Dislocation Multiplication
Dislocation Motion - II

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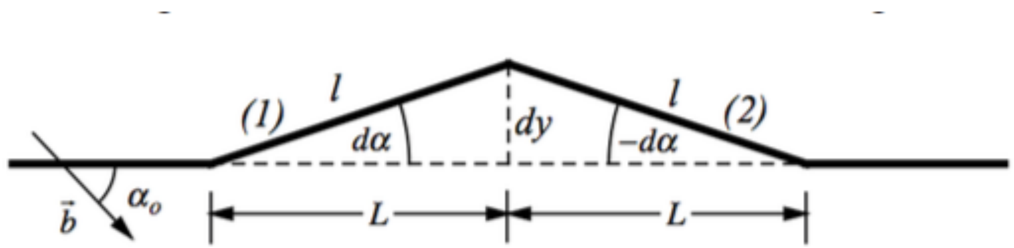
Lecture 10

Fall 2015

Line Tension



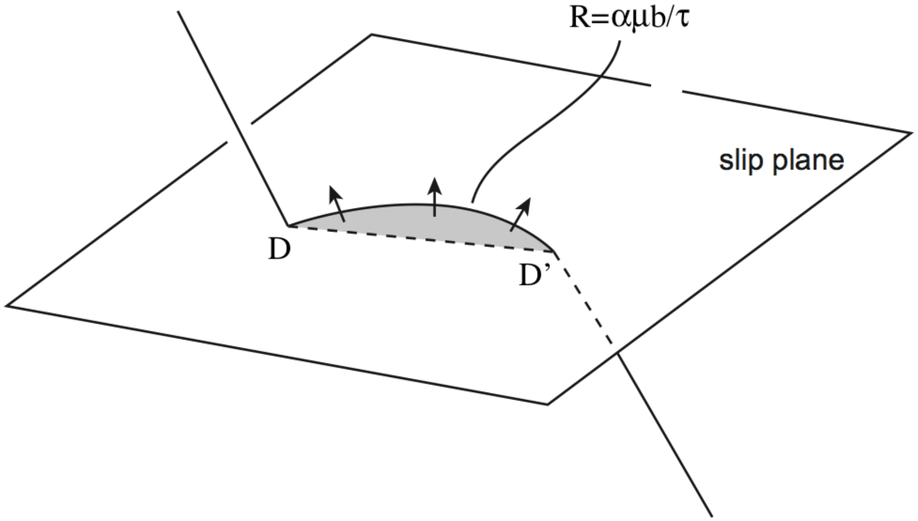
$$l^2 = L^2 + \left(L\tan(d\alpha)\right)^2 \approx L^2\left(1+(d\alpha)^2\right),$$

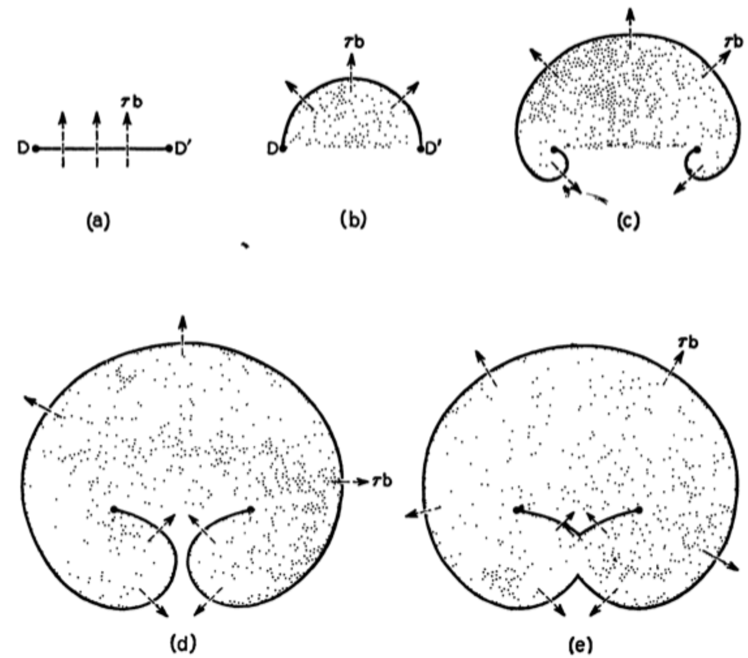
$$l = L\left(1+(d\alpha)^2\right)^{1/2} \approx L\left(1+\frac{(d\alpha)^2}{2}+\ldots\right) = L\left(1+\frac{(d\alpha)^2}{2}\right).$$

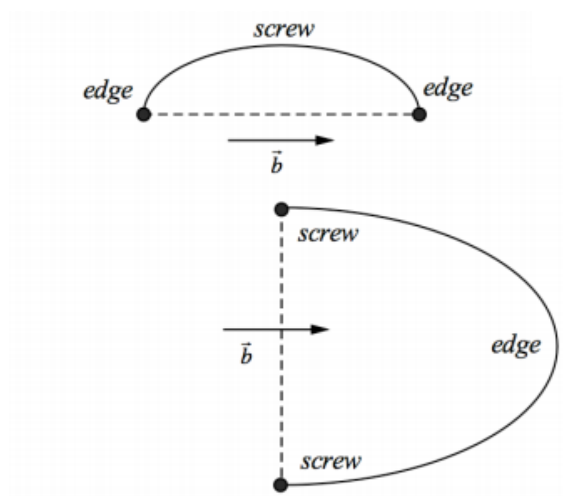
$$E(\alpha) \approx E(\alpha_o) + \frac{\partial E(\alpha)}{\partial \alpha}d\alpha + \frac{\partial^2 E(\alpha)}{\partial \alpha^2}\frac{(d\alpha)^2}{2}.$$

[Lecture Notes by Julia Greer, Caltech, http://www.jrgreer.caltech.edu/teaching.php#116]

Frank-Read Source







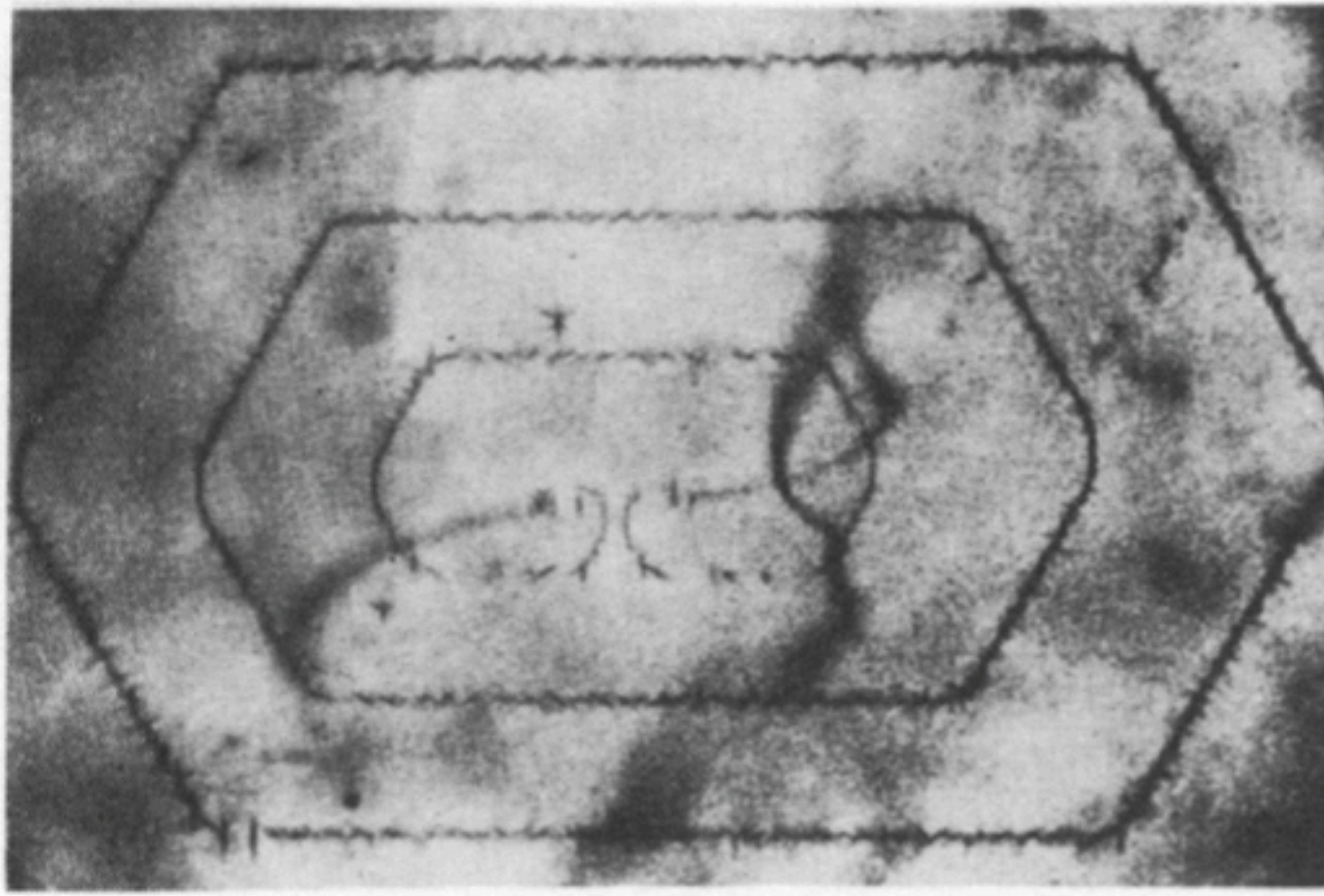


FIGURE 35. Frank-Read source in silicon. Photograph obtained by infrared technique.
(courtesy of W.C. Dash [24].)

Dislocation Pile-up

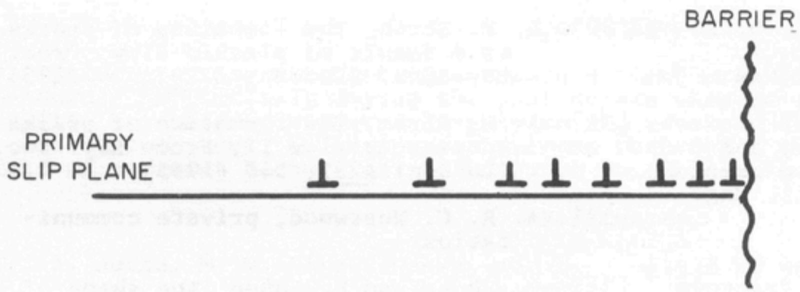


FIGURE 4. Sketch showing how dislocations pileup at barrier.

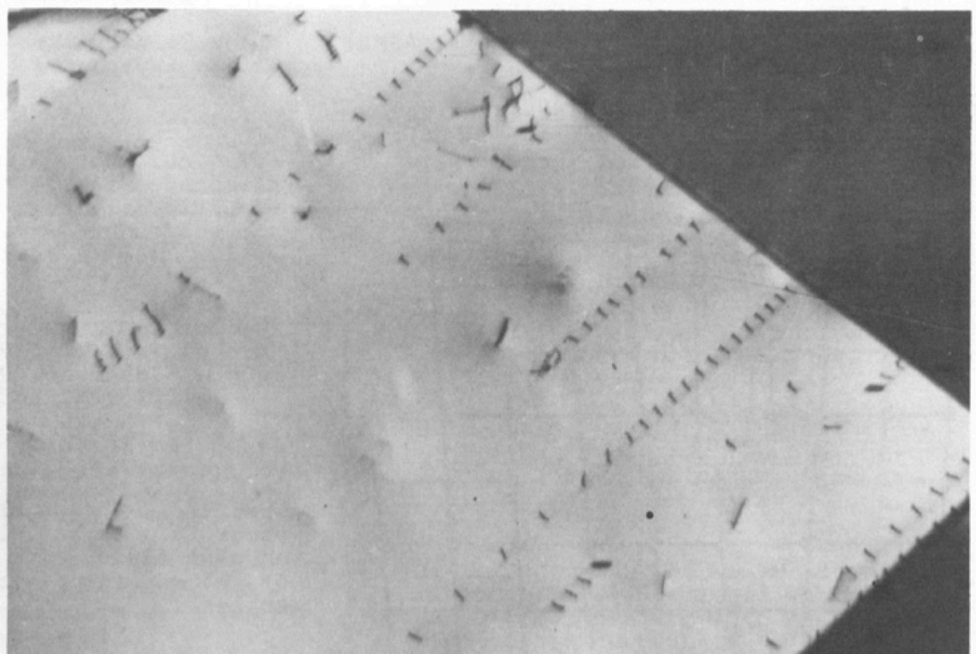


FIGURE 5. Transmission electron micrograph showing dislocations piledup at grain boundary in copper-aluminum alloy 45,000X. (courtesy P. Swann.)

Dislocation Motion at High Velocities

For edge dislocation moving at constant velocity

$$\frac{\partial^2 u_1^i}{\partial x_1^2} - \frac{1}{a_1^2}\frac{\partial^2 u_1^i}{\partial t^2} + \frac{a_2^2}{a_1^2}\frac{\partial^2 u_1^i}{\partial x_2^2} + \left(1 - \frac{a_2^2}{a_1^2}\right)\frac{\partial^2 u_2^i}{\partial x_1 \partial x_2} = 0$$

$$\frac{\partial^2 u_2^i}{\partial x_1^2} - \frac{1}{a_2^2}\frac{\partial^2 u_2^i}{\partial t^2} + \frac{a_1^2}{a_2^2}\frac{\partial^2 u_2^i}{\partial x_2^2} - \left(1 - \frac{a_1^2}{a_2^2}\right)\frac{\partial^2 u_1^i}{\partial x_2 \partial x_1} = 0 .$$

where a_1 and a_2 are longitudinal and shear wave velocities, respectively:

$$a_1 = \sqrt{\frac{\lambda + 2\mu}{\rho}} \text{ and } a_2 = \sqrt{\frac{\mu}{\rho}}$$

Lorentz transformations can solve the above equations

$$x_1'^i = \frac{x_1^i - v^i t}{\sqrt{1 - \frac{v^{i2}}{a_2^2}}}; \quad x_2'^i = x_2^i; \quad x_3'^i = x_3^i; \quad t'^i = \frac{t - v^i x_1^i / a_2^2}{\sqrt{1 - \frac{v^{i2}}{a_2^2}}} .$$

Elastic Fields around a Moving Dislocation

Burgers vector of magnitude b^i along the positive or negative x_1-direction. Introducing the longitudinal wave velocity a_1 and the shear wave velocity a_2, according to

$$a_1 = \sqrt{\frac{\lambda + 2\mu}{\rho}} \quad \text{and} \quad a_2 = \sqrt{\frac{\mu}{\rho}}, \tag{1}$$

respectively, where λ and μ denote the Lamé elastic constants and ρ is the material density, and defining

$$\alpha^i = \sqrt{1 - \frac{v^{i^2}}{2a_2^2}}, \quad \beta_1^i = \sqrt{1 - \frac{v^{i^2}}{a_1^2}} \quad \text{and} \quad \beta_2^i = \sqrt{1 - \frac{v^{i^2}}{a_2^2}}, \tag{2}$$

we can write the high-velocity displacement fields u_1^i and u_2^i of dislocation i as [4]

$$u_1^i(\Delta x_1^i, \Delta x_2^i) = \frac{b^i}{\pi}\frac{a_2^2}{v^{i^2}}\left\{\arctan\left(\frac{\beta_1^i \Delta x_2^i}{\Delta x_1^i}\right) - \alpha^{i^2}\arctan\left(\frac{\beta_2^i \Delta x_2^i}{\Delta x_1^i}\right)\right\}, \tag{3}$$

$$u_2^i(\Delta x_1^i, \Delta x_2^i) = \frac{b^i}{2\pi}\frac{a_2^2}{v^{i^2}}\left\{\beta_1^i \ln\left((\Delta x_1^i)^2 + (\beta_1^i \Delta x_2^i)^2\right) - \frac{\alpha^{i^2}}{\beta_2^i}\ln\left((\Delta x_1^i)^2 + (\beta_2^i \Delta x_2^i)^2\right)\right\} \tag{4}$$

with $(\Delta x_1^i, \Delta x_2^i) \equiv (x_1 - x_1^i(t), x_2 - x_2^i(t))$. The corresponding stresses are given by

$$\sigma_{12}^i(\Delta x_1^i, \Delta x_2^i) = \frac{2\mu b^i}{\pi}\frac{a_2^2}{\beta_2^i v^{i^2}}\left\{\frac{\beta_1^i \beta_2^i \Delta x_1^i}{(\Delta x_1^i)^2 + (\beta_1^i \Delta x_2^i)^2} - \frac{\alpha^{i^4}\Delta x_1^i}{(\Delta x_1^i)^2 + (\beta_2^i \Delta x_2^i)^2}\right\}, \tag{5}$$

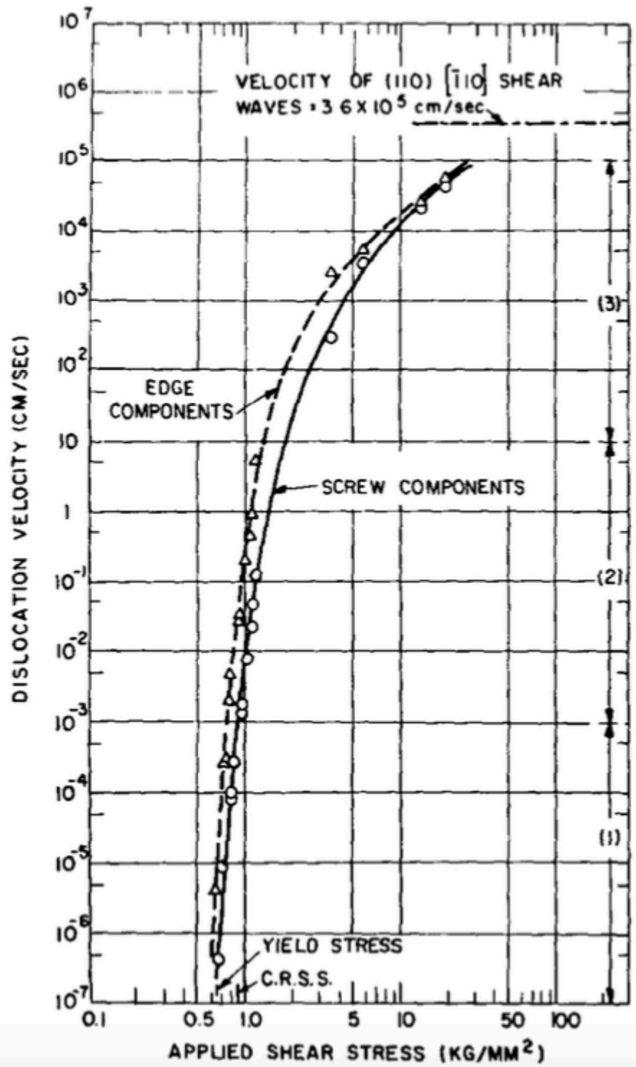
$$\sigma_{11}^i(\Delta x_1^i, \Delta x_2^i) = \frac{2\mu b^i}{\pi}\frac{a_2^2}{v^{i^2}}\left\{\frac{-\beta_1^i\left(\beta_2^{i^2} + 1 - \alpha^{i^2}\right)\Delta x_2^i}{(\Delta x_1^i)^2 + (\beta_1^i \Delta x_2^i)^2} + \frac{\alpha^{i^2}\beta_2^i \Delta x_2^i}{(\Delta x_1^i)^2 + (\beta_2^i \Delta x_2^i)^2}\right\}, \tag{6}$$

$$\sigma_{22}^i(\Delta x_1^i, \Delta x_2^i) = \frac{2\mu b^i}{\pi}\frac{\alpha^{i^2} a_2^2}{v^{i^2}}\left\{\frac{\beta_1^i \Delta x_2^i}{(\Delta x_1^i)^2 + (\beta_1^i \Delta x_2^i)^2} - \frac{\beta_2^i \Delta x_2^i}{(\Delta x_1^i)^2 + (\beta_2^i \Delta x_2^i)^2}\right\}, \tag{7}$$

[Roos, et al, Computational Materials Science, Vol 20, 2001]

Glide Velocity

LiF



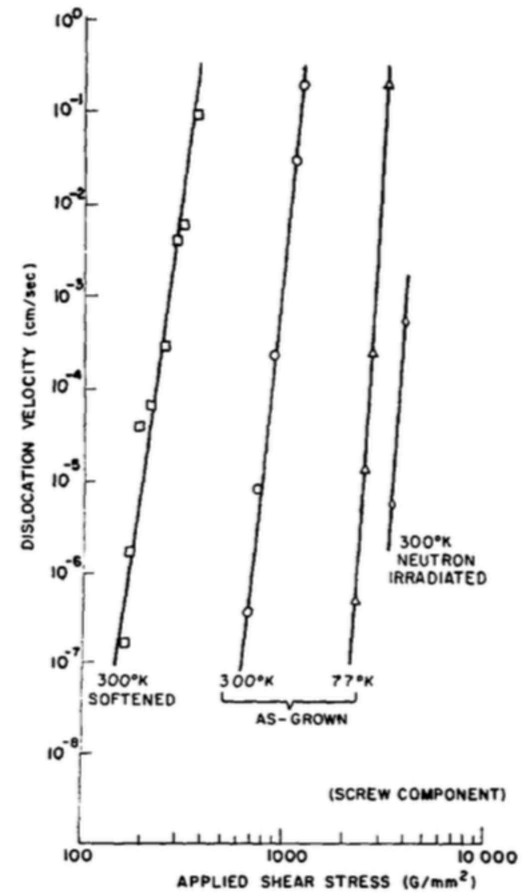


FIG. 6. Velocities of the screw components of dislocation loops *versus* applied shear stress for crystals of different hardnesses.

[Johnston & Gilman, JAP, 1959]

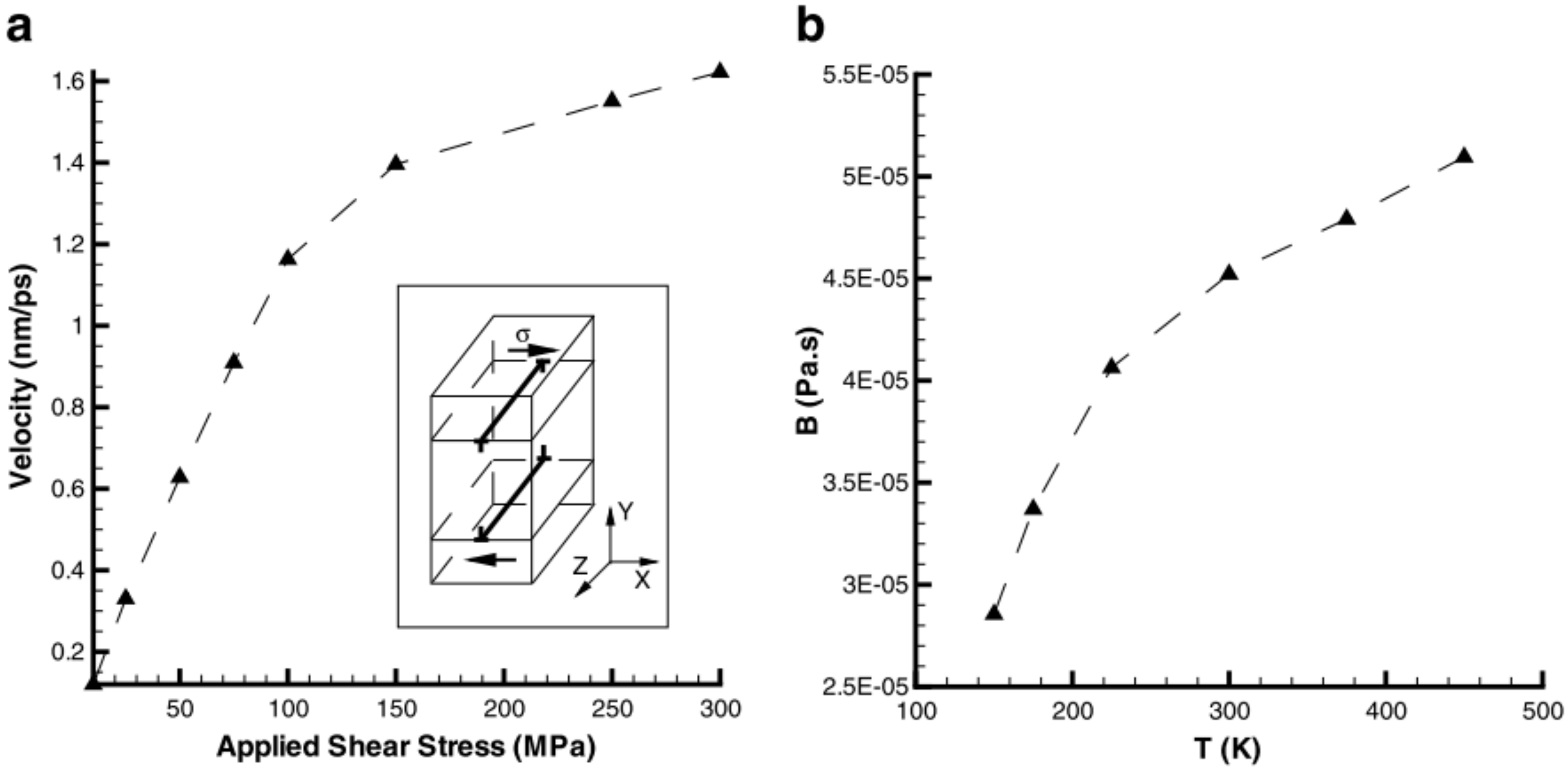


Fig. 2. (a) Velocity as a function of the applied shear stress for edge dislocations in Al. The inset figure represents the initial dipole configuration and the boundary conditions. (b) Dislocation damping constant vs. temperature.

[Groh et al, Inter J. Plasticity, 2009]

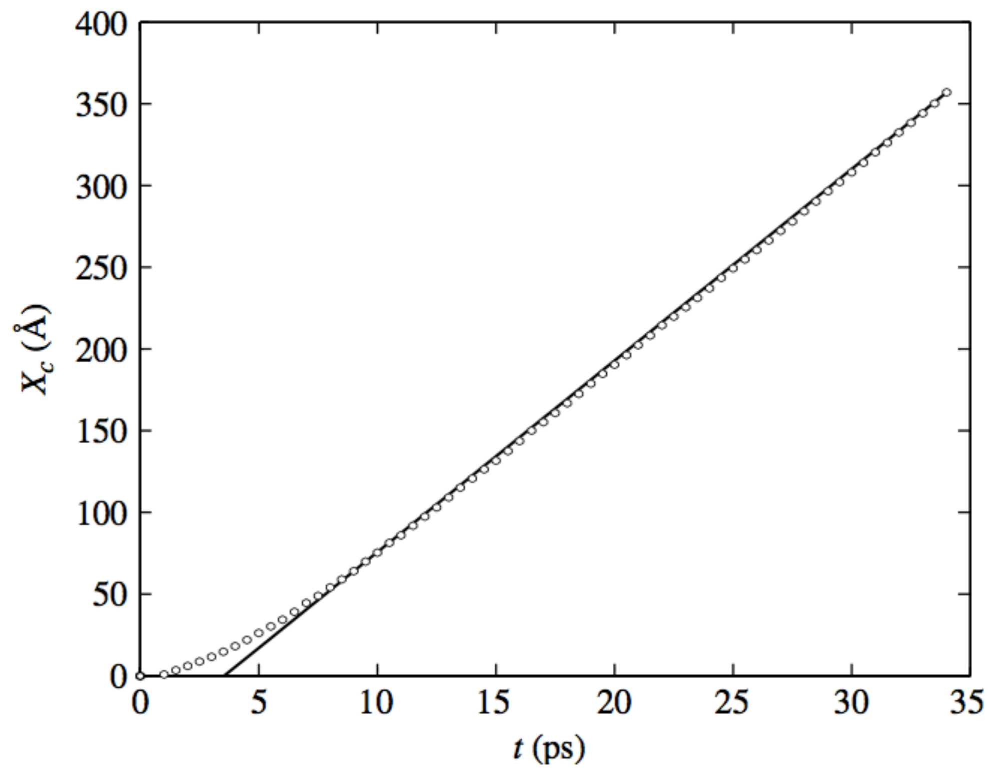


FIG. 4.4. Dislocation position as a function of time (circles), obtained in an MD simulation at $T = 300\,\mathrm{K}$ and stress $\sigma_{xy} = 300\,\mathrm{MPa}$. The straight line is a linear fit of the data for $t > 10\,\mathrm{ps}$, corresponding to an average dislocation velocity of $v = 1170\,\mathrm{m\,s^{-1}}$.

[Bulatov & Cai, Computer Simulations of Dislocations, Oxford University Press, 2006]

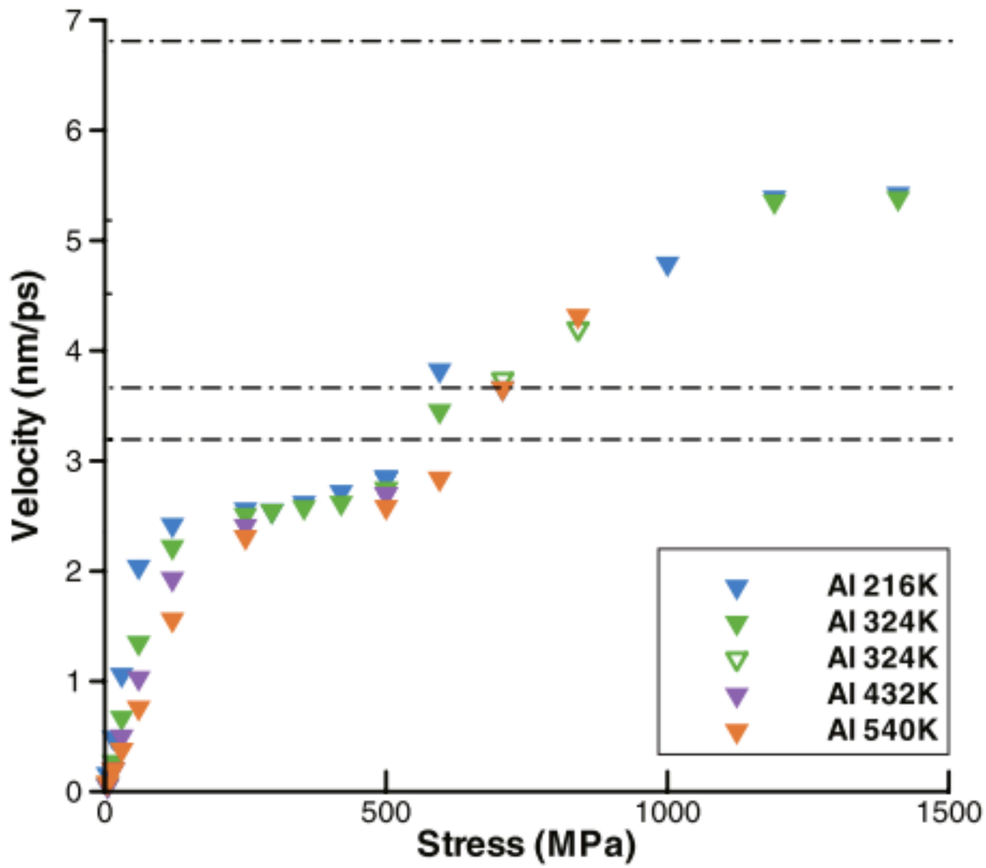


Figure 5. Velocity as a function of the applied shear stress for an edge dislocation in aluminium. The dashed lines are the forbidden velocities from continuum linear elasticity, which for the edge dislocation are equal to the wave speeds. For simulations with σ/T at least about 0.9, and σ no more than about 400 MPa there is a plateau region where the velocity saturates at about 2.6 nm ps^{-1}, independent of temperature. There is some evidence of a jump across the velocity region of at least the lower of the two similar shear wave speeds. The open symbols for 324 K for 707 MPa and 841 MPa are described in the text.

[Olmsted, et al., Modeling and Simulation in Mater Sci and Eng, 2005]