Quiz 2 – Properties-Microstructure-Processing
Callister Chapters, 7,3,4

You need to know/be able to

- Name the two types of solid solutions (interstitial and substitutional) and explain how they differ.
- Describe the difference between amorphous and crystalline and state how that structure affects properties.
- Name the three most common types of unit cells for metals and explain how the unit cell affects properties
- *State the relationship of dislocation motion and planar slip on the behavior of metals, and explain how it affects strength and ductility.*
- For the following processes, determine (from graphs and/or calculations) the strength/ductility and describe the governing microstructural mechanism
    - Solid Solution Strengthening
    - Grain Size Refinement
    - Cold Work and Annealing
- For Cold Work and Annealing
    - Calculate %cold work from change in cross-sectional geometry
    - Describe the microstructural and property changes during *Recovery, Recrystallization and Grain Growth*, and the relationship between microstructure and properties
    - Use tables and graphs (such as fig. 7.19) to design a process that will produce a set of desired properties

Vocabulary

Chapter 7

Cold working
Dislocation Density
Grain Growth
Lattice Strain
Recovery
Recrystallization
Recrystallization Temperature
Slip
Slip System
Solid-solution strengthening
Strain hardening

Chap 3

Amorphous
Anisotropy
Body-centered-cubic
Crystal structure
Crystalline
Face Centered-cubic
Grain
Grain Boundary
Hexagonal close-packed
Isotropic
Noncrystalline
Polycrystalline
Unit cell

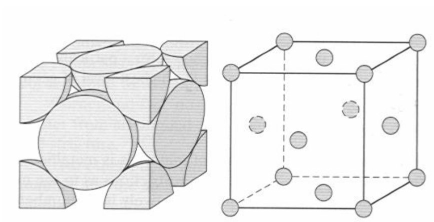
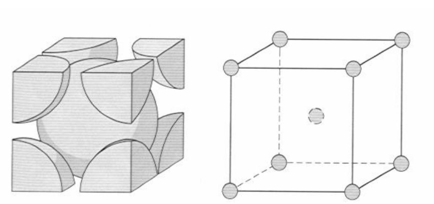
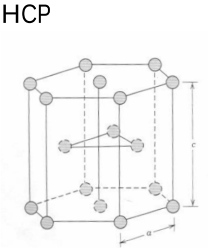
Chap 4

Alloy
edge dislocation
interstitial solid solution
microstructure
screw dislocation
solid solution
solute
solvent
substitutional solid solution
vacancy

Exam 2 Review

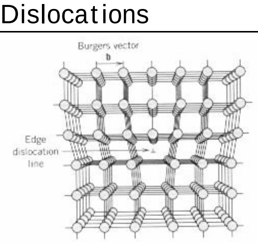
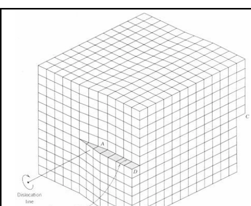
Metal Crystal Structures

Type	Name	Properties	Example
FCC	Face-Centered-cubic	Ductile at all temps	Aluminum, copper, Nickel
BCC	Body-centered-cubic	ductile-brittle transition with temp or strain rate	Iron (steel) tungsten
HCP	Hexagonal-close-packed	less ductile	Magnesium, zinc

FCC 	This is a close packed structure (packing factor is 0.74, max possible). Has close packed planes and close packed directions in several orientations.	Excellent slip systems leads to excellent ductility
BCC 	Not a close packed structure (packing factor of 0.68). No close packed planes, several close packed directions.	Good slip systems lead to good ductility unless cold or rapidly loaded
HCP 	Close packed structure with close packed planes and directions. Unfortunately, the planes are only in one orientation.	One excellent slip system in a single orientation leads to less ductility. (Mag wheels vs Al wheels)

(Figures from Materials Science and Engineering, An Introduction by Callister)

Dislocations

	Edge Dislocation: An "extra" half plane of atoms; a line defect in a crystal			Screw Dislocation: A line defect similar to a tearing a phone book.

(Figures from Materials Science and Engineering, An Introduction by Callister)

Importance: Dislocations make planar slip much easier. Since only one row of atoms moves at a time, many fewer atomic bonds must break for plastic deformation to occur

Grand Truth - Strengthening in metals

1. Yield strength is the onset of plastic flow
2. Plastic flow results from planar slip
3. Planar slip results from dislocation motion

Therefore

To increase Strength - Prevent/Impede Dislocation Motion

Ductility Corollary

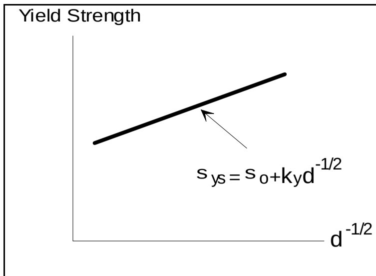
1. Impeding dislocation motion makes slip harder
2. Lower slip means lower ductility

Therefore:

Increasing Strength generally Lowers Ductility

Strengthening Methods for Metals

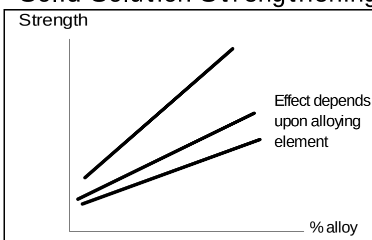
Grain Size Reduction - Small grained metals are stronger than coarse grained metals



Effect of Grain Size Reduction

Mechanism:	Process:
Grain boundaries block dislocation motion. More grains (smaller grains) means more boundaries and more blocking of dislocations	Cold work to add internal energy, anneal to recrystallize and form new small grains. Note: Strength increases without loss of toughness

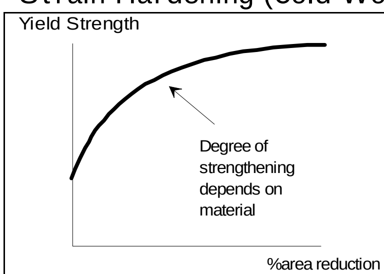
Solid Solution Strengthening - Often alloying with a second element increases strength



Solid Solution Strengthening

Mechanism:	Process:
Solute atoms are too big or too small and cause distortion ins the crystal lattice	Add other elements to the melt e.g. add Al and V to Ti to get Ti6Al4V.

Strain Hardening (Cold Work) - Plastic deformation often increases strength



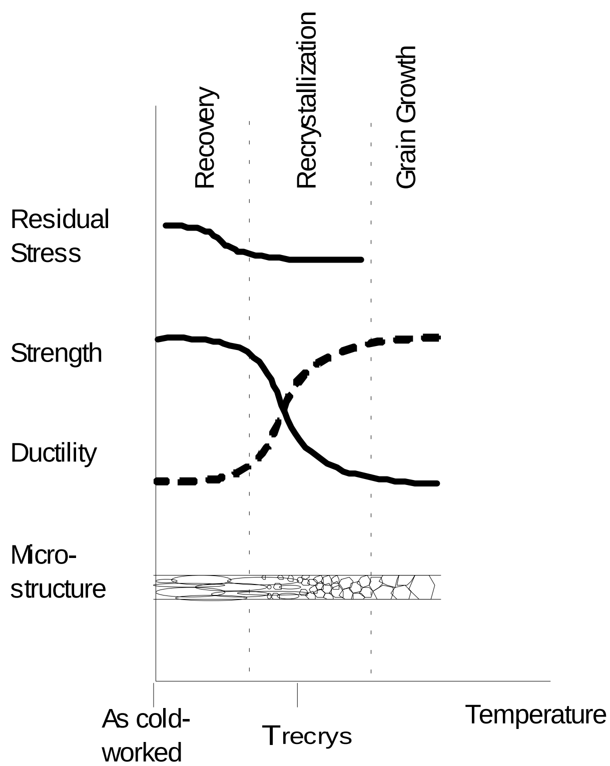
Effect of Plastic Deformation

Mechanism:	Process:
Number of dislocations increases by orders of magnitude, distorting lattice and impeding dislocations	Mechanically deform plastically. (e.g. cold roll, wire draw)

Annealing - Reversing the effects of Strain Hardening

Stages

- **Recovery** - residual stresses are relieved
- **Recrystallization** - If previously cold worked, new equiaxed, strain-free grains nucleate from high energy regions.
- **Grain Growth** - Grains grow with higher temperature and longer time (diffusion -)



This process is best understood by remembering that everything is spontaneously heading toward lowest potential energy.

Therefore, if we have no cold work, we can have no annealing since we are already at lowest potential.

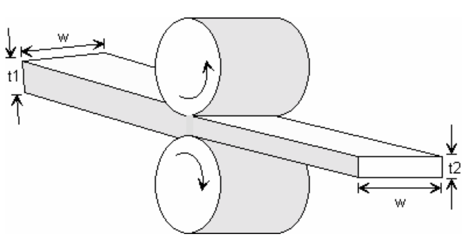
It is the high internal energy (from strain energy) of a cold worked metal that provides the energy potential for action. The increase in temperature adds enough energy (and interatomic distance) for diffusion to occur so the atoms can rearrange into new grains.

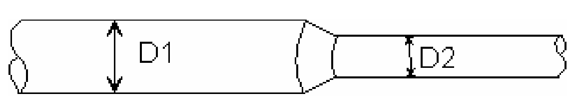
Note that the Recrystallization Temp is about 0.4*Absolute Melting temperature of the metal.

%Cold Work

The %Cold work is the %area reduction of the cross section

$$\%CW = \frac{A_0 - A_1}{A_0}(100\%)$$





In Cold rolling only thickness changes