Dislocation Dynamics

Dorn, Mitchel and Hauser (1965)

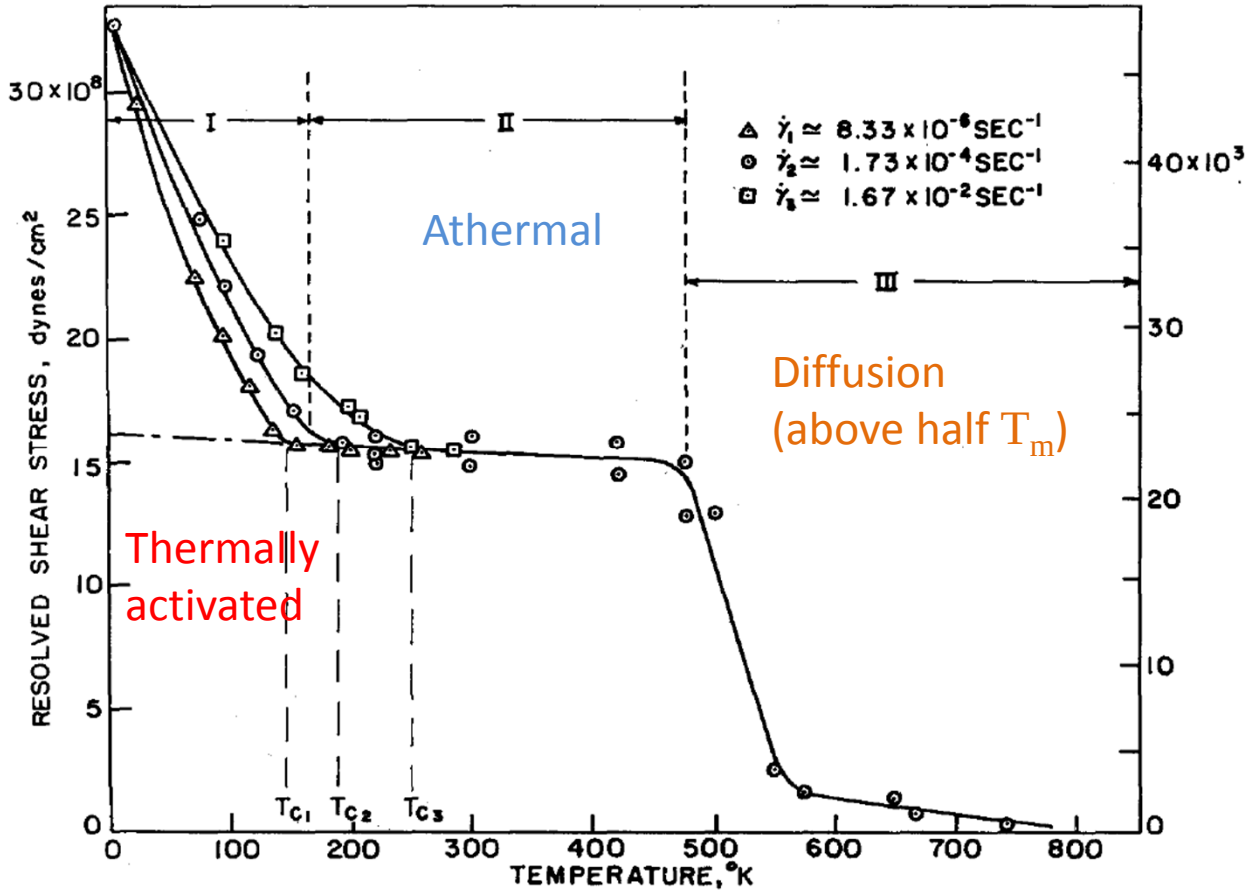
Review dislocation mechanisms:

Athermal

Thermally activated

High-velocity damping

Relativistic effects

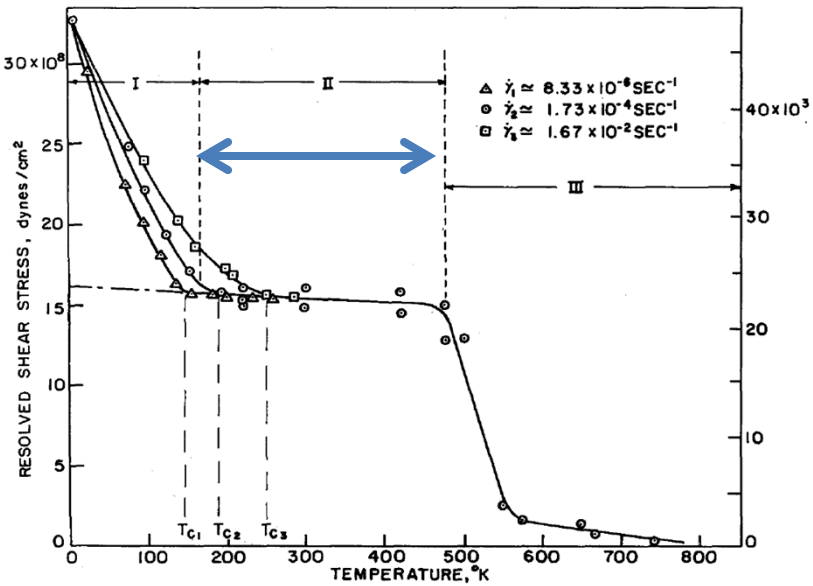


Effect of temperature on CRSS for prismatic slip of Ag 33at.% Al single crystal

Athermal Mechanisms

- Yield stress decreases slightly with T (so does shear modulus G)
- Yield stress independent of strain rate
- von Karman assumption that deformation stress is only a function of strain is good

- Surmounting long range stress field
- Breaking attractive junctions (x functions)
- Overcoming strong-solute atom locking
- …



Thermally Activated Mechanisms

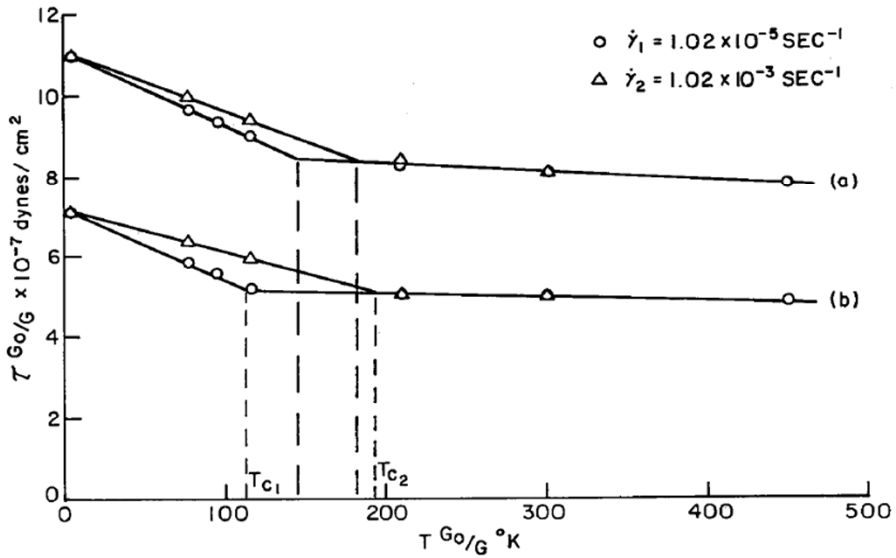
- When barriers are **localized** and **not too high**
- Yield stress depends on T and strain rate
- T_c increase with strain rate

$$\tau = \tau_A + \frac{U_j}{Lb^2} - \frac{kT}{Lb^2} \ln\left\{\frac{NAb^2\nu_0}{L\dot{\gamma}}\right\} \qquad T \leq T_c$$

$$\tau = \tau_A \qquad T \geq T_c$$

$$\tau_A = \tau_{A_0} G/G_0$$

- Intersection (forest dislocation)
- Peierls mechanism (kink pair)
- Cross slip
- Solute atom
- Diffusion controlled mechanisms



Effect of temperature on flow stress of Al single crystal at two pre-strains

Kink Pair Nucleation Mechanism

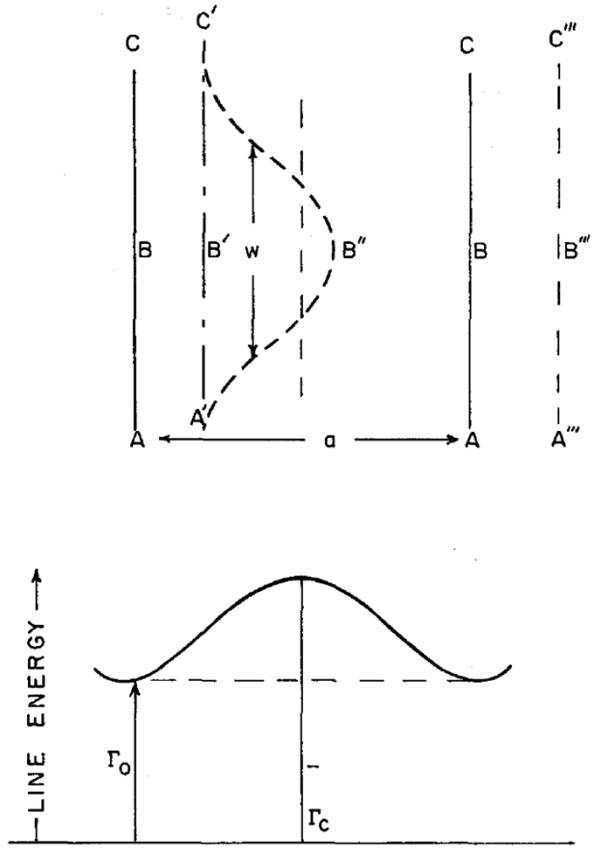


Fig. 4—Nucleation of a pair of dislocation kinks in the Peierls process

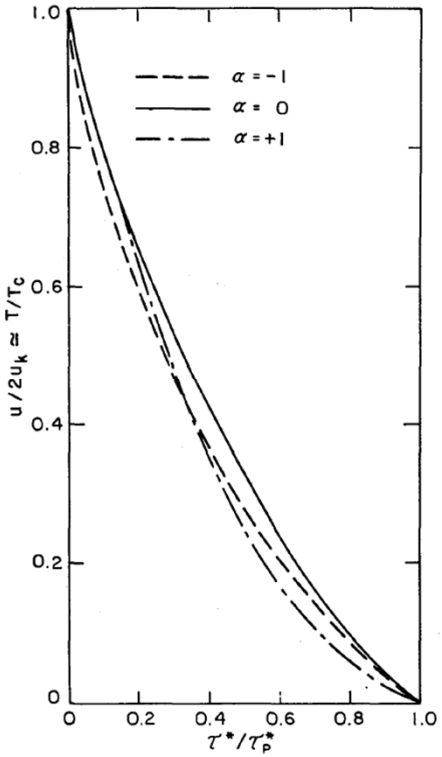


Fig. 5—Effect of stress on the activation energy for kink nucleation

$$v = \frac{\nu a L}{w} e^{-U_n/kT} \qquad T \leq T_c$$

$$\dot{\gamma} = \frac{\rho b a L \nu}{w} e^{-U_n/kT} \qquad T \leq T_c$$

$$\dot{\gamma} = \frac{\rho b a L \nu}{w} e^{-2U_k/kT_c} \quad \text{At } T_c$$

High-velocity Damping

- When stress exceeds $\tau^* + \tau_A$

$$(\tau - \tau_B) \simeq \frac{CvT}{25c} \frac{\dot{\gamma}}{\rho b} = \frac{CvT\sqrt{3}\dot{\epsilon}}{25c\rho b}$$

- Thermoelastic
  (local T change as dislocation move)
- Phonon viscosity
  (change of phonon modes)
- Anharmonic damping
  (non-linear dislocation core)
- Phonon scattering
  (by disl stress field, by disl vibration)

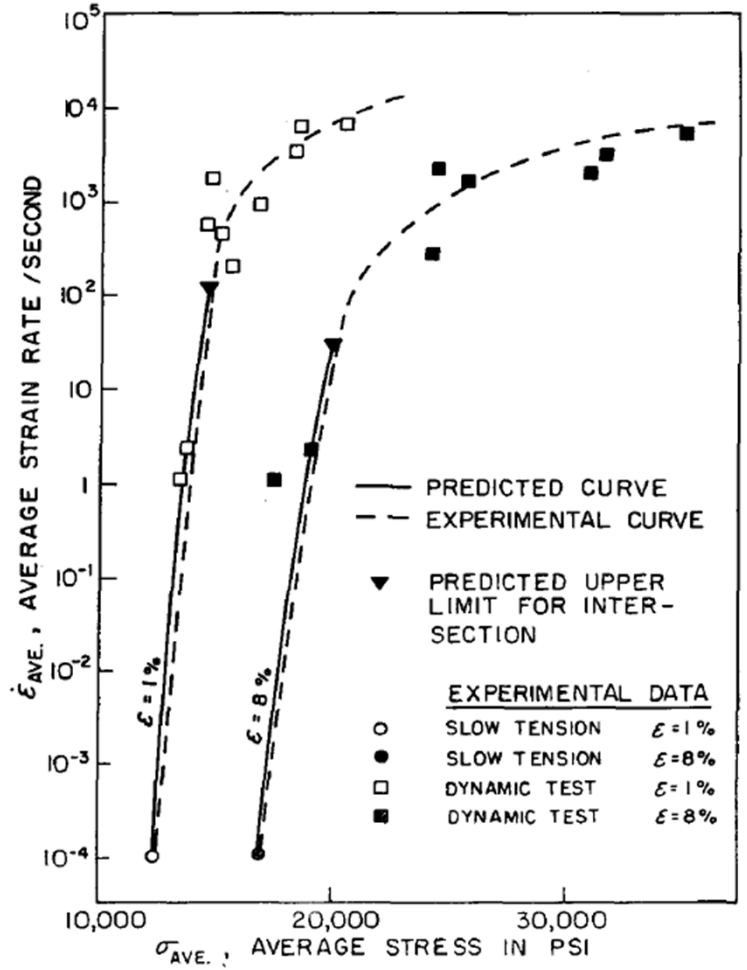


Fig. 7a—Prediction of the dynamic plastic behavior in the intersection region for pure Al at T = 77°K

Relativistic Effects

- Line energy of screw dislocation

$$\Gamma = \Gamma_0 / \left\{ 1 - \left(\frac{v}{c} \right)^2 \right\}^{1/2}$$

- Experimental verification difficult

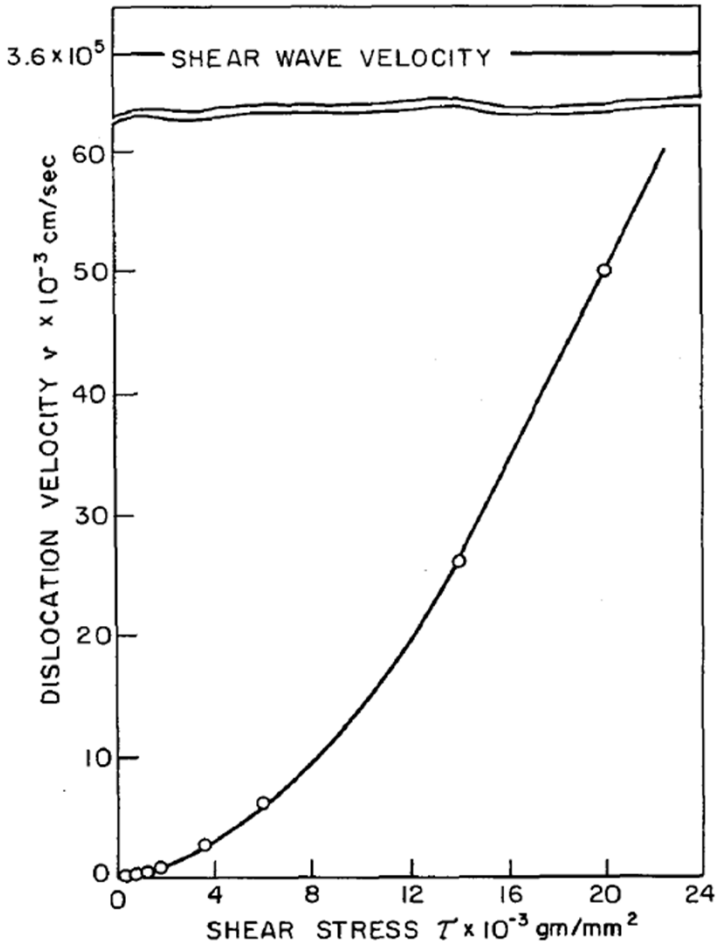


Fig. 8b—Edge-dislocation velocity vs. resolved shear stress for LiF[30]

Johnston & Gilman, J. Appl. Phys. 30, 129 (1959)

Dislocation Mobility Data

$$F = (\tau - \tau_B)b = Bv \qquad (20)$$

B is **drag coefficient**
$M = B^{-1}$ is **mobility**

τ in unit of 1 = dynes/cm^2 = 0.1 Pa
B in unit of 0.1 Pa·s

TABLE 4—DISLOCATION-DAMPING COEFFICIENTS [B of eq (20)]

Material	LiF	NaCl	KCl	Quartz	Cu	Cu–0.13% Mn
Observed Values						
Dislocation-velocity measurements	7×10^{-4}[30]	2×10^{-4}[31]				
Acoustical-attenuation measurements	1.3×10^{-3}[38]	2×10^{-3}[40]	3.5×10^{-4}[38]	6×10^{-4}[24]	6×11^{-5}[24] 7.9×10^{-5}[38] 8×10^{-4}[41] 6.5×10^{-4}[42]	4.5×10^{-4}[38]
Theoretical Values						
Thermoelastic	1.7×10^{-4}[24]	7.1×10^{-5}[24] 7.7×10^{-5}[38]		2.5×10^{-5}[24]	1×10^{-5}[24]	
Phonon viscosity	9×10^{-4}[24] 4.5×10^{-5}[38]	2.1×10^{-3}[24] 1.1×10^{-4}[38]	1.9×10^{-4}[38]	6×10^{-4}[24]	5×10^{-5}[24] 7×10^{-5}[38]	1×10^{-4}[38]
Phonon scattering	5.6×10^{-5}[24,38]	7.7×10^{-5}[24]	5.9×10^{-5}[38]	4×10^{-5}[24]	1×10^{-4}[24] 1.1×10^{-4}[38]	9×10^{-5}[38]