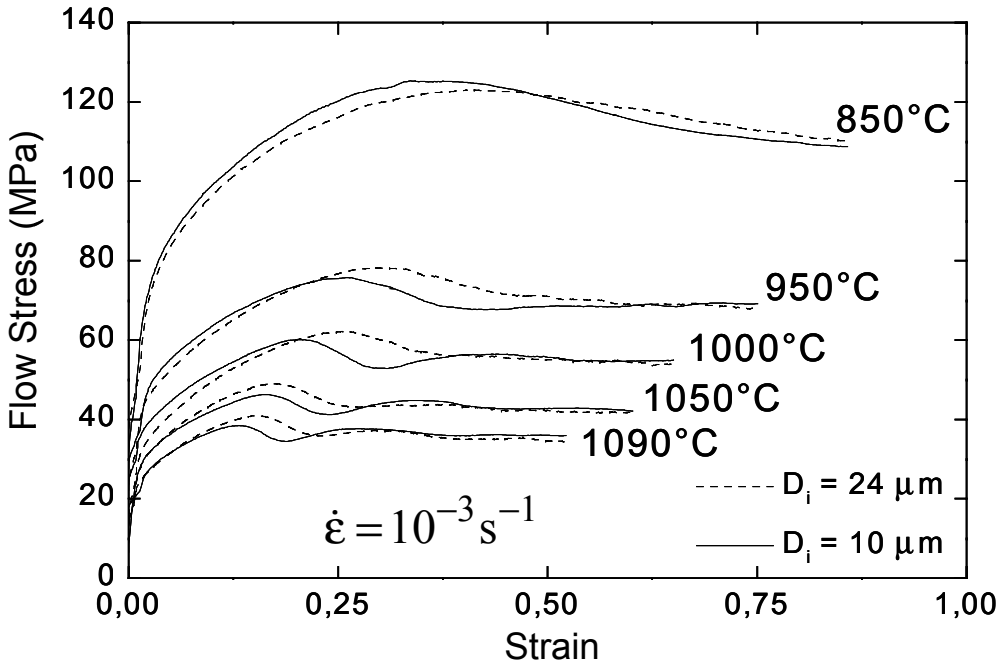


Schematic representation of the CDRX crystallite microstructure



[Gourdet & Montheillet , 2003]

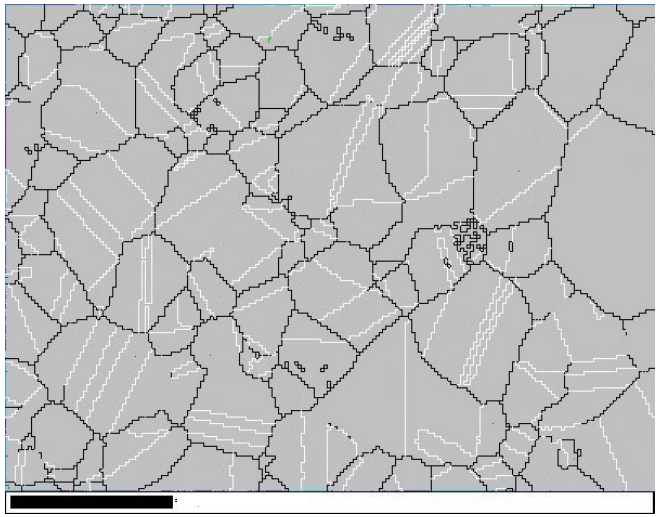
DRX in a high purity base austenitic stainless steel
close to the A304 grade (18 %Cr, 12.2 %Ni, 15 ppm C, 10 ppm S, and 10 ppm N)
[Gavard, 2001]



$Q \approx 400$ kJ/mol

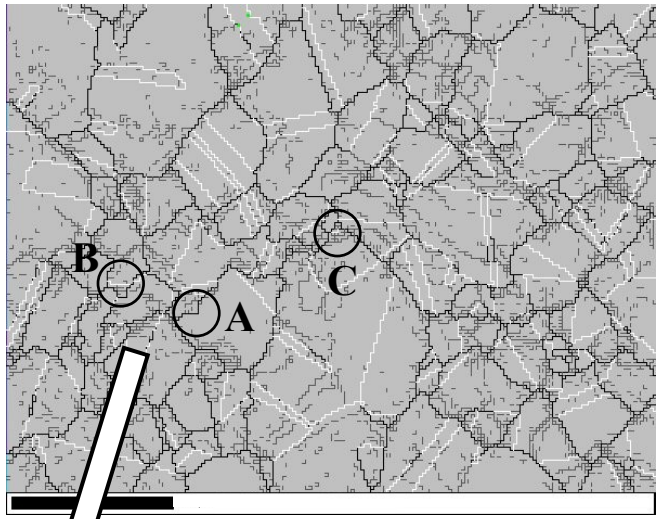
Multiple to single peak transition
$Z \approx 10^{13} - 10^{14}\ s^{-1}$

Microstructural changes – 850 °C, 10^{-3} s^{-1}



50 µm

initial state

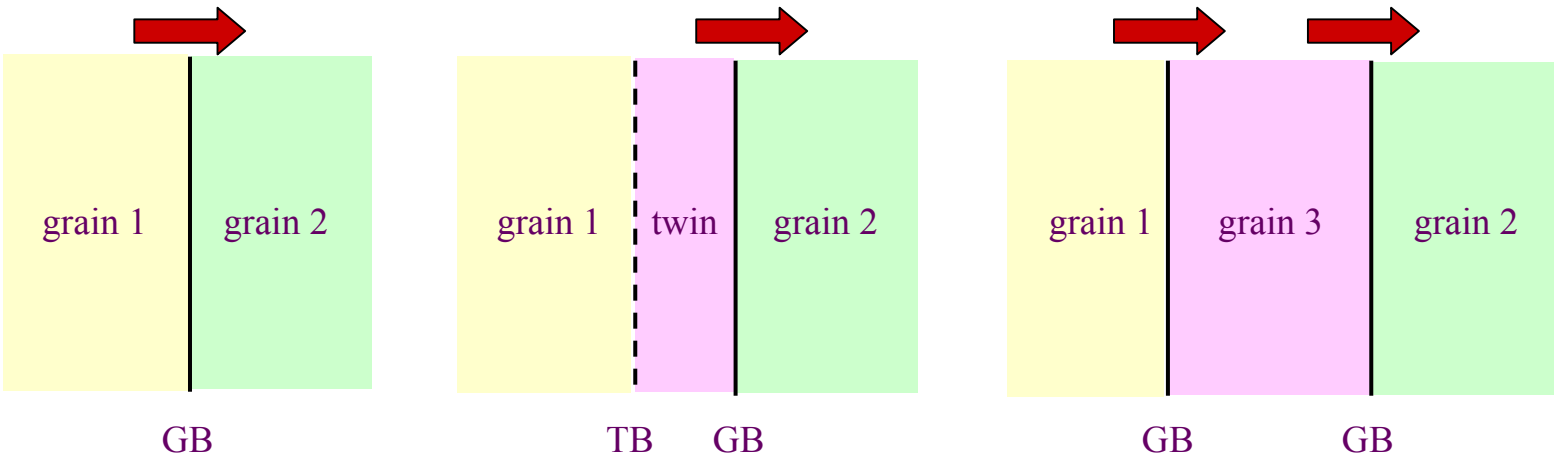


ε = 0.1

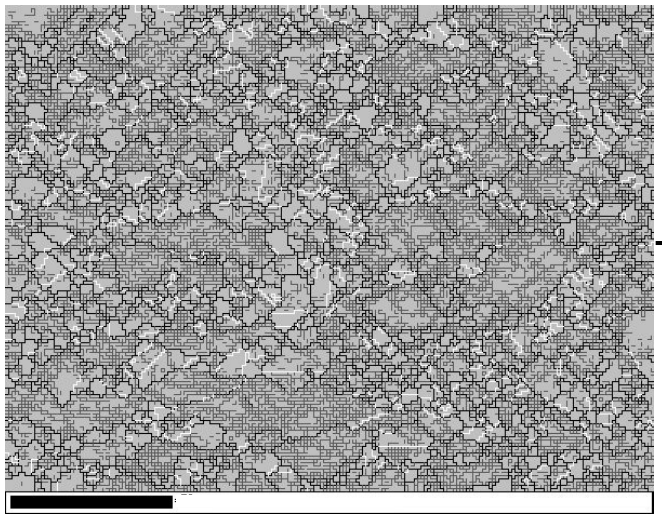
Nucleation by
(initial) grain boundary bulging
and (growth) twinning

Nucleation by (growth) twinning

increasing time and strain →

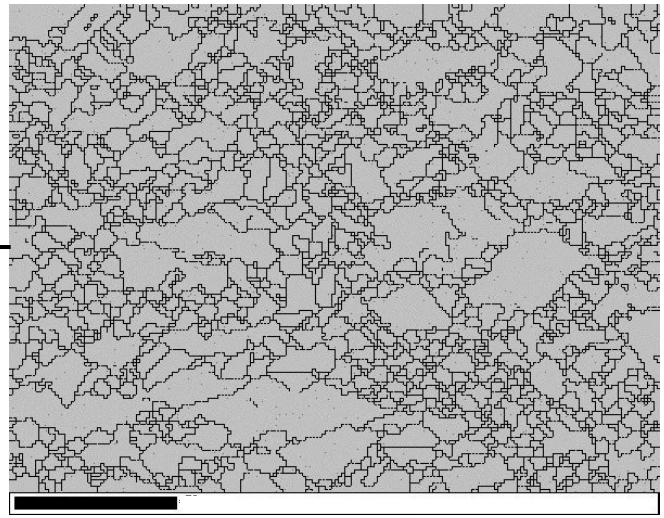


Microstructural changes (cont'd)



50 µm

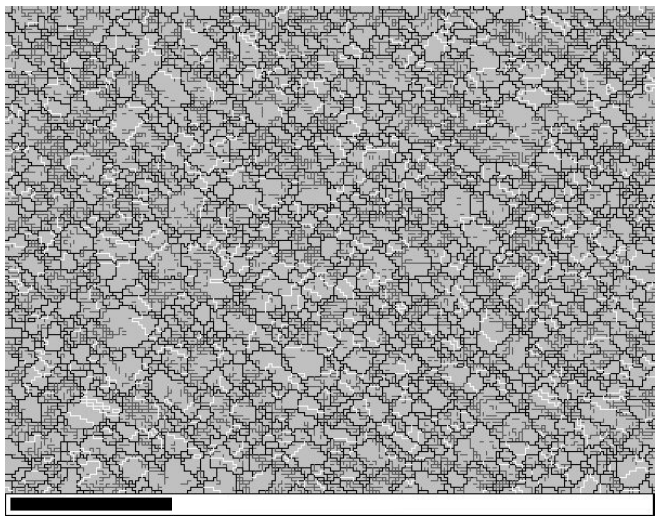
ε = 0.7



same area without SGB

Necklace DRX

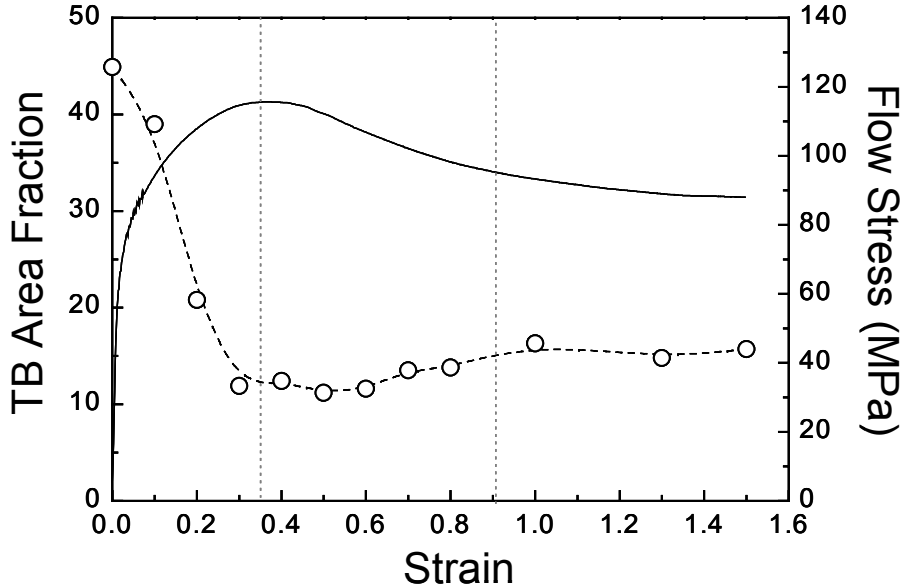
Mixture of "young" and "old" grains



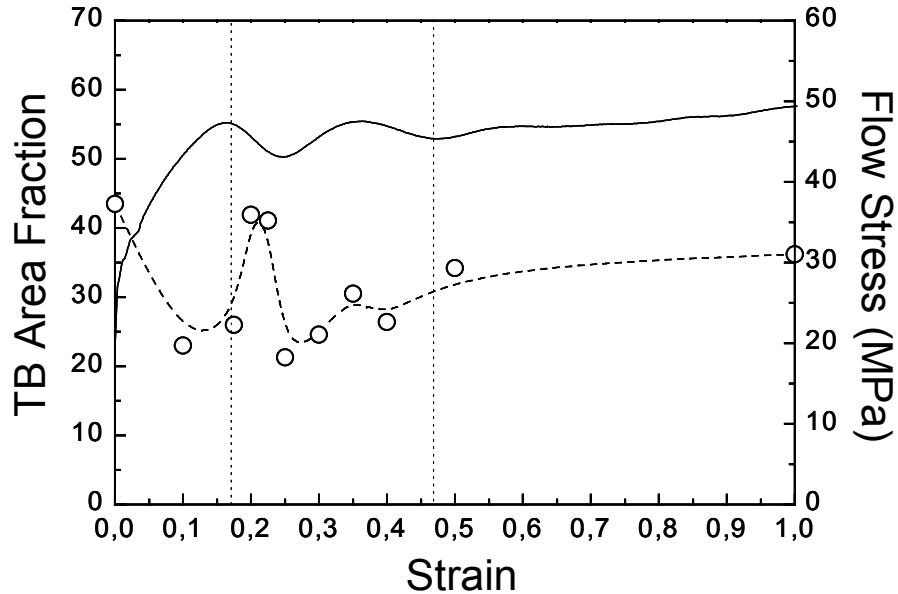
ε = 1.5 (≈ steady state)

Evolutions of the twin boundary area fractions

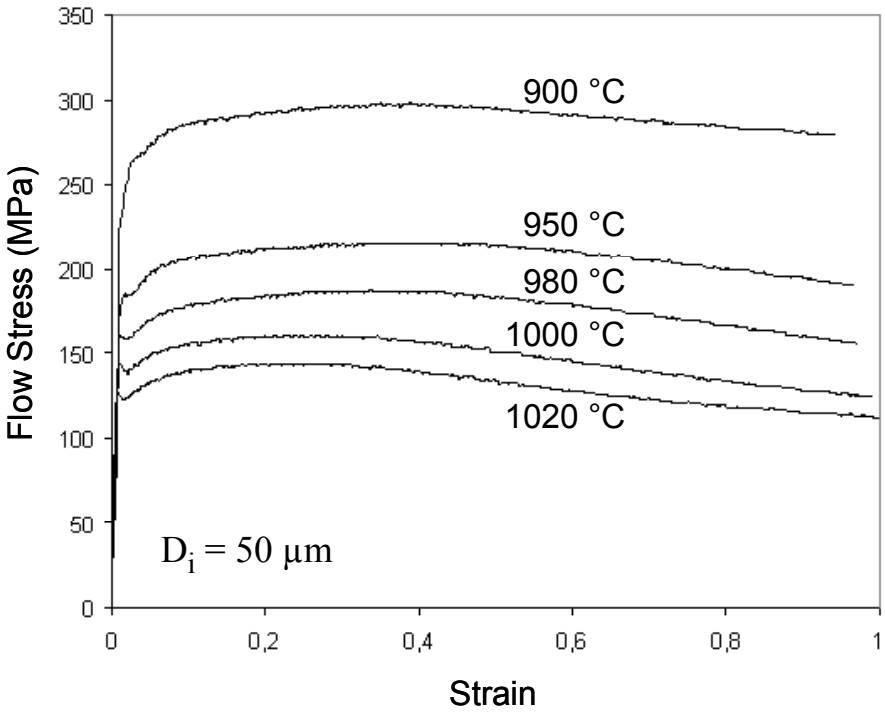
Single peak case
(850 °C, 10^{-3} s^{-1})



Multiple peak case
(1050 °C, 10^{-3} s^{-1})



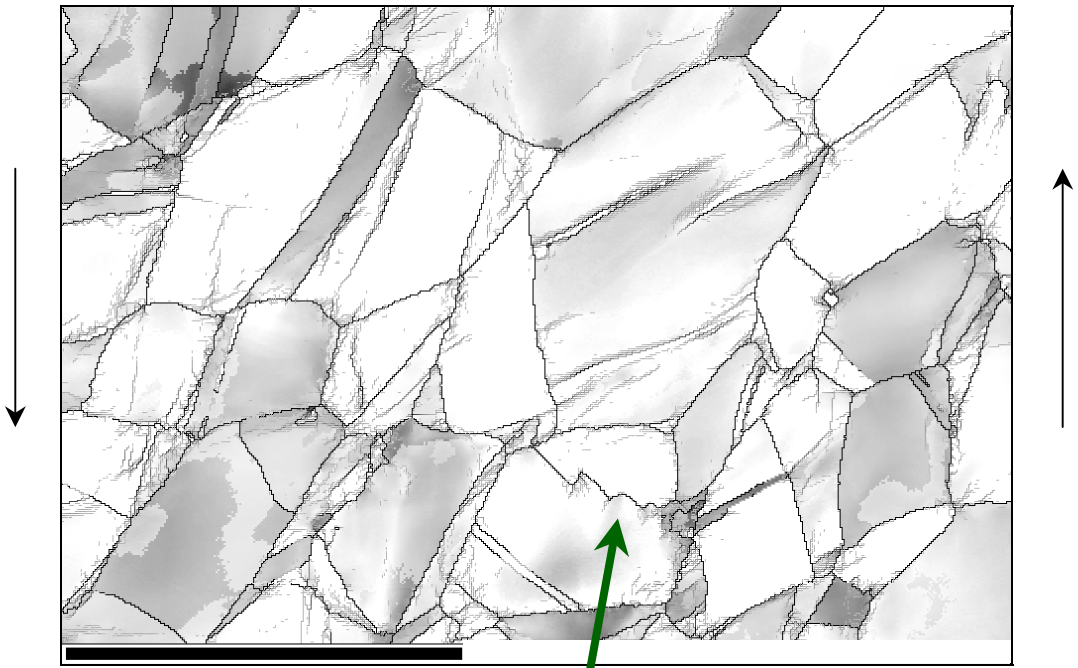
DRX in a 718 grade nickel base superalloy (after solution treatment of δ Ni_3Nb phase)



Q ≈ 400 kJ/mol

Single peak type
Grain refinement

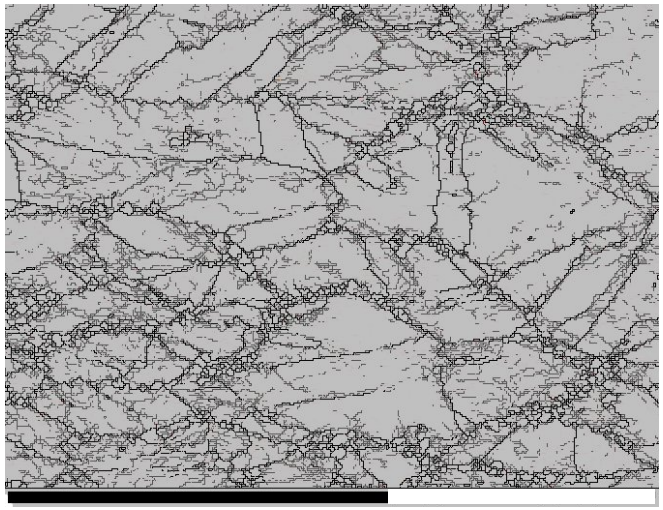
Fragmentation of the initial microstructure
(torsion at 900 °C, = 10^{-2} s^{-1}, $\varepsilon = 0.4$)



500 μm

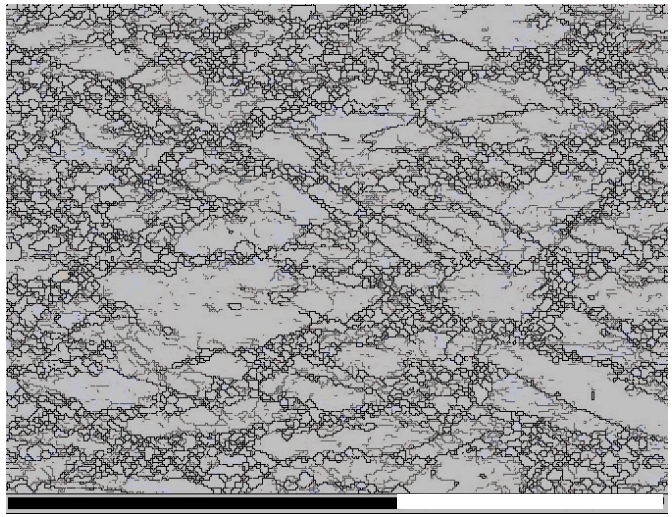
nucleation by (initial) grain boundary bulging

Microstructural changes – 980 °C, 10^{-2} s^{-1}

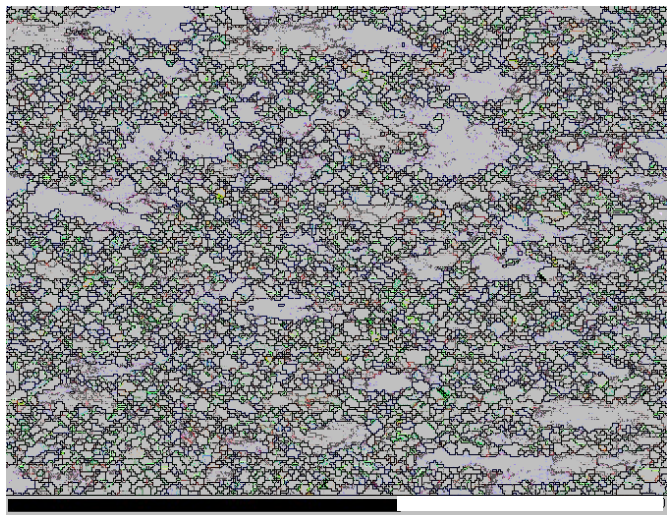


200 μm

ε = 0.4

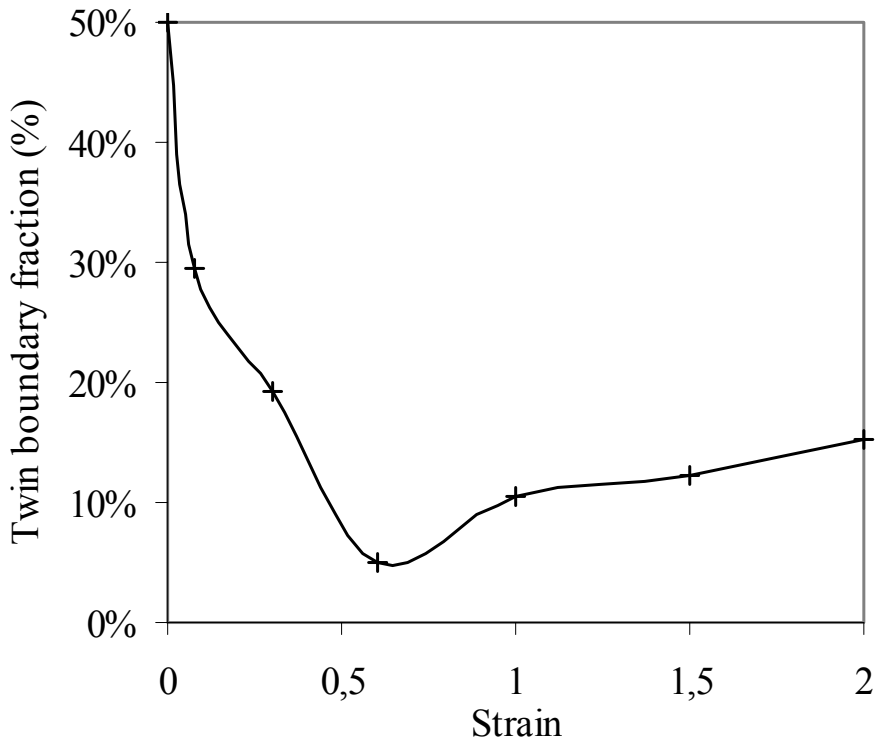


ε = 0.7



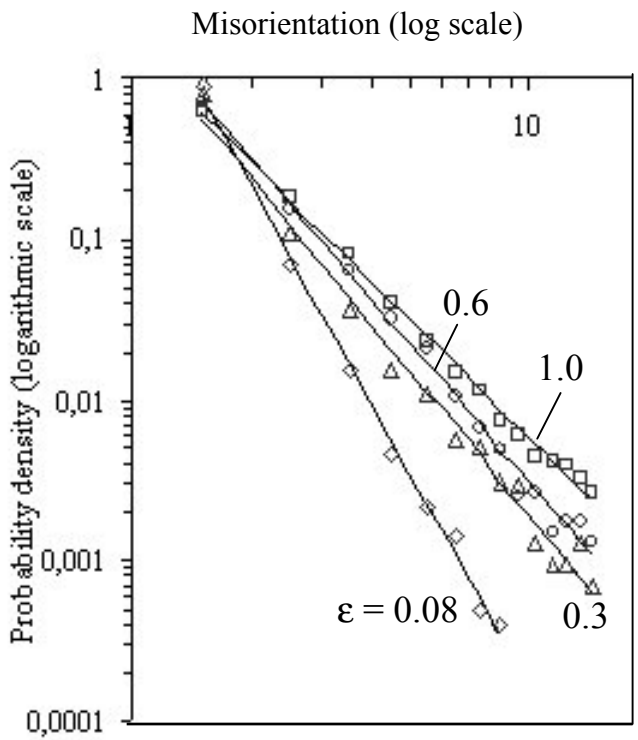
ε = 1.0

Evolution of the twin boundary area fraction



nucleation by (growth) twinning

Strain dependence of the subgrain boundary misorientation distributions



$$\varphi(\theta) = k\,\theta^{-q}$$

where q increases with strain

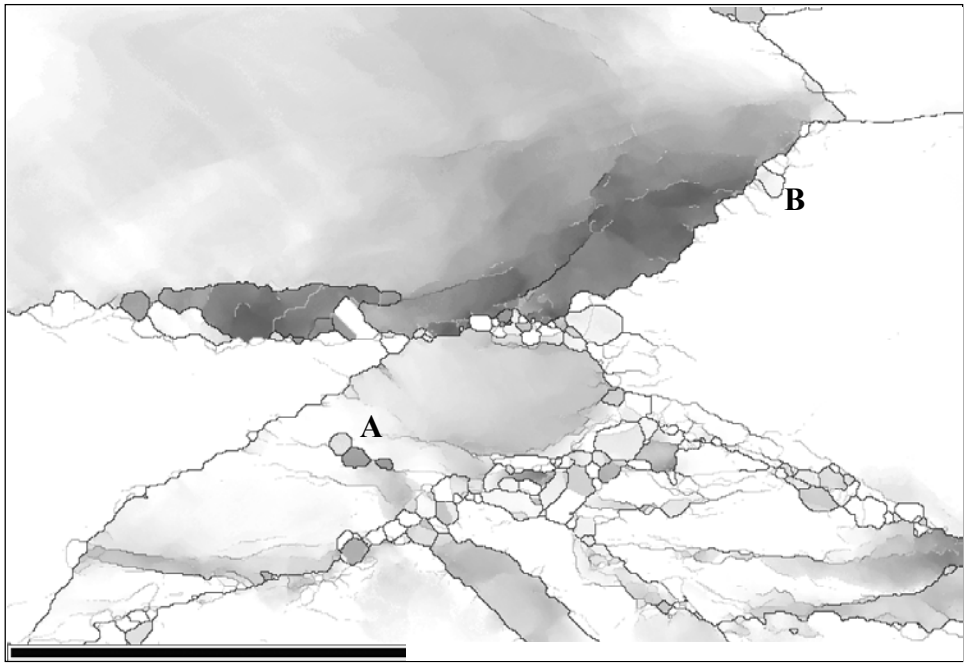
For the steady state ($q = q_s$) ,

$$\varphi(\theta)\,\dot{\theta} = k\,\theta^{-q_s}\,\dot{\theta} = \text{constant}$$

$$\Rightarrow \quad \dot{\theta}(\theta) = C\,\theta^{q_s}$$

(For Al alloys, $q_s = 0$)

"Continuous nucleation" (A)



50 µm

Conclusions

- Discontinuous DRX in low stacking fault energy metals occurs with variable kinetics, e.g. much more slowly in 718 alloy than in 304 steel

- Nucleation of new grains takes place by three distinct mechanisms:
  - (initial) grain boundary bulging,
  - repeated (growth) twinning,
  - and, in alloy 718, "continuous nucleation", similar to CDRX

- Slower grain boundary migration rates in alloy 718 may be attributed to
  - smaller driving forces due to more efficient dynamic recovery,
  - grain boundary mobility reduced by niobium solutes

- Respective contributions of CDRX and DDRX in nickel base superalloys could be controlled by adjusting volume fractions of Nb or other addition elements