Key

MTE 579 - Homework #4
Due W, April 26th 2017

1. (10 pts) What is the criteria for a dislocation to cross slip from one plane to another? Can an edge dislocation cross-slip, why or why not?

2. (10 pts) Consider two parallel, indefinitely long straight dislocations in an FCC crystal with $\xi_1 = \mathbf{k}$, $\mathbf{b}_1 = \mathbf{i}b_1$, $\xi_2 = \mathbf{k}$, $\mathbf{b}_2 = -\mathbf{j}b_2$ (where ξ is the sense vector, **b** is the Burger's vector and **i**, **j**, **k** are the base vectors of an orthogonal coordinate system). Determine the force from #2 on #1 between the two dislocations.

3. (40 pts) A perfect a/2[-101] dislocation reaction takes place on a (111) plane.
   a. Identify the Burger's vectors of the two partial dislocations, i.e. tell me what the two partial $\mathbf{b}_2$ and $\mathbf{b}_1$ are.
   b. If another perfect dislocation of a/2[110] on (-11-1) dissociates into partials, determine its partials as well.
   c. Finally, describe (using specific Shockley partials from (a) and (b) above) a reaction that would lead to a Lomer-Cottrell lock (stair rod dislocation)
   d. How does a stair rod dislocation a hardening mechanism?

4. (40 points) Explain, in detail, (and provide label diagrams if needed) the hardening mechanism below using elementary dislocation theory.
   a. Solid solution hardening
   b. Orowan bowing between precipitates
   c. Hall-Petch relationship for small grains
   d. Describe the formation of dislocations from a Frank-Reed source

5. (30 pts) A heavily work hardened material is annealed.
   (a) Describe the major changes in dislocation and grain structures during the working hardening process.
   (b) Explain how the fraction of recrystallized material depends on temperature and time, and how such data may be used to calculate the activation energy for recrystallization.
   (d) As a process engineer you know that a particular cold worked alloy recovers 50% in 10 min. at 455°C or in 100 min. at 300°C. How long would it take for 50% recovery at 40°C?

6. (10 pts) What are the three underlying assumptions for normal grain growth that exhibits parabolic behavior?

7. (10 pts) In solute grain boundary drag, solute that is attracted and repealed from the grain boundary can slow down grain boundary motion. How does each type of solute (attractive and repulsive) do this? Provide diagrams if necessary.

1. Cross slip is the glissile movement of a disl. from one plane to another.

For a plane to ~~contain~~ be a slip plane it must contain both the $\vec{b}$ & $\hat{\xi}$

Since a screw disl. has $\vec{b}$ & $\hat{\xi}$ parallel, all planes can be a slip plane

However sine $\vec{b}$ is normal to $\hat{\xi}$ for edge disl., there is only one unique slip plane defined as $\vec{b} \times \hat{\xi} = \hat{n}$ ~~dan~~ where $\hat{n}$ is normal to the slip plane.

Thus an edge disl. can not cross slip b/c there is not two planes that contain both simultaneous $\vec{b}$ & $\hat{\xi}$ ($\vec{b} \equiv$ burgers vector ; $\hat{\xi} \equiv$ line sense of disl.)

2. Disl #1   Disl. #2

$\hat{\xi}_1 = [001]$ $\hat{\xi}_2 = [001]$

$\vec{b}_1 \; [b_1 00]$ $\vec{b}_2 = [0 b_2 0]$

Force of #2 on #1

$$\frac{F}{L} = (\hat{\sigma}\vec{b}) \times \hat{\xi} \Rightarrow (\hat{\sigma}_2 \vec{b}_1) \times \hat{\xi}_1$$

$$= \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} \begin{bmatrix} b_1 \\ 0 \\ 0 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$[\, b_1 \sigma_{11} \hat{i} \quad b_1 \sigma_{21} \hat{j} \quad b_1 \sigma_{31} \hat{k} \,] \times \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

For edge disl. $\sigma_{31} = \emptyset$ $\sigma_{11} \neq \emptyset$ $\sigma_{21} \neq \emptyset$

$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ b_1 \sigma_{11} & b_1 \sigma_{21} & 0 \\ 0 & 0 & 1 \end{vmatrix} = b_1 \sigma_{21} \hat{i} - b_1 \sigma_{11} \hat{j} + 0 \hat{k}$$

$$\frac{F}{L} = b_1 \left(\frac{G b_2}{2\pi(1-\nu)} \frac{\cos\theta \cos 2\theta}{r} \right) \hat{i} + b_1 \left(\frac{G b_2}{2\pi(1-\nu)} \frac{\sin\theta (2 + \cos(2\theta))}{r} \right) \hat{j}$$

OK

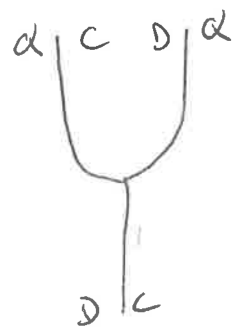
$$\frac{F}{L} = b_1 \left(\frac{G b_2}{2\pi} \frac{x(x^2 - y^2)}{(x^2 + y^2)^2} \right) \hat{i} - b_1 \left(\frac{G b_2}{2\pi(1-\nu)} \right) \left(\frac{y(3x^2 + y^2)}{(x^2 + y^2)^2} \right)$$

3. $\frac{1}{2}[\bar{1}01] \rightarrow CB$ $\quad\delta$ plane (111)

(a) CB

$$\frac{1}{2}[\bar{1}0\bar{1}] \rightarrow \underset{\text{leading}}{\frac{1}{6}[\bar{2}11]} + \underset{\text{STACKING FAULT}}{SF} + \underset{\text{trailing}}{\frac{1}{6}[\bar{1}\bar{1}2]}$$

(b) $\frac{1}{2}[110] \rightarrow DC$ $\quad$ on α $(\bar{1}1\bar{1})$



$$\frac{1}{2}[110] \rightarrow \frac{1}{6}[21\bar{1}] + SF + \frac{1}{6}[121]$$

3.(c) which partial react to form a Lomer-Cottrell lock?

A Lomer-Coltrell lock is formed by 2 Shockley partials & a $\frac{1}{6}\langle 110\rangle$ type locking disl.

A: $\frac{1}{6}[\bar{2}11]$ B: $\frac{1}{6}[\bar{1}\bar{1}2]$ C: $\frac{1}{6}[21\bar{1}]$ D: $\frac{1}{6}[121]$

A + C

$\frac{1}{6}[\bar{2}11] + \frac{1}{6}[21\bar{1}] \rightarrow \frac{1}{6}[020]$

A + D

$\frac{1}{6}[\bar{2}11] + \frac{1}{6}[121] \rightarrow \frac{1}{6}[\bar{1}32]$

B + C

$\frac{1}{6}[\bar{1}\bar{1}2] + \frac{1}{6}[21\bar{1}] \rightarrow \frac{1}{6}[101]$

B + D

$\frac{1}{6}[\bar{1}\bar{1}2] + \frac{1}{6}[121] \rightarrow \frac{1}{6}[013]$

The $\frac{1}{6}[\bar{1}\bar{1}2]$ ($C\delta$) on (111) reacts with the $\frac{1}{6}[21\bar{1}]$ (αC) on $(\bar{1}1\bar{1})$ to form a new Burger's vector $\vec{b} = \frac{1}{6}[101]$ on the (010) plane. This occurs b/c the square of it is less than the sum of the square of each partial,

$$\left(\frac{1}{6}[\bar{1}\bar{1}2]\right)^2 + \left(\frac{1}{6}[21\bar{1}]\right)^2 > \left(\frac{1}{6}[101]\right)^2$$

3. (d) It is a strengthening mechanism b/c the $\frac{1}{6}$ [101] is not on a favorable slip plane (010) → consequently it becomes sessile. Thus, the ~~the~~ other partials on either the (111) or $(\bar{1}1\bar{1})$ planes are pinned. For them to move, the line length of the disl. increases & is not energically favorable. This makes the metal harder

4. (a) Solid solution hardening (SSH):

SSH comes from the strain fields created by alloy elements in solution with the matrix. These strain fields interact with the disl.

Specifically:

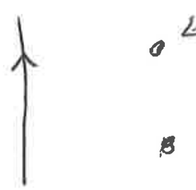
(1) Parelastic interactions → changes in lattice parameter b/c different sized radii

(2) Dielastic interaction → alloy elements alter local bonding & thus the shear modulus

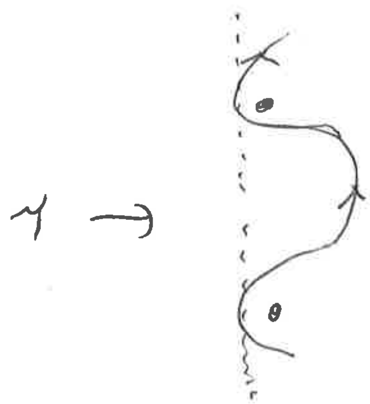
(3) Chemical interaction or Suzuki effect → Solutes will alter S.F.E. as well as be attracted to or repeal to disl. cores ~~effected~~ effecting disl. mobility (velocity)

4. (b) Orowan

Disl. approaches a pinning barrier



For the disl. to continue, the disl. line length must increase which is not energetically favorable to do & provides strengthening (resistance to disl. motion

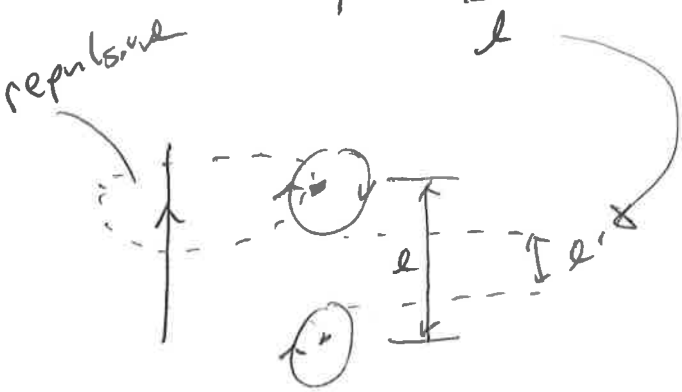


~~Even~~ Eventually the disl. around the pinning sites come into closer proximity; however the line senses are opposite & attract and pinch off a loop around the barrier

4. (b) continued.

Next disl. that comes up to the loop disl. has same line sense and now has additional repulsive force to over come. Furthermore the ~~sens~~ spacing between the barrier has reduced b/c of the loop making the stress higher → ~~rec~~ recall

$$\tau = \frac{\mu b}{l}$$



4. (c) Hall - Petch

As the grain size decreases, the hardness increases →

$$\sigma_i = \sigma_o + \frac{k}{\sqrt{d}}$$

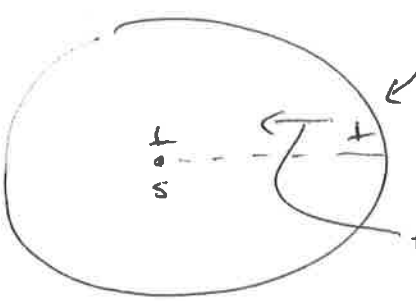
where σ_o is large grain (initial) yield strength

k constant related to multiplicity of slip systems

& d is grain size

As the grain emits disl., the propogate or glide till they are impeded @ the grain boundary. Since deformation requires disl. movement, the ceasing of disl. motion increases strength. Another disl must be emitted but it will have the same sign of the initial disl. → thus the disl. @ the grain boundary

disl. impeded @ g.b



produces back stress source to repeal more disl.

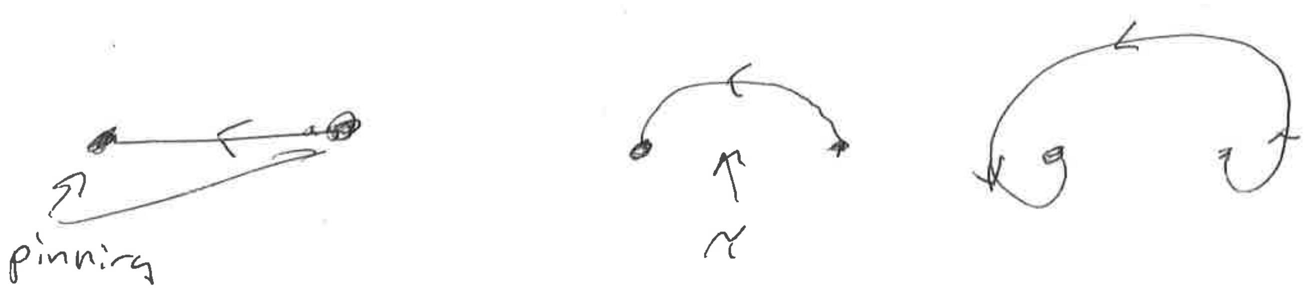
~~As grain~~ s

4.(c) continued

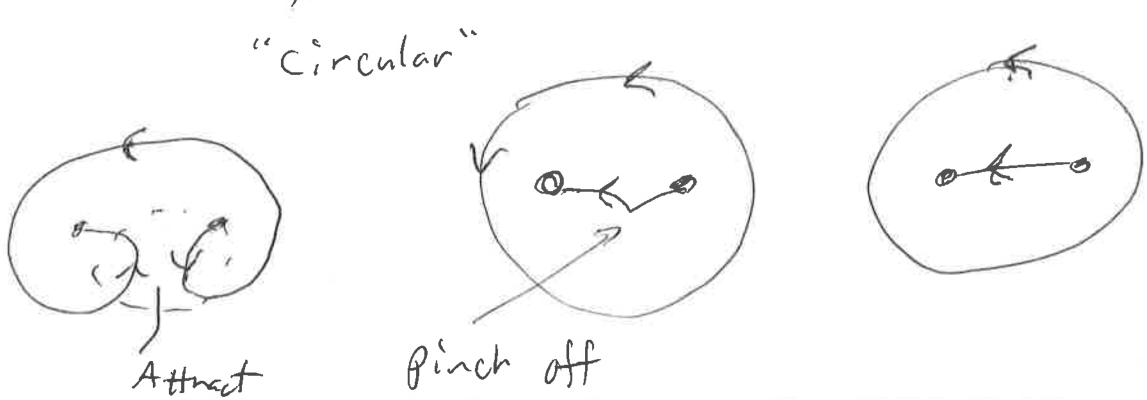
As grain size is small volume, it limits the # of disl. it can accomodiate as well ~~places~~ places back stress on source quicker to shut it down

4.(d) Frank-Reed source

A disl. is pinned and as the stress increases, the disl. bows out

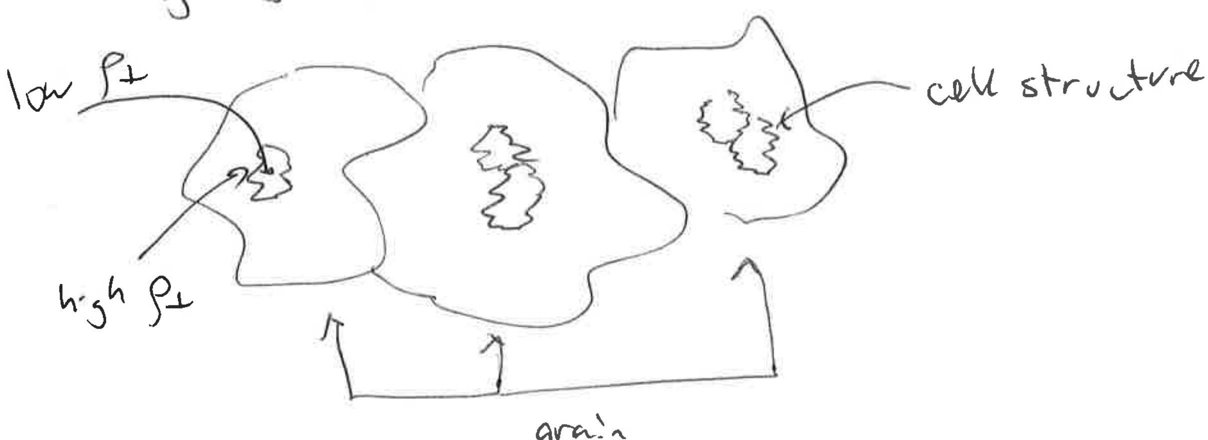


Eventually the disl. ends, which have opposite line sense, attract and pinch off releasing a disl outward. Process repeats



5.

(a) When a material deforms, disl. are emitted. These can be statisically stored & geometrically necessary disl. As a disl. is not an energically favorable defect, the system aims at trying to reduce/annihelate them. In this process they form cells or sub grains within the grains. This is shown below



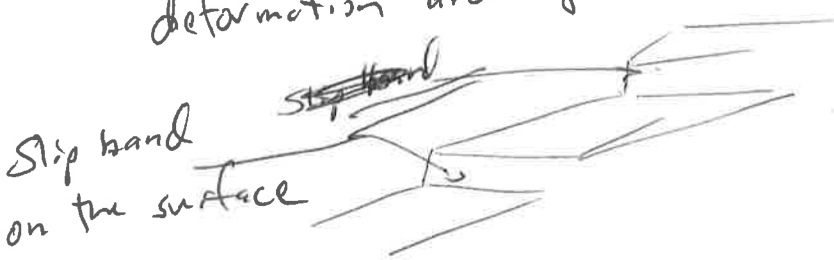
The cell walls & contain a higher disl. density whereas within the subgrain is a lower disl. density region.

As the material is deformed more, the cell walls thicken as, more & more disl. are accomediated in this location

5(a). continued...

The cell eventually break down & form micro bands of very high disl. content

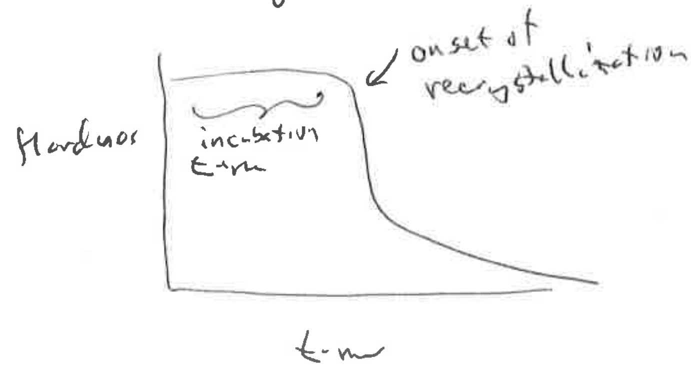
Upon further deformation, slip bands form on the surface due to the continuous deformation and production of disl.



5.(b) Chpt. 15 in text

Recrystallization is the nucleation of new, disl. free grains. The energetics of their formation is driven by the stored energy that is imparted by the disl. content from deformation.

Thus as the disl. density increases, the driving force for recrystallization increases, and the temp. ~~to~~ to initiate decreases. In reference to time, being a nucleation event, there is an incubation time after which recrystallization occurs quite readily



The time of recrystallization is an Arrhenius relationship, where $\frac{1}{\tau}$ is the rate of recrystallization

$$\frac{1}{\tau} = A \exp\left(-Q/RT\right)$$

The activation barrier, Q, is found, by measuring the time (or rate) for recrystallization for different temp.

5. (c)

50% recrystal. in 10 min @ 455°C #2

" " " 100 " 300°C #1

How long for 50% @ 40°C

$$(\text{Rate}) = A e^{-Q/RT}$$

$$A = (\text{Rate})_1 e^{Q/RT_1}$$

$$(\text{Rate})_2 = \left[(\text{Rate})_1 e^{Q/RT_1} \right] e^{-Q/RT_2}$$

$$\frac{(\text{Rate})_2}{(\text{Rate})_1} = e^{-Q/R\left(\frac{1}{T_2} - \frac{1}{T_1}\right)}$$

$$\ln \frac{(\text{Rate})_2}{(\text{Rate})_1} = -\frac{Q}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\ln\left(\frac{10}{100}\right) = \frac{-Q}{8.314 \text{ J/K}\cdot\text{mol}} \left[\frac{1}{455+273} - \frac{1}{310+273} \right]$$

$$-2.3 = -\frac{Q}{8.314 \text{ J/K}\cdot\text{mol}} \left[-3.7 \times 10^{-4} \text{ K}^{-1} \right]$$

$$Q = -51.5 \text{ kJ/mol}$$

5. (C) Cont.

-10.8

~~[illegible]~~

$$A = (\text{Rate})_1 * e^{-Q/RT_1} = 100 \times e^{+51.5 \times 10^3 \,J/mol / 8.314\, J/K\cdot mol \cdot \frac{1}{30+273}}$$

$= \text{~~[illegible]~~}\ 4.9 \times 10^6$ min

6. Assumptions for normal grain growth

- Single phase
- (*) - uninhibited g.b. motion (no solute drag / zener pinning)
- Self similar structure

$\underbrace{\hspace{6cm}}$

leads to parabolic growth $D = kt^{1/2}$

- (*) - Istropic g.b. energy & mobility
- (*) - purely curvature growth

7. If a solute is attractive to the g.b., as the g.b. moves, the solute will provide a drag (or "pull back" force) so the g.b. does not move faster than the solute can diffuse with the g.b.

If the solute is repulsive (anti-segregating) to the g.b., it will resist the g.b. from diffusing towards it so the solute does not get absorped by the passing g.b. through the matrix