Influence of precipitates on strengthening and on recrystallization

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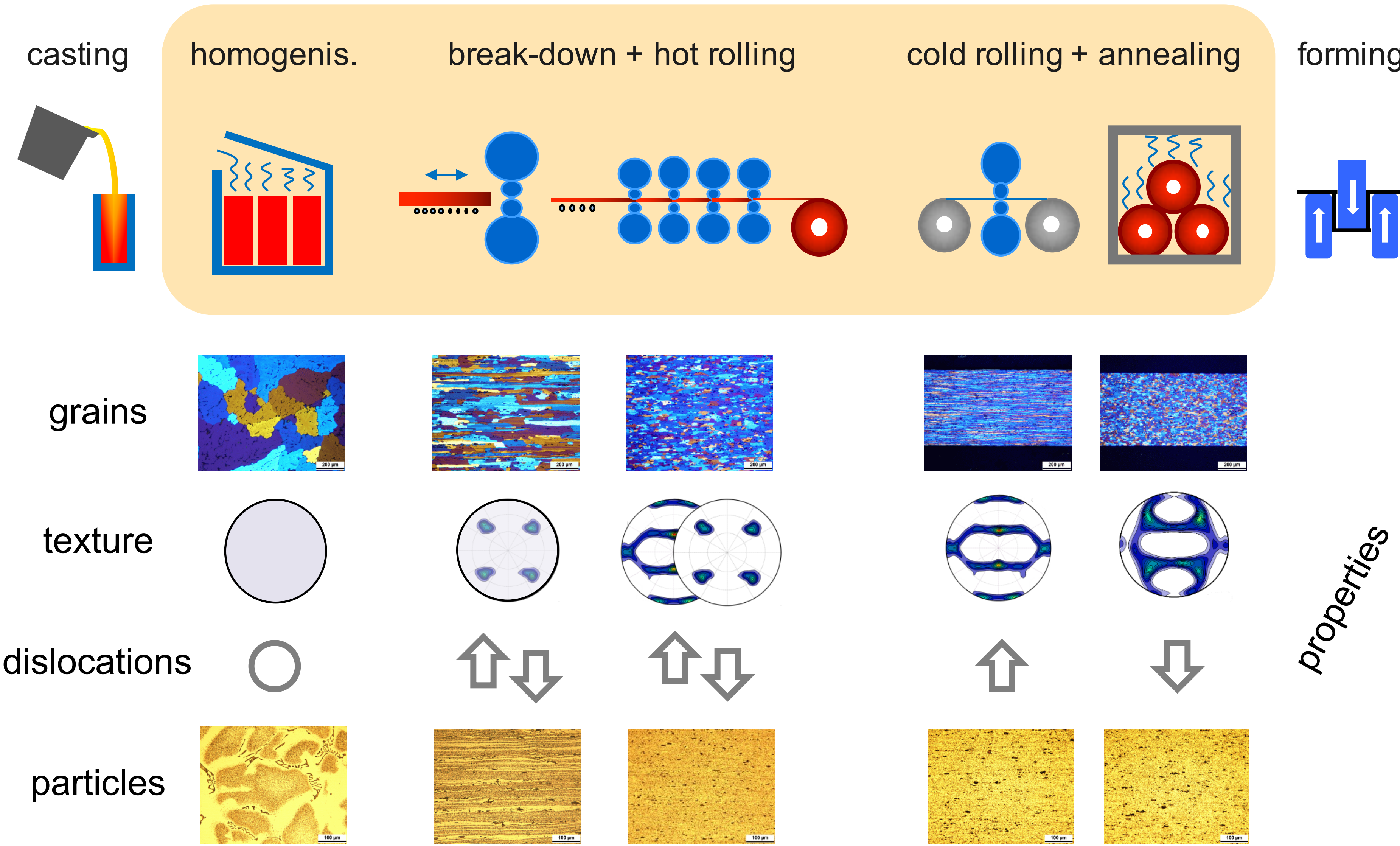
AMAP 3rd anniversary
Aachen, 21.1.2016

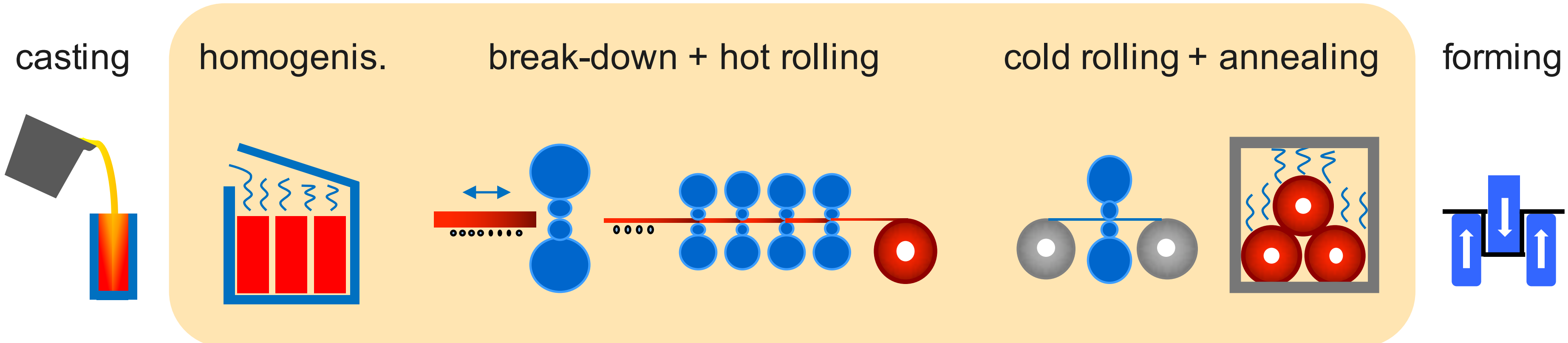
Institut für Metallkunde und Metallphysik

RWTH AACHEN UNIVERSITY

IMM interests



IMM interests



experiments & simulations

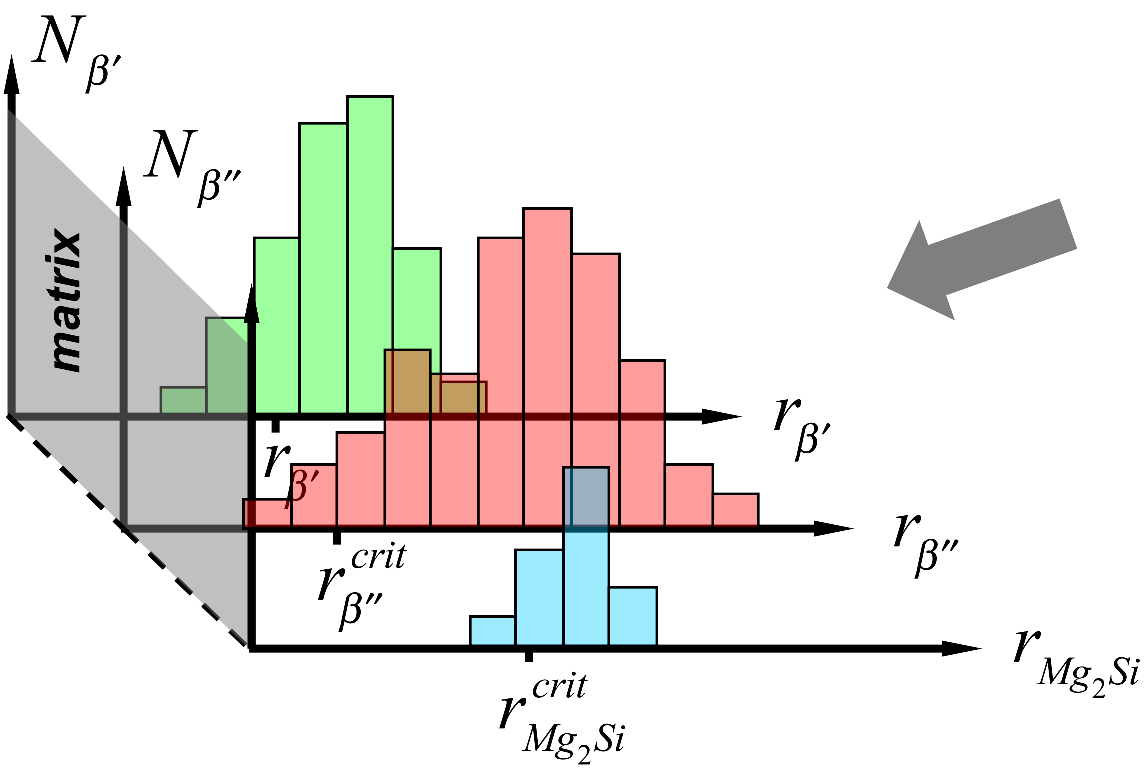
- deformation: work hardening, texture evolution, particle strengthening
- annealing: recovery, recrystallisation, grain growth, precipitation
- underlying physics: micro plasticity, grain boundary motion
- model coupling for through-process modelling

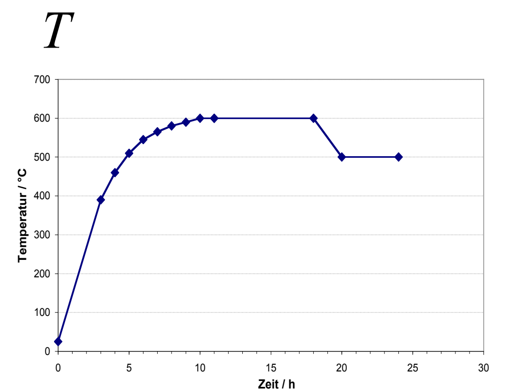
Statistical precipitation models

2001 - 2011 ClaNG: Classical Nucleation and Growth
VAW / Hydro RDB, BMBF

2013 - 2016 KiNG: Kinetic Nucleation and Growth: metastable phases
AMAP P1

2016 - new model specialized model for Al cast alloys
AMAP P9

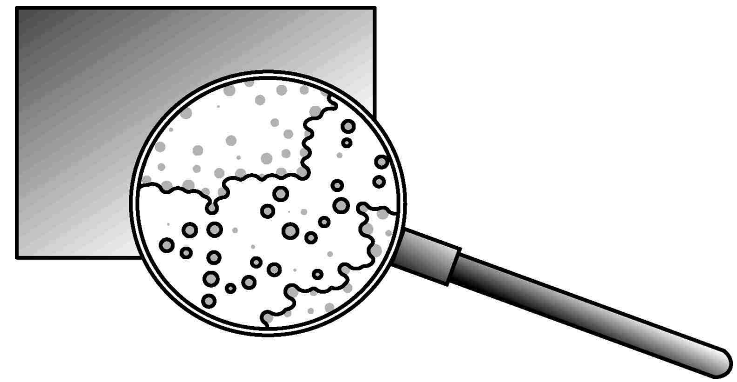




heat treatment
⇒ particle size distributions

Effects of precipitates

interaction with dislocations:



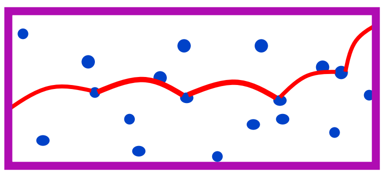
- direct strengthening
- increased work hardening
- creep reduction

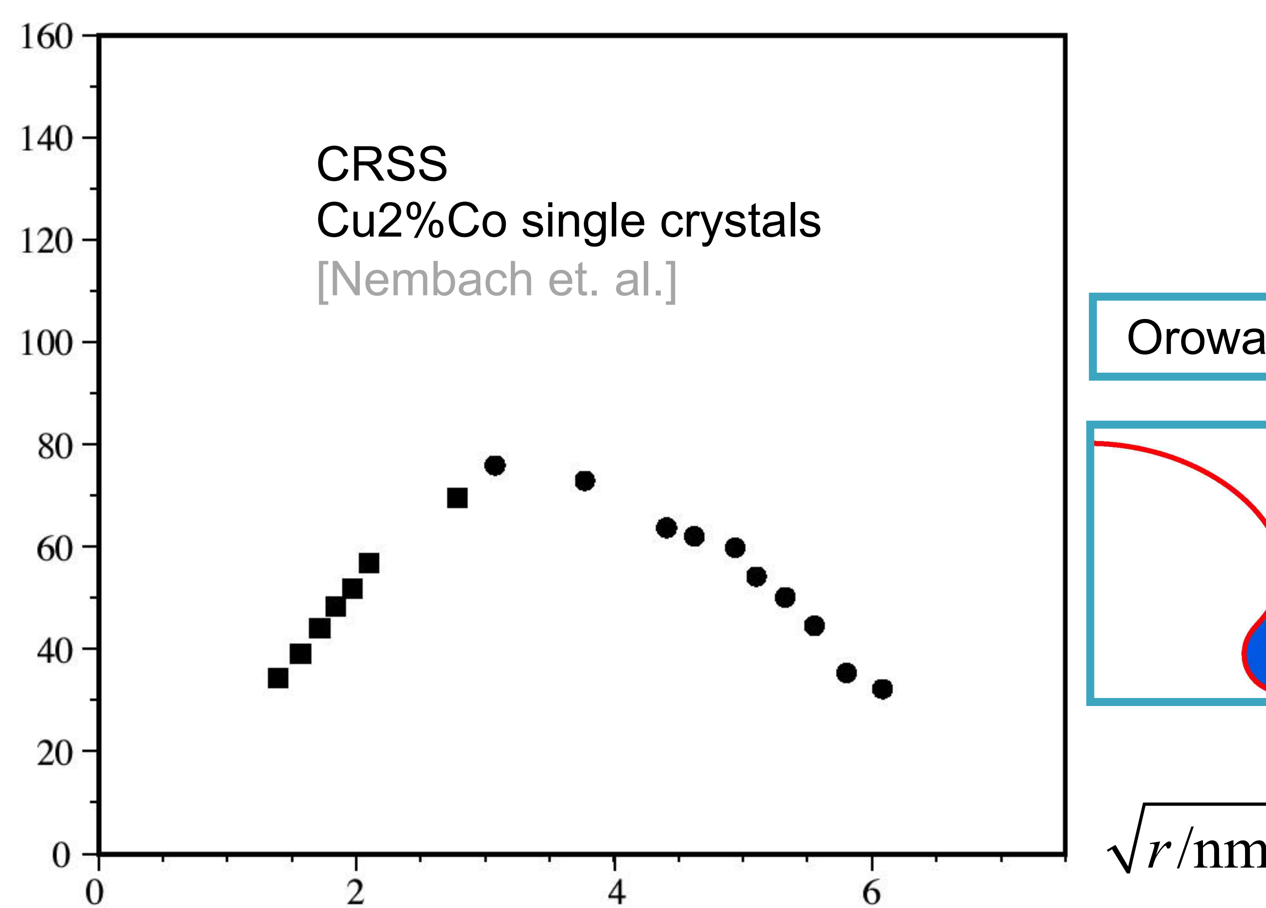
interaction with grain boundaries: Zener drag

- control of recrystallisation
- control of grain growth

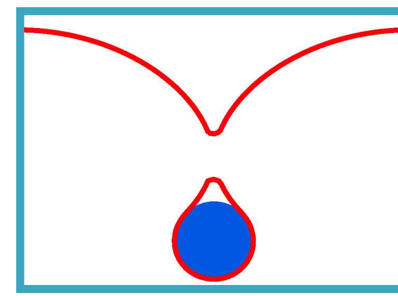
Particle strengthening theories

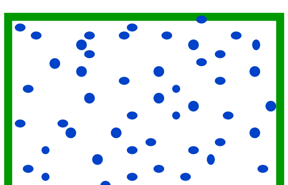
Friedel theory



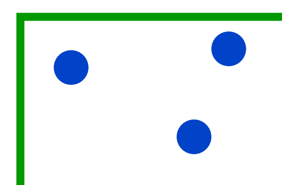


Orowan theory

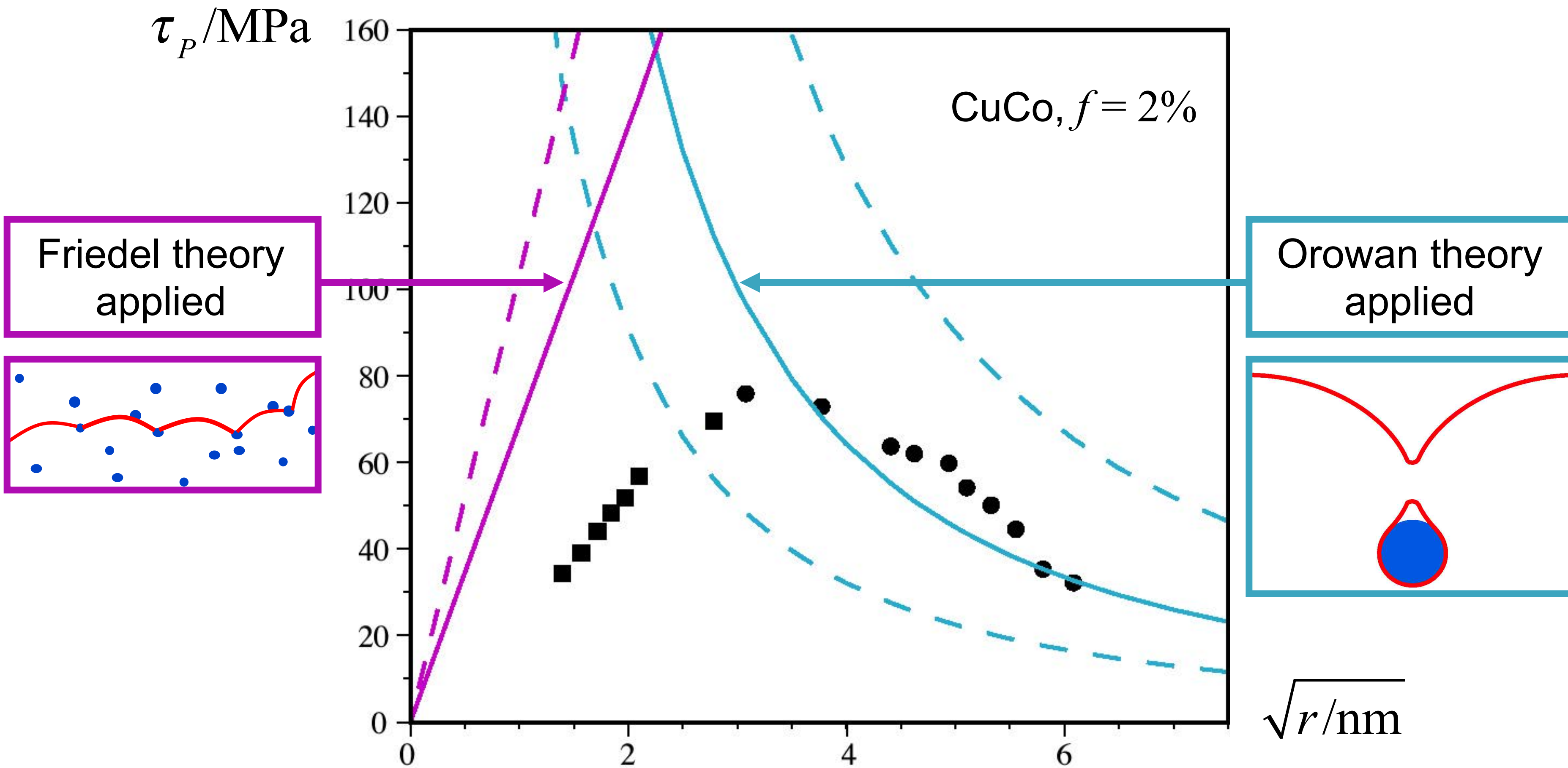




ageing
coarsening



Particle strengthening theories

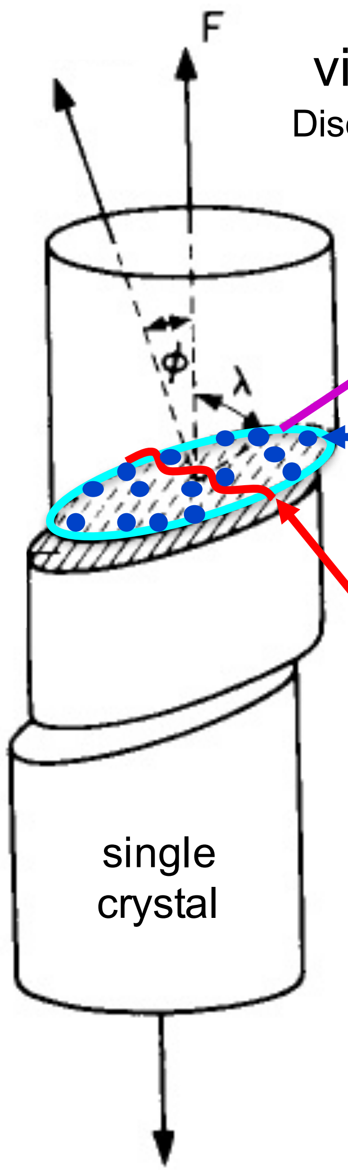


How flexible is the dislocation ?
How strong is the interaction ?
How many particles are effective ?

Particle strengthening simulations

virtual tension tests

Discrete Dislocation Dynamics

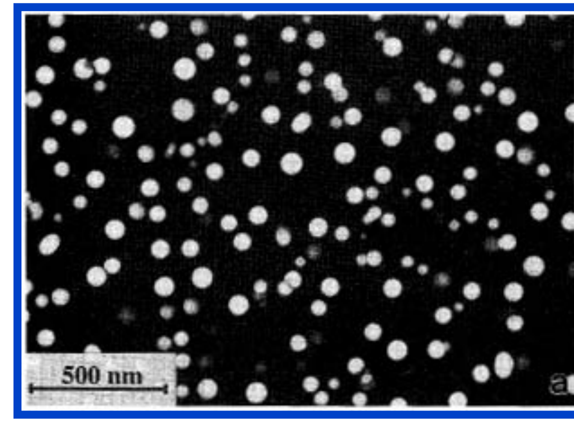


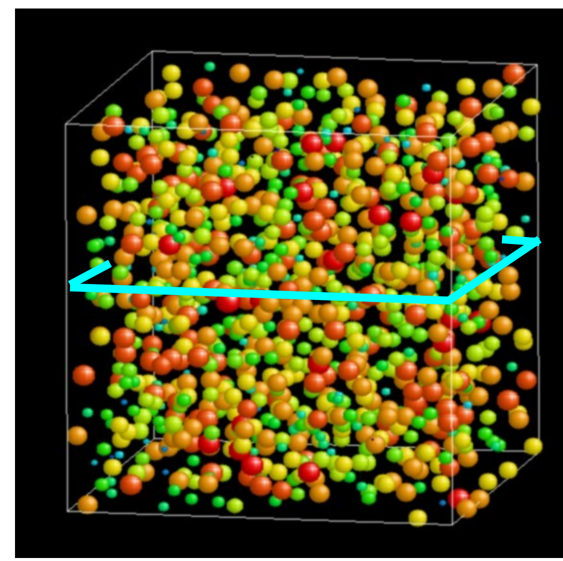
slip direction

particles of secondary phases

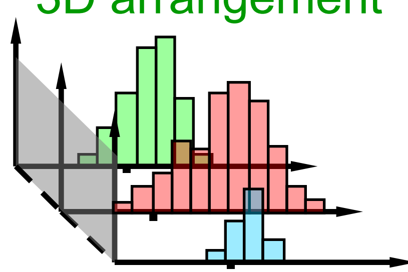
realistic interactions

dislocation with elastic self interaction

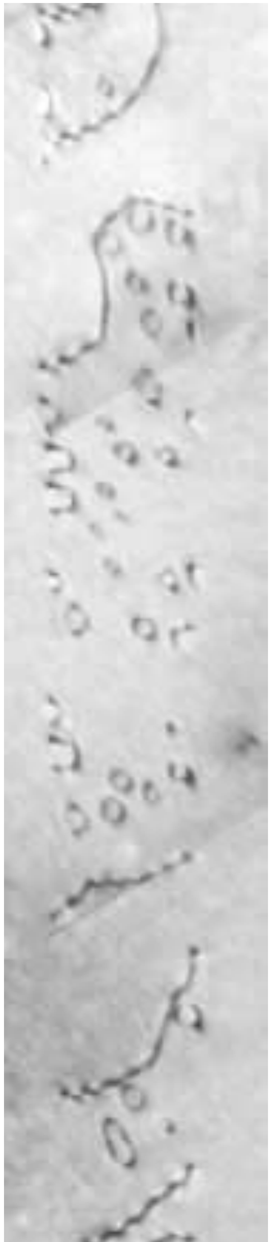


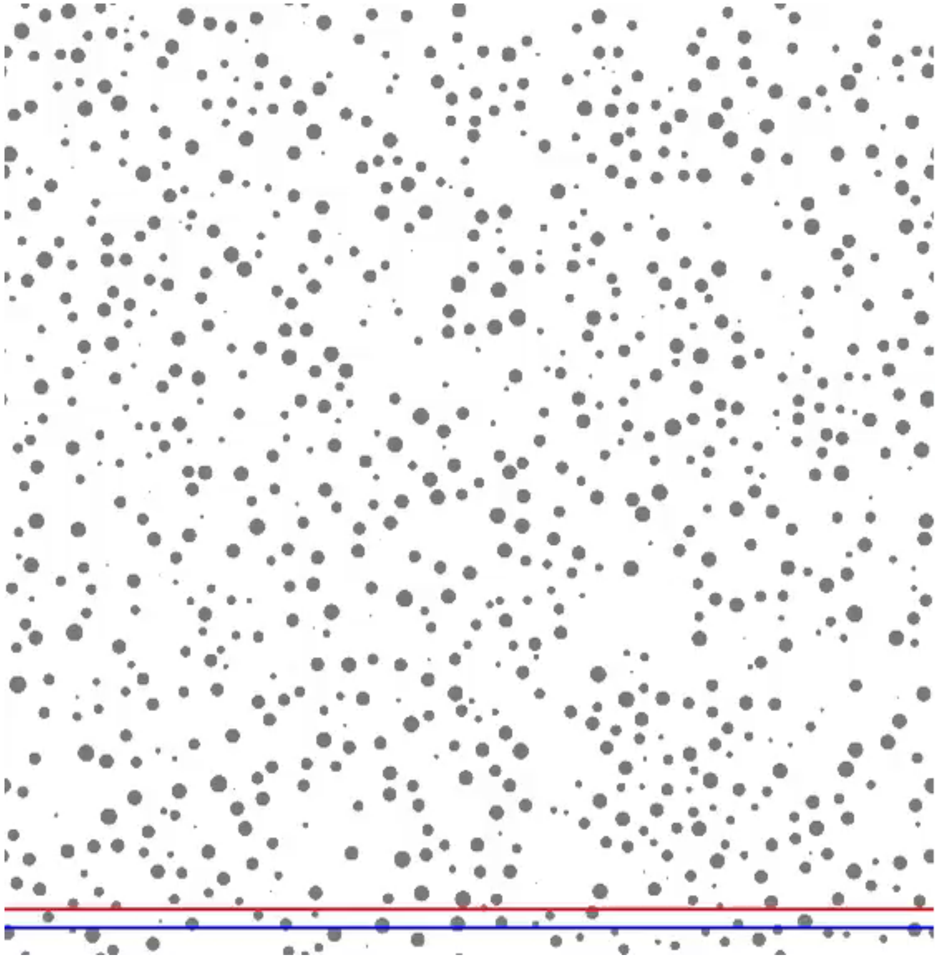


realistic 3D arrangement



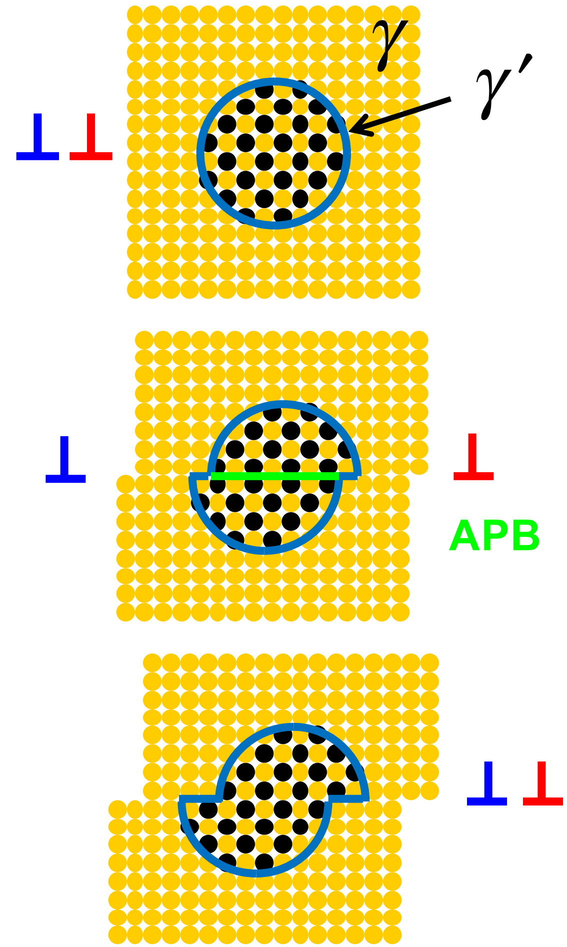
Order strengthening simulation



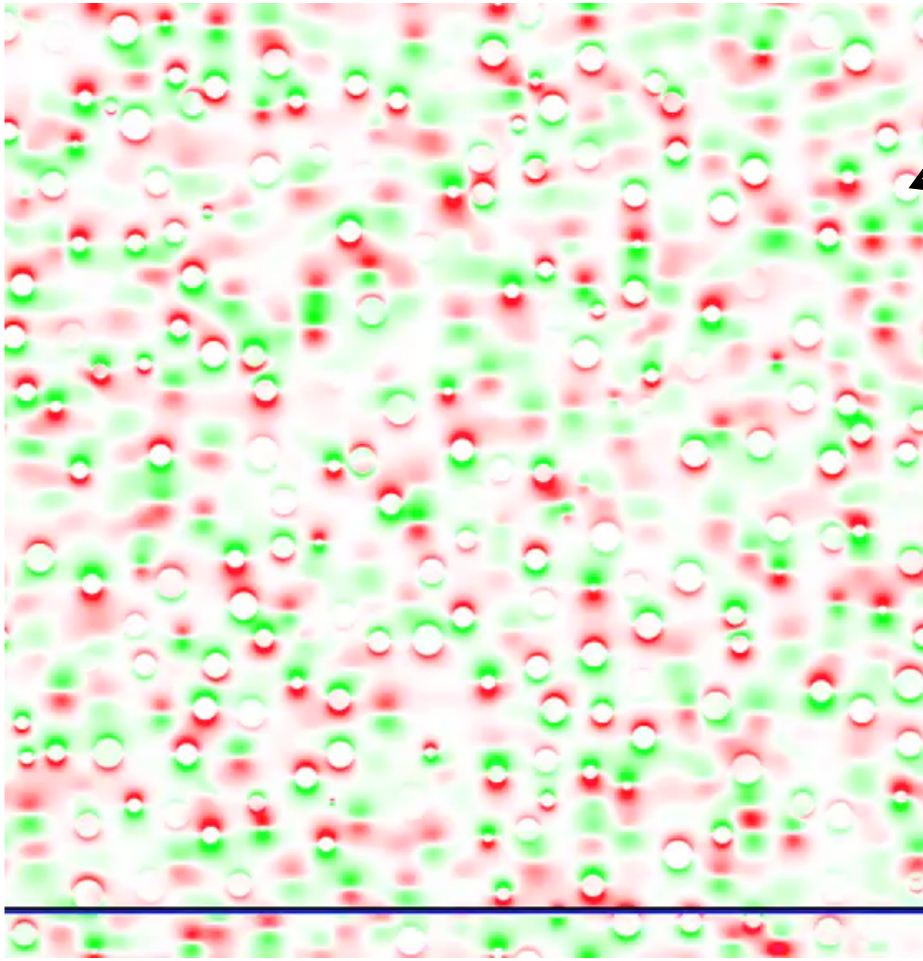


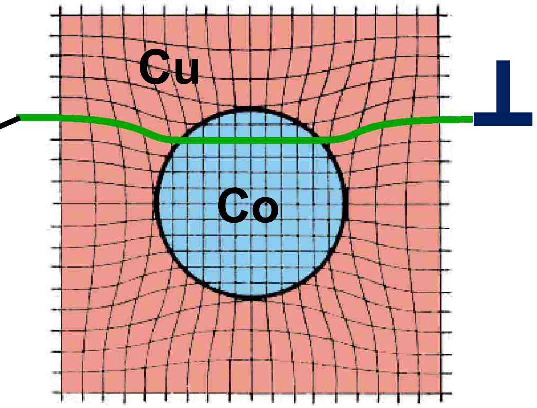
Superalloy Nimonic PE16

$f = 0.1,\ \ r = 50\mathrm{nm}$



Lattice mismatch strengthening simulation



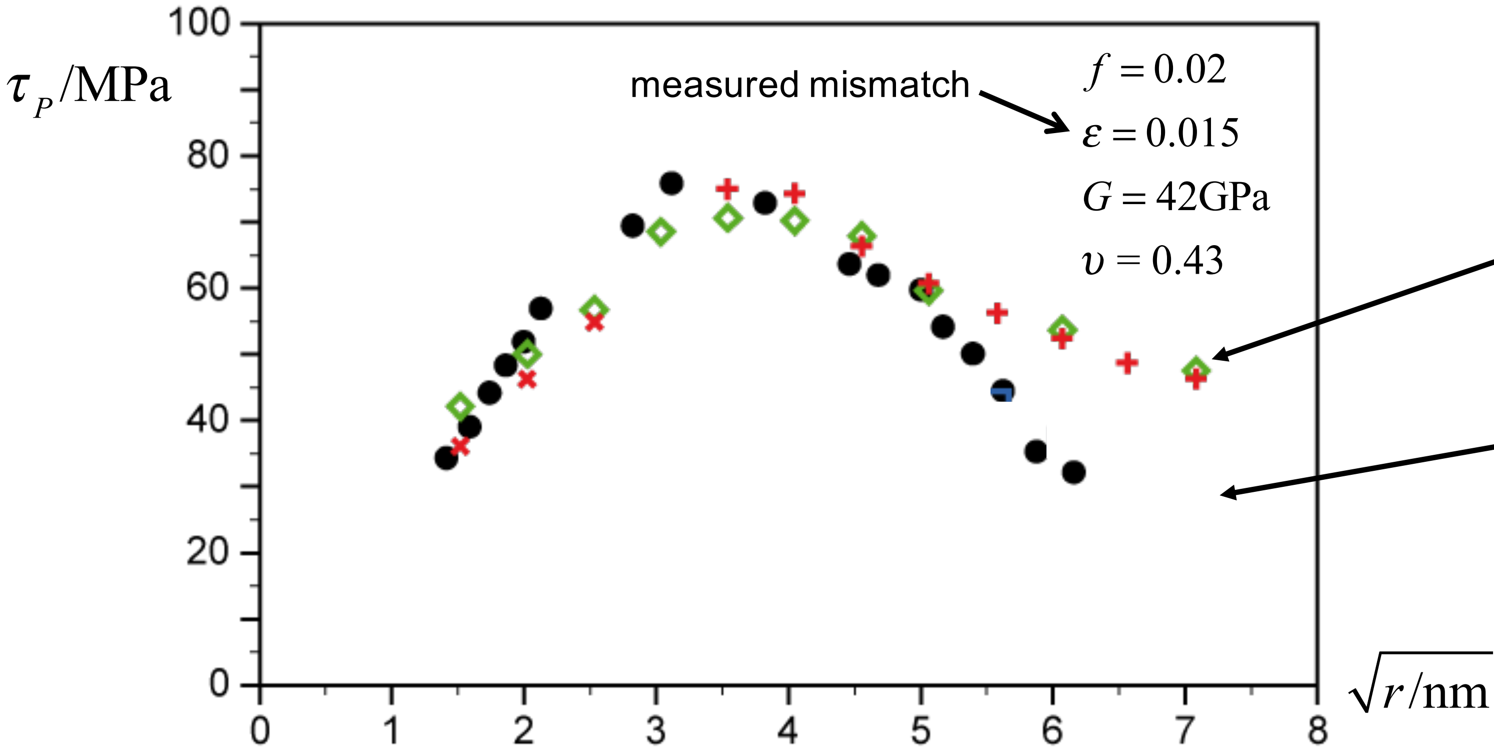


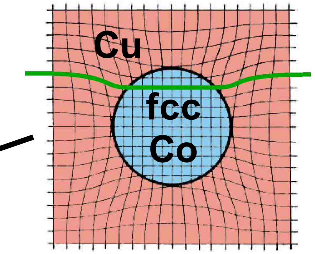
CPU time:
few minutes

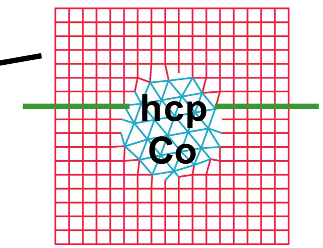
Cu10at.%Co

$f = 0.1, \ r = 25\text{nm}$

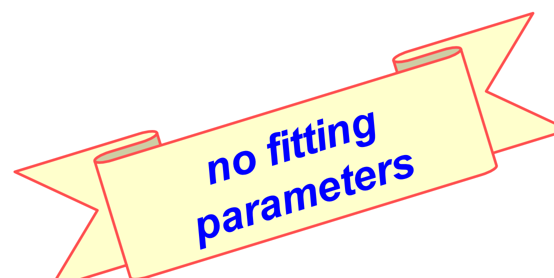
Lattice mismatch strengthening simulation







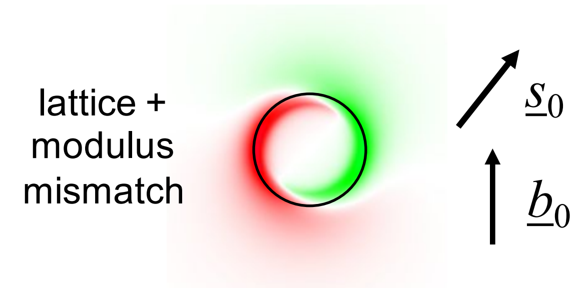
- ● **compression tests, Nembach et al.**
- ◇ + × **simulations, lattice mismatch (+SF mismatch)**
- □ **simulations, incoherent particles**



Particle strengthening outlook

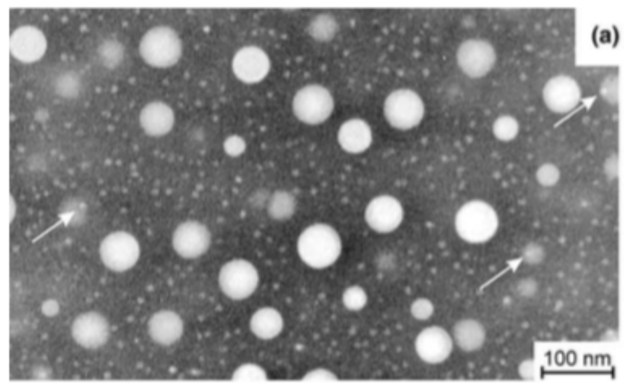
any combination of interaction mechanisms

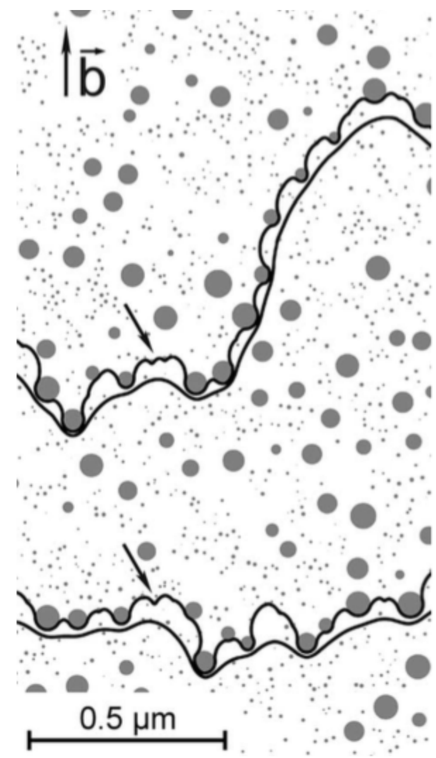
- lattice mismatch, modulus mismatch, stacking fault energy mismatch, long range order, interface energy



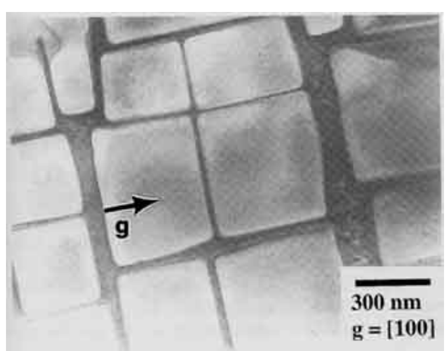
any particle geometry

- arrangement
- size distribution
- shapes: needles, cubes, ...

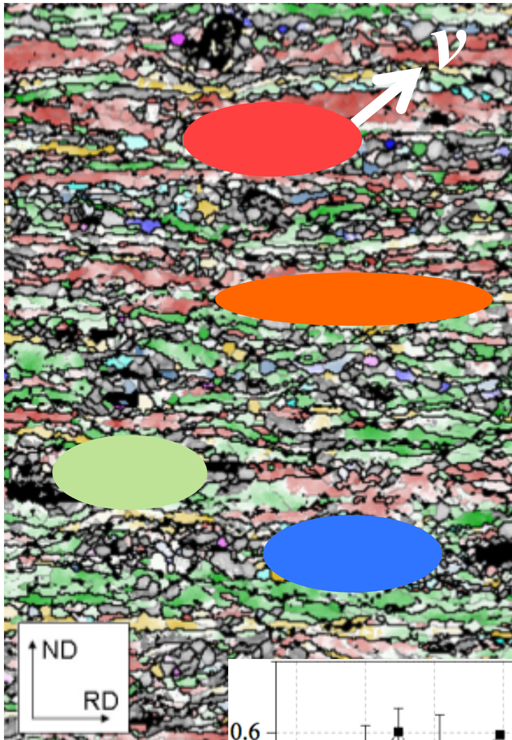




any particle combination



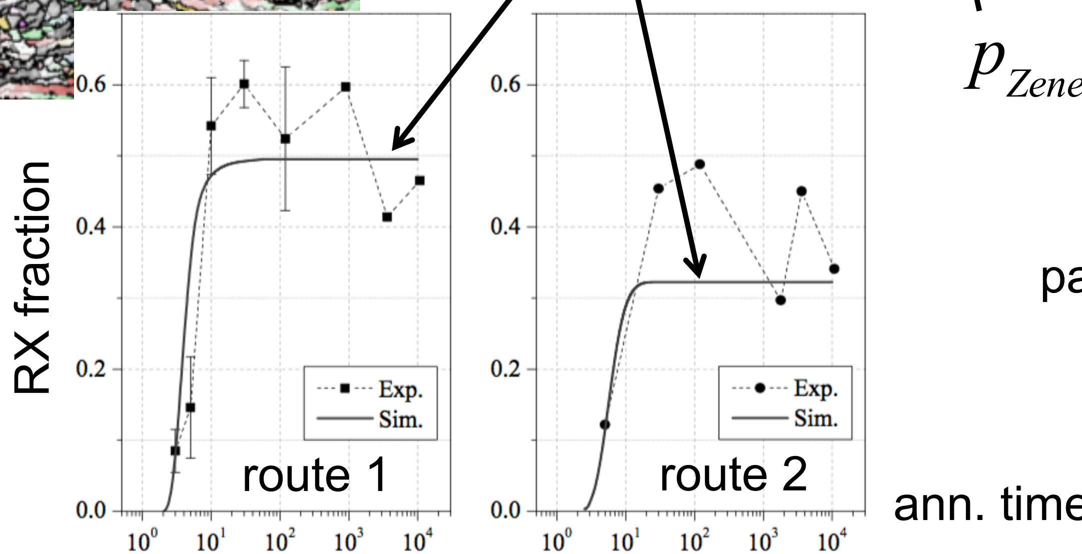
Recrystallisation



driving force from dislocation density and subgrain boundaries from work hardening models „3IVM+“ or „4IVM“

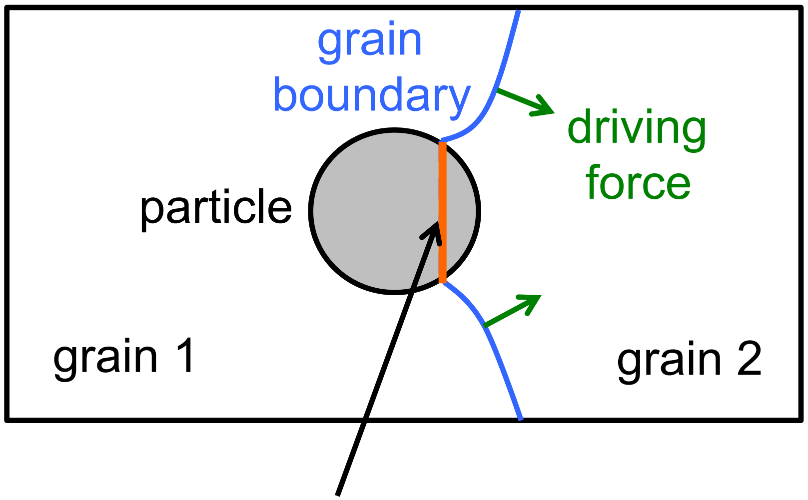
$$v \sim \begin{cases} p_{drive} - p_{Zener} & \text{if } p_{drive} > p_{Zener} \\ 0 & \text{otherwise} \end{cases}$$

$$p_{Zener} = \frac{3}{2} \gamma_{GB} \frac{f}{r}$$



partial RX very sensitive to the Zener drag

Zener drag

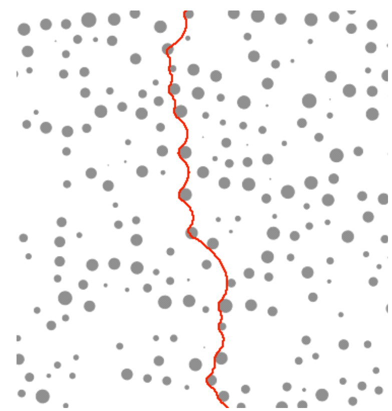


particles reduce grain boundary area

$$\Rightarrow \quad p_{Zener} = \frac{3}{2}\,\gamma_{GB}\,\frac{f}{r}$$

influence of **triple line** energy ?

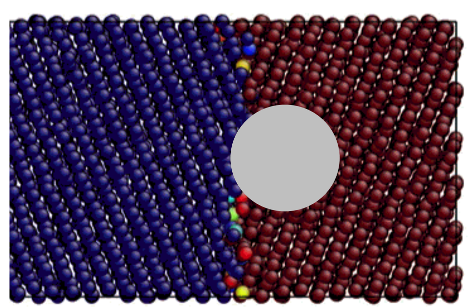
influence of grain boundary bowing ?



3D

aspired DFG project:

GB/particle interaction



$$p_{Zener}(f,r)$$

Summary

::: mesoscopic models provide the link:

- specific phase properties (fixed parameters)
  lattice mismatch (T),
  modulus mismatch (T), ...

- dispersion geometry heat treatment
  volume fraction,
  size / shape distribution, ...

$\Rightarrow$ information about material properties

::: directly usable models available for particle strengthening

::: refined models for Zener drag in preparation