

Grain Boundary Sliding and Low Friction in Metals

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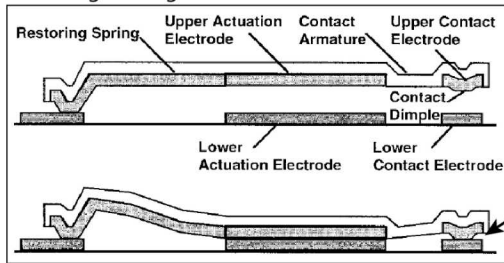
Electrical Contacts use Bare Metal

Phone Interconnects

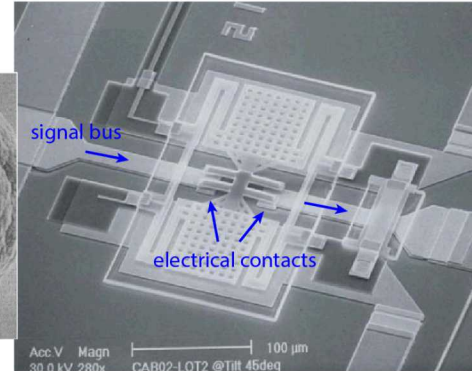
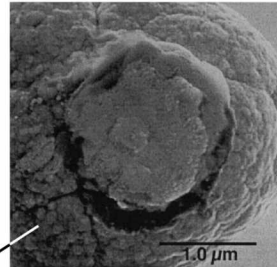


RF Micro Electromechanical Systems (MEMS)

switching GHz signals



Source: D. Hyman and M. Mehregany, IEEE Trans. & Pack. Tech. 22-3, 1999



Source: Rockwell Scientific metal-metal switch

Electronics (e.g. PCB blade connectors):
200 - 500 nm thick electroless hard gold

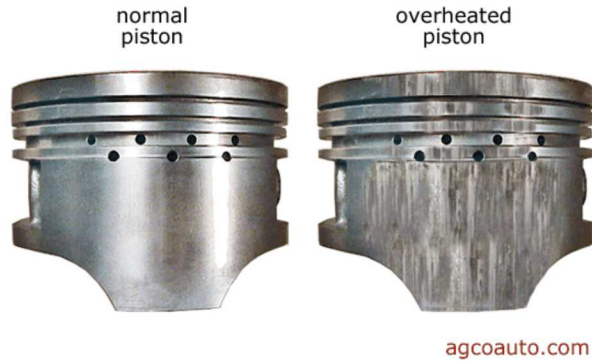


Aerospace and Energy



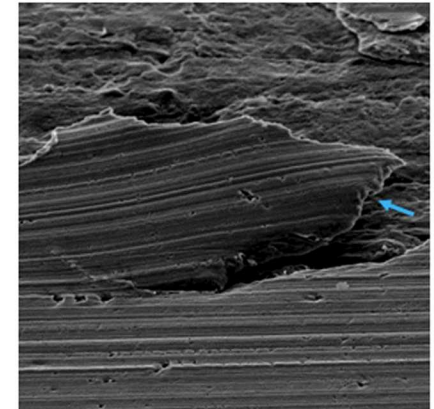
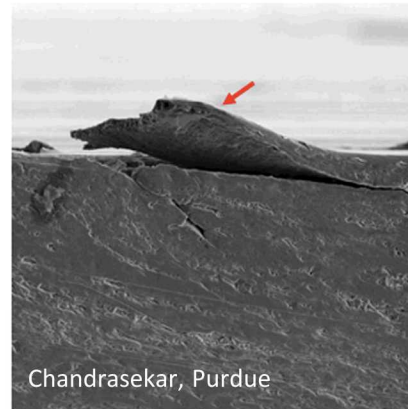
Source: Honeybee Robotics (<http://www.honeybeerobotics.com/portfolio/rolling-contact-connector/>)

Metals are Ductile and Sticky



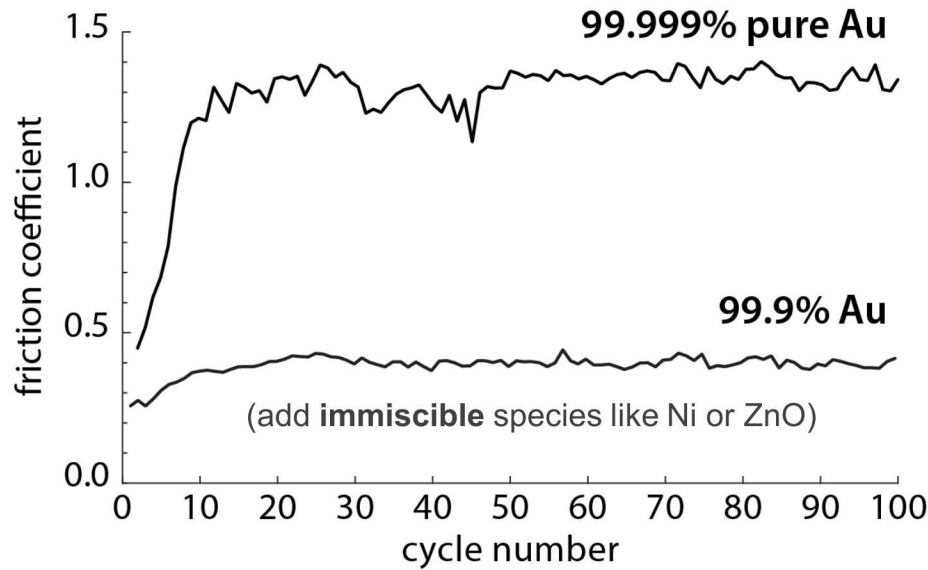
Materials	μ
Aluminum/Aluminum	1.2
Copper/Copper	1.0
Nickel/Nickel	0.9
Rubber/Asphalt	0.9
Waxed Ski/Snow (0° C)	0.05

- Sliding metal contacts are everywhere
 - Electrical interconnects
 - Wind turbines
 - Hip replacements
 - Car Engines (~12% loss)
- High adhesion and friction
- Lots of plasticity and wear



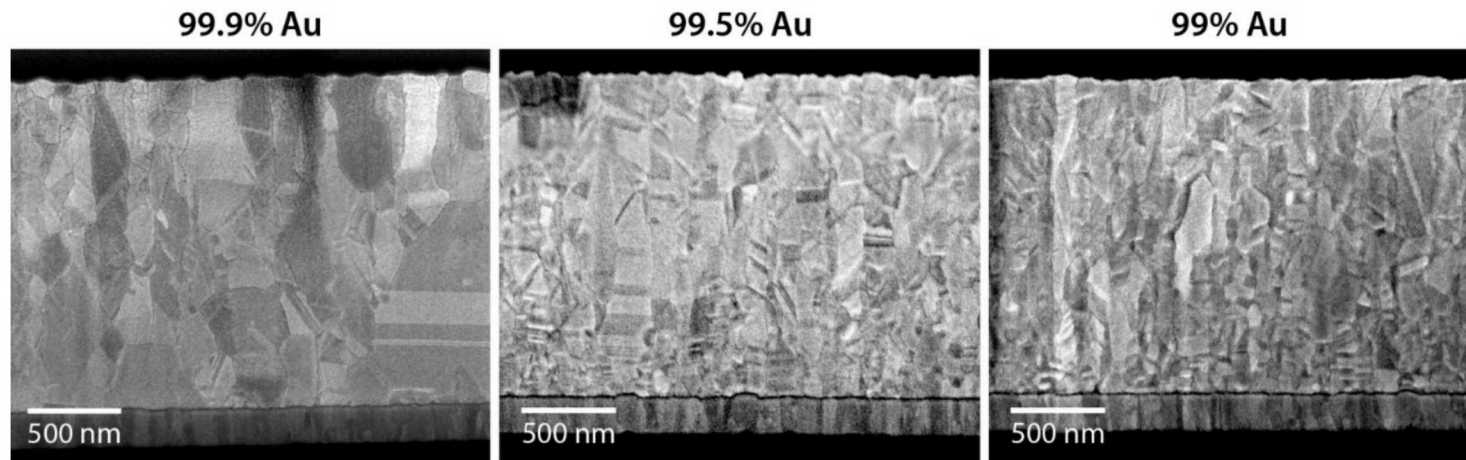
Reduced Friction and Wear of Nanocrystalline Metals

Alloying reduces friction coefficient:

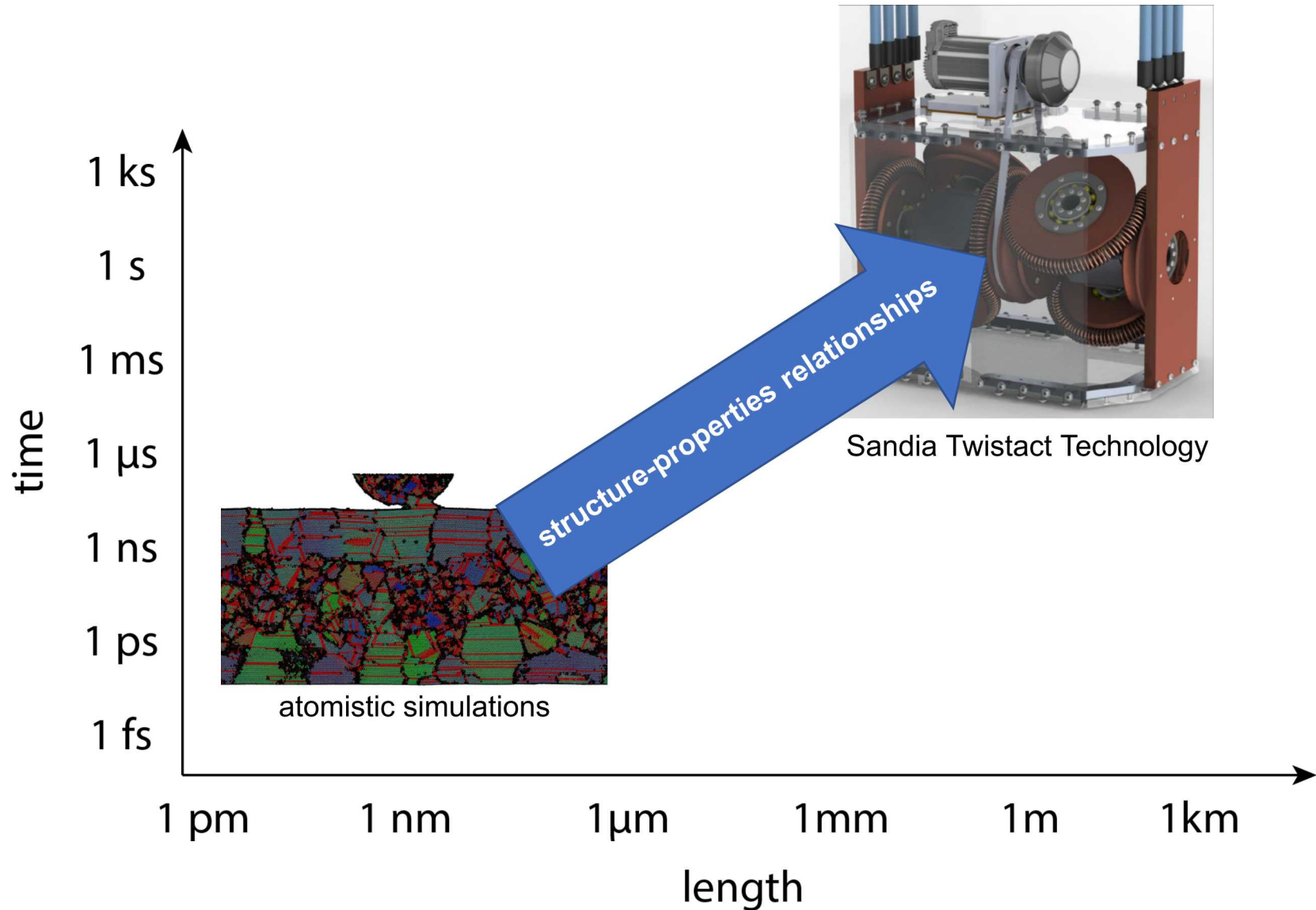


Alloying improves
friction & wear performance by reducing
and stabilizing grain size

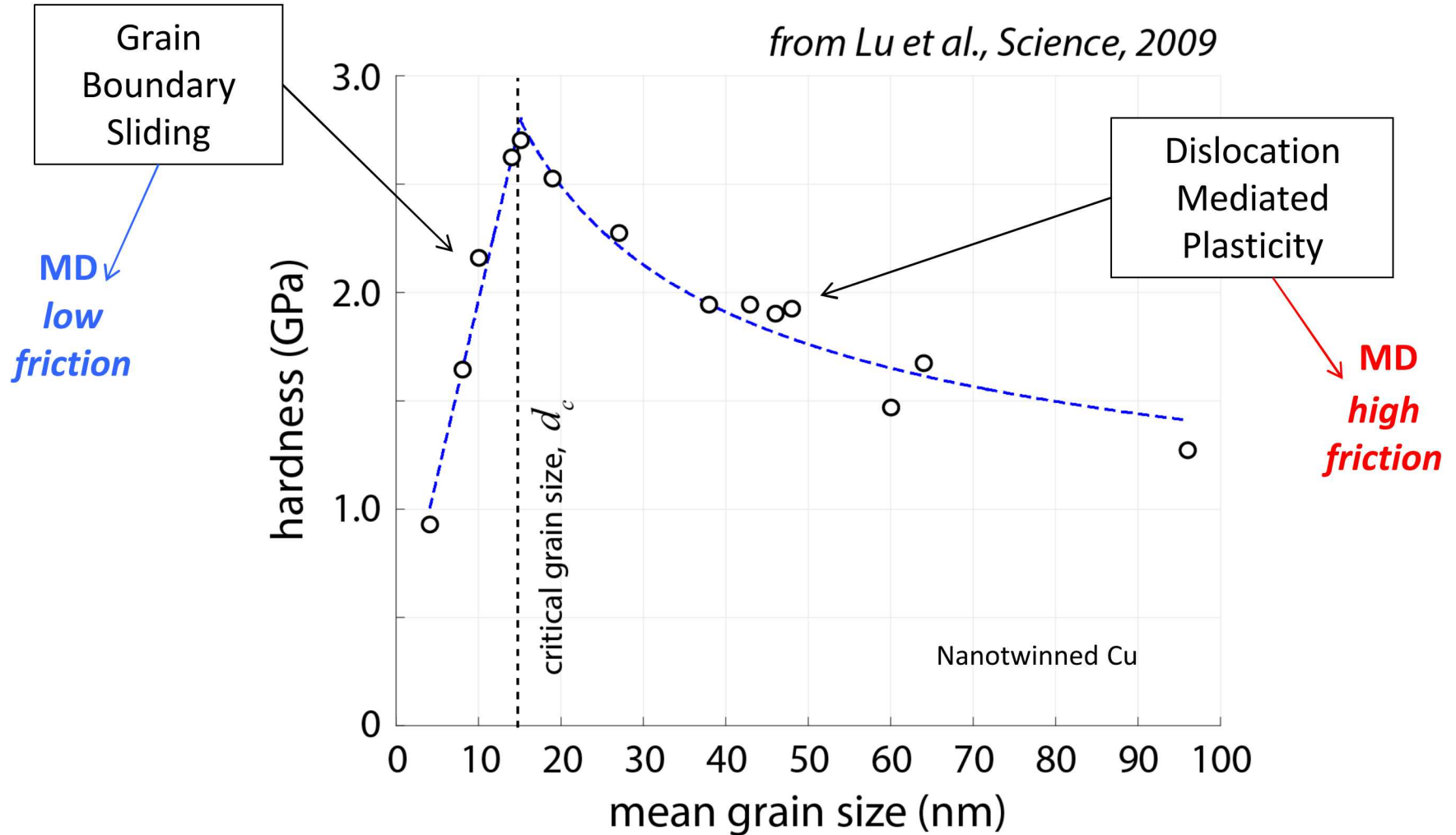
...by reducing grain size:



Bridging the Gap from Atomistic Modeling to Macroscale Applications

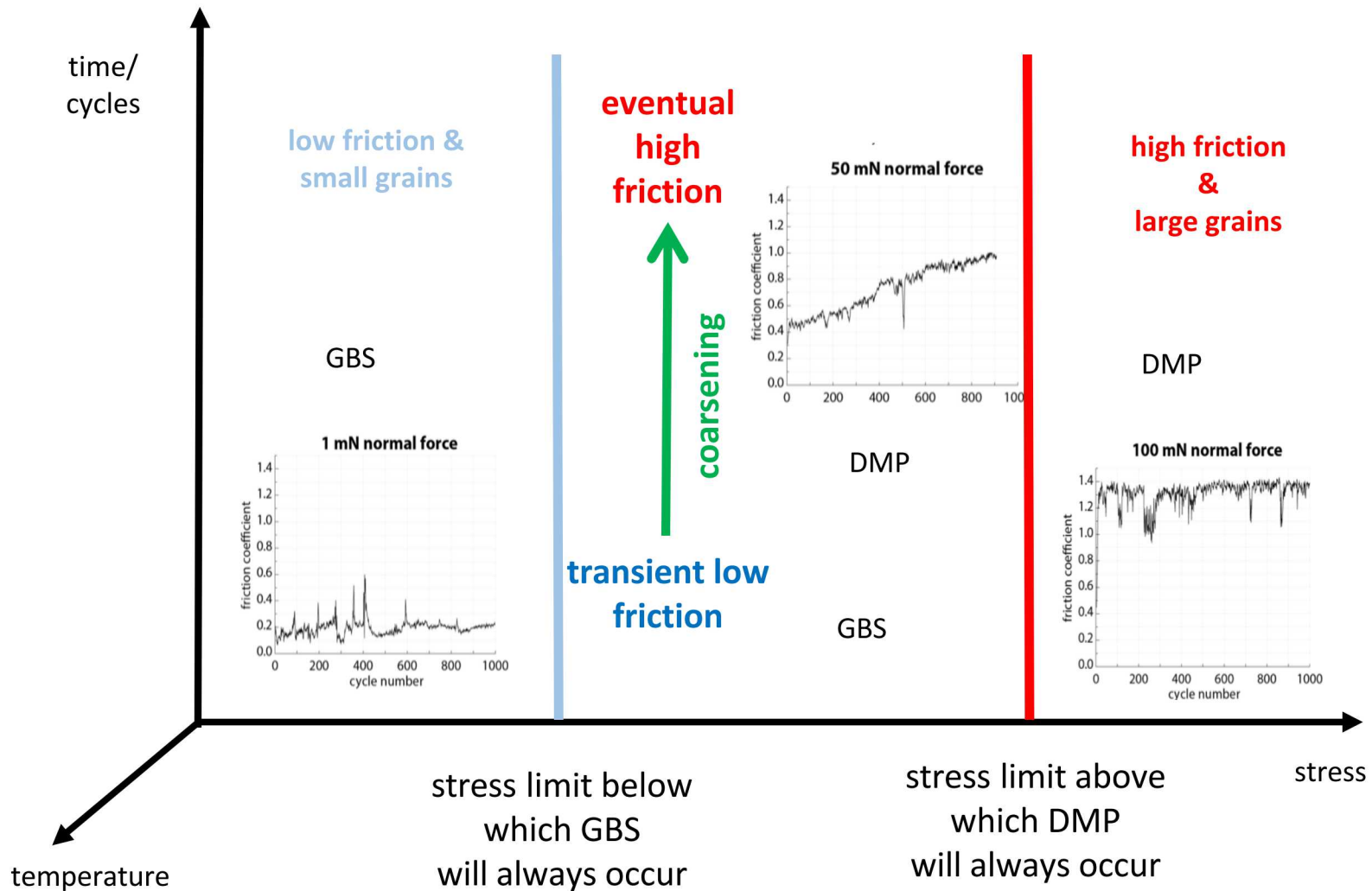


Grain size and Materials Properties

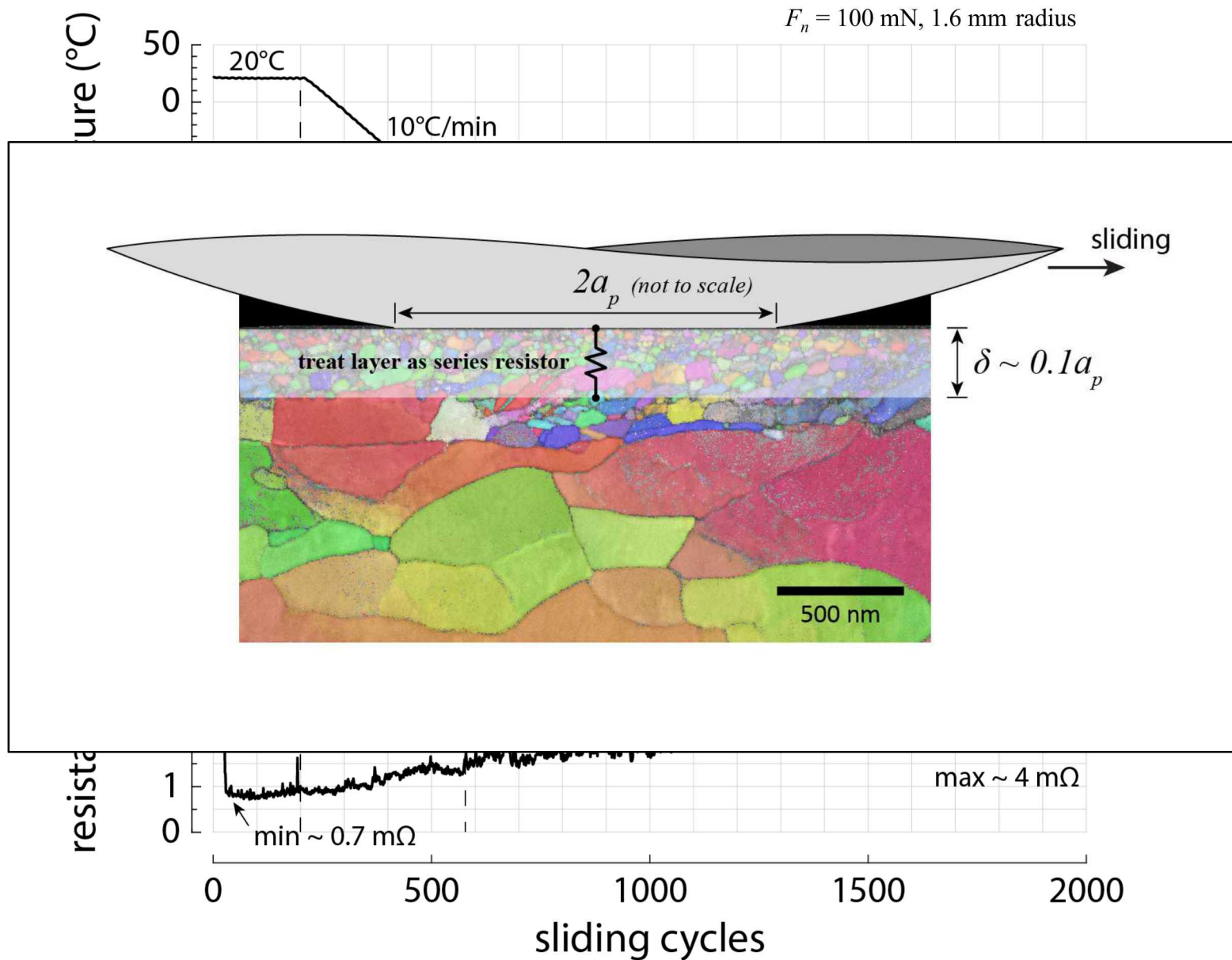


Generalized Friction Map for Metals

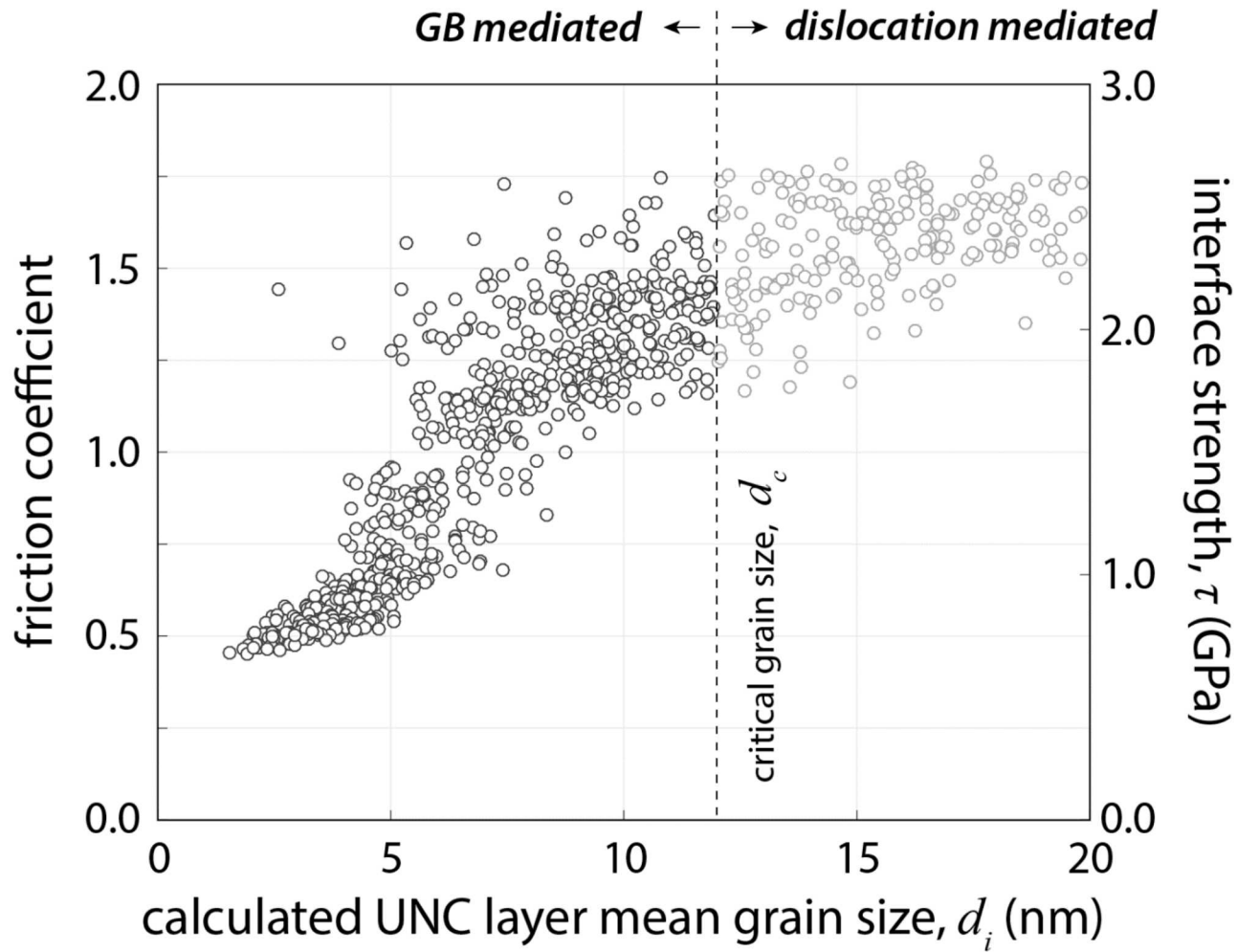
Argibay, Chandross, Cheng, Michael; J. Mater. Sci. (2017)



Evidence for GBS as a Low Friction Mechanism

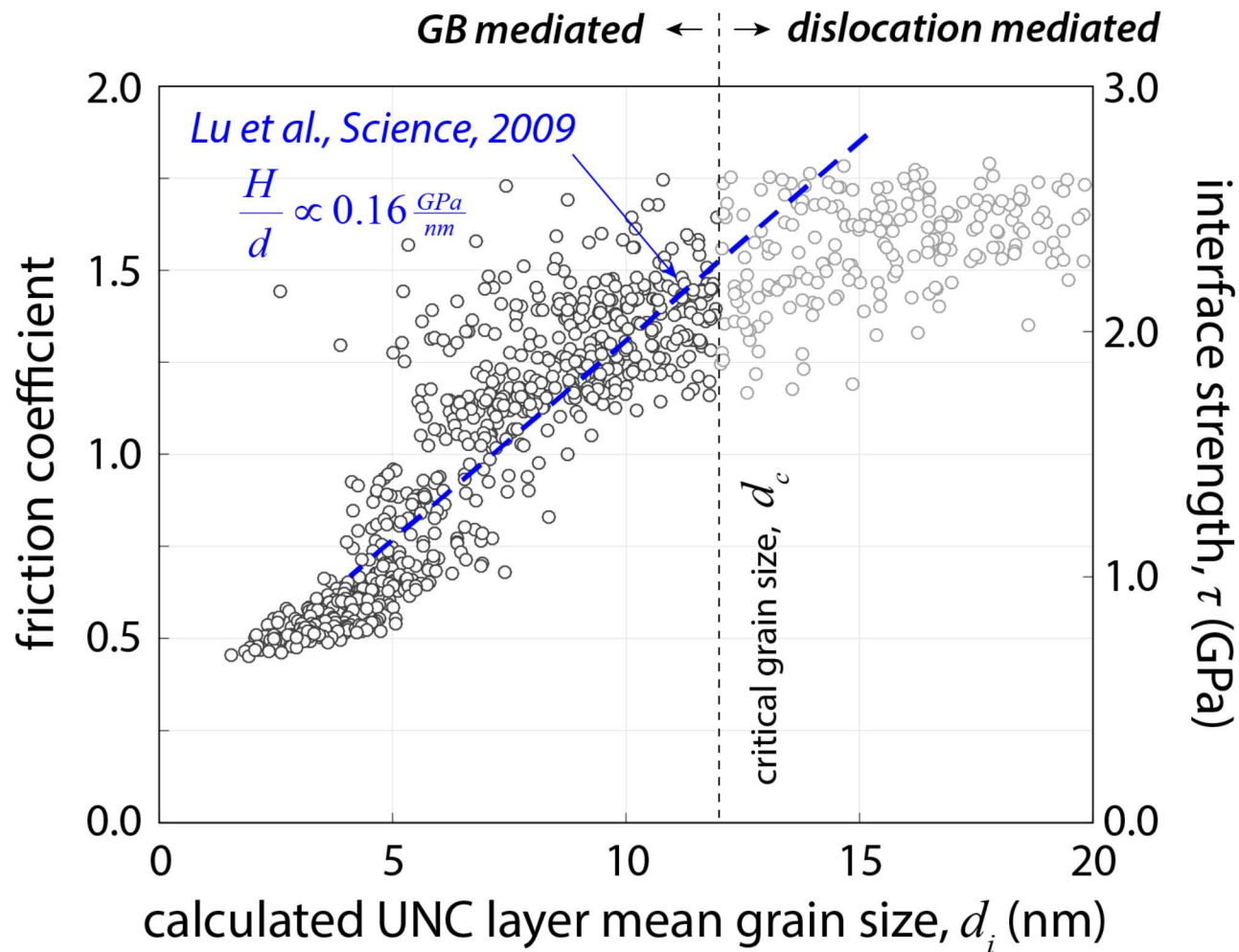


Direction Connection between Friction and Grain Size



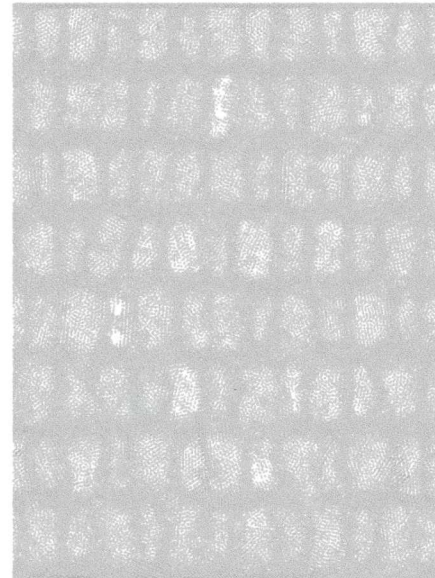
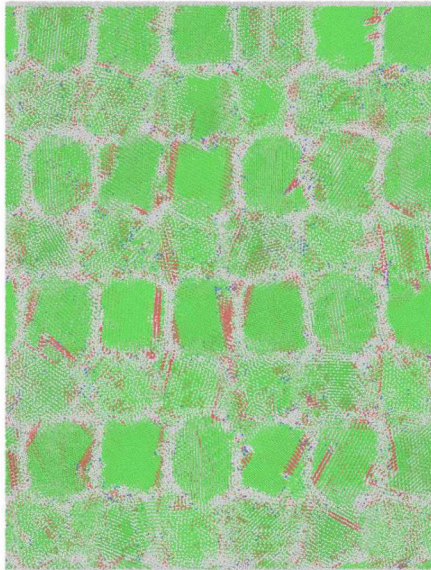
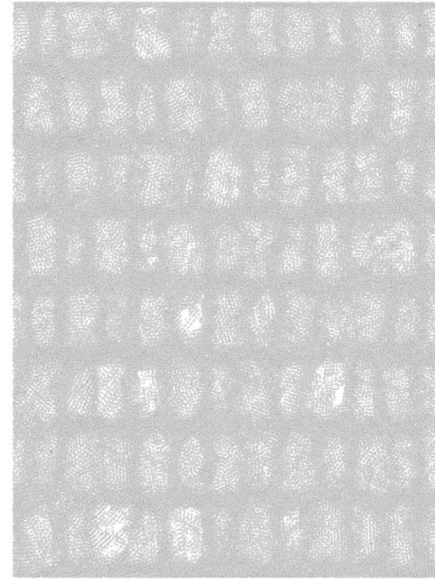
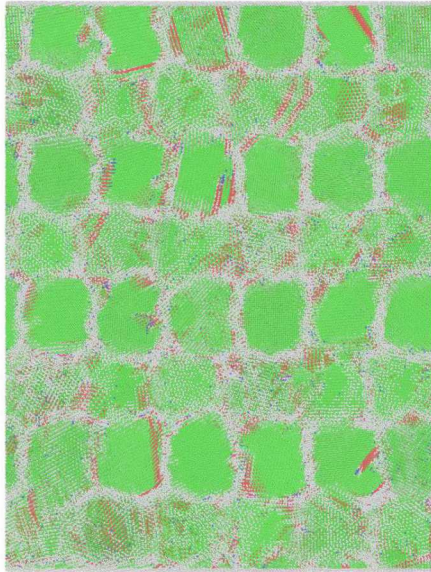
Direction Connection between Friction and Grain Size

Chandross, et al. *Scripta Mat.* (2017)

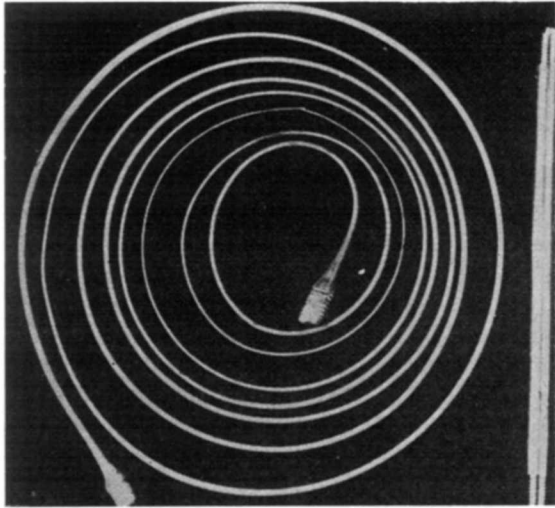


First evidence of (1) grain size dependent friction and (2) inverse H-P linked to low friction. Also, provides validation of inverse H-P behavior of metals.

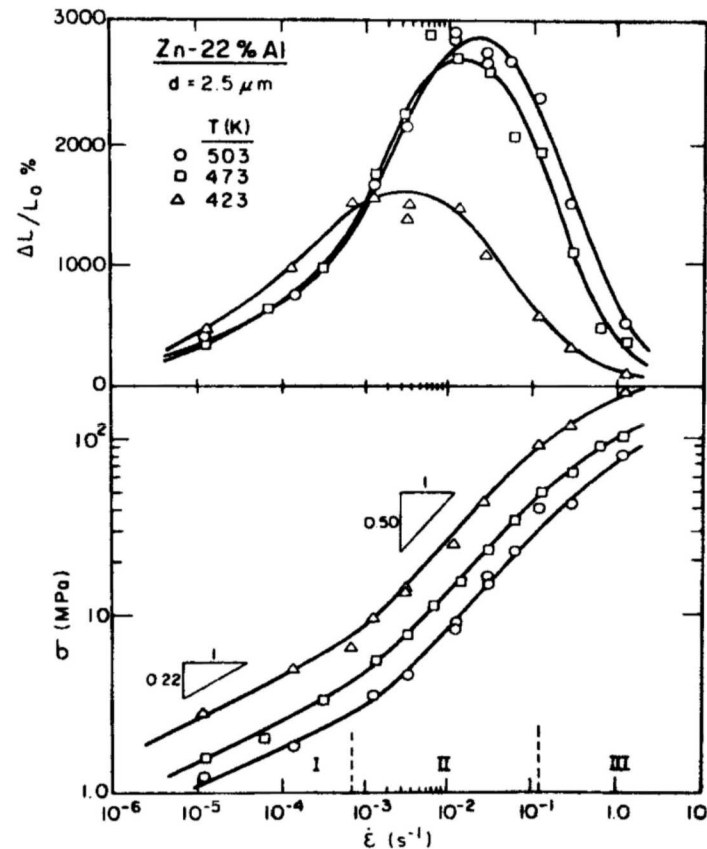
Evidence of GBS in MD simulations (FeNi)



Link Between GBS and Superplasticity



Edington, J.W., K.N. Melton, and C.P. Cutler. "Superplasticity." *Progress in Materials Science*, 1976



- General equation: $\dot{\epsilon}^m = K(\sigma_f - \sigma_0)$
- When $m=1$, pure GBS
- Implies: $\epsilon = \frac{\sigma_f - \sigma_0}{\eta}$ with η as a GB viscosity

Link Between Superplasticity and Friction?

$$F_f = \tau A \quad \leftarrow \text{Classic Bowden \& Tabor friction formula}$$

$$\text{Expand } \tau = \tau_0 + \alpha P + \beta \dot{\epsilon}^m$$

$$F_f = \tau_0 A + \alpha F_N + \beta A \dot{\epsilon}^m$$

$$\tau_f = \tau_0 + \alpha \sigma_N + \beta \dot{\epsilon}^m \quad \leftarrow \text{fundamental shear strength of an interface}$$

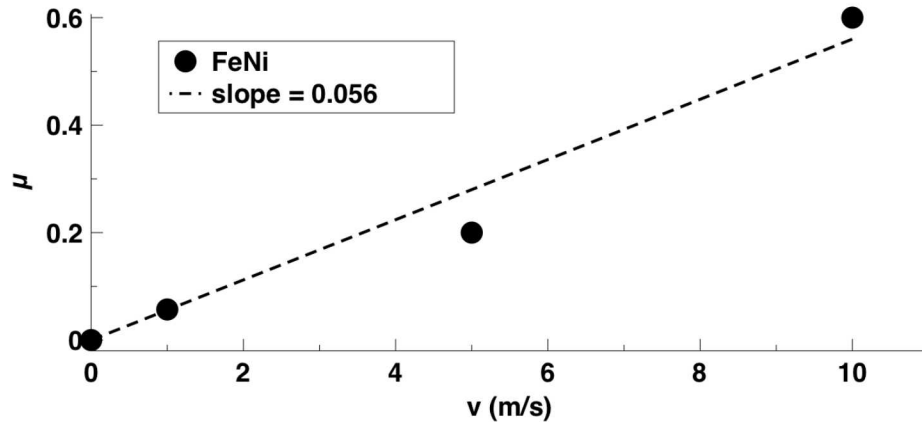
$$\text{At } F_N = 0$$

$$\tau_f = \tau_0 + \beta \dot{\epsilon}^m$$

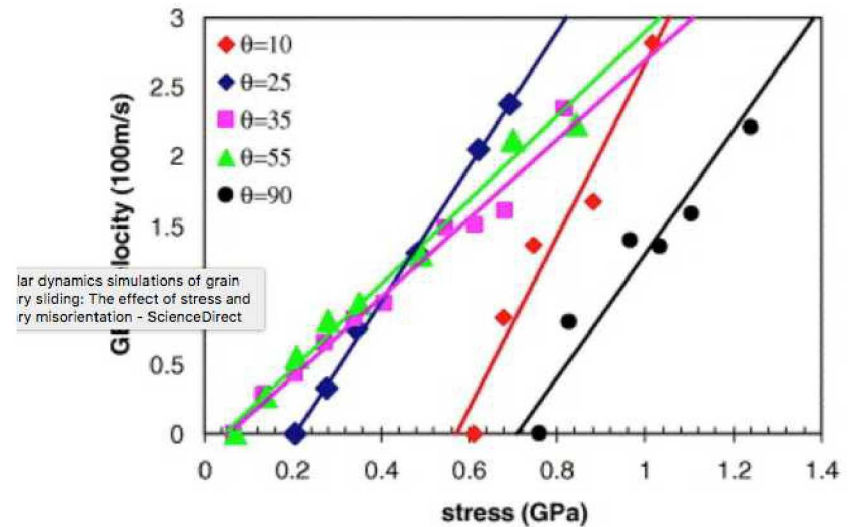
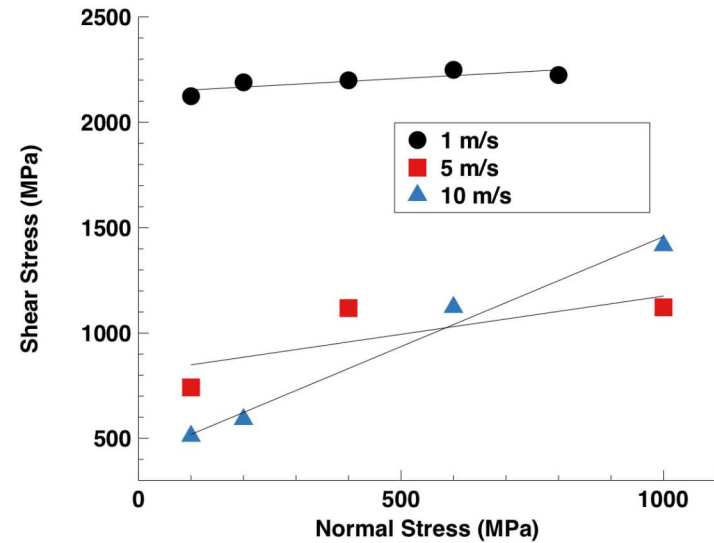
$$\text{Or: } \dot{\epsilon}^m = K(\tau_f - \tau_0) \quad \leftarrow \text{Superplasticity! (when } m > 0.3)$$

- Extension of Bowden & Tabor's fundamental friction model
- Recovers superplasticity equations at $F_N=0$
- No refinement: all grain boundary sliding!

Link Between GBS and Friction



- Simulations clearly show GBS
- Linear dependence of friction on velocity or shear rate



Conclusions

- GBS is linked to inverse H-P and low friction
 - Experiments @ cryogenic temperature
 - Experiments with stabilized boundaries
 - Pure metals
 - Stable NC alloys
 - Simulations on alloys w/ stable boundaries
- Tribological experiments maintain inverse H-P regime
 - High strain rates
 - Repeated contact
- Link to superplasticity
 - Linear strain rate dependence
 - Implies new potential for friction models

Title

Title
