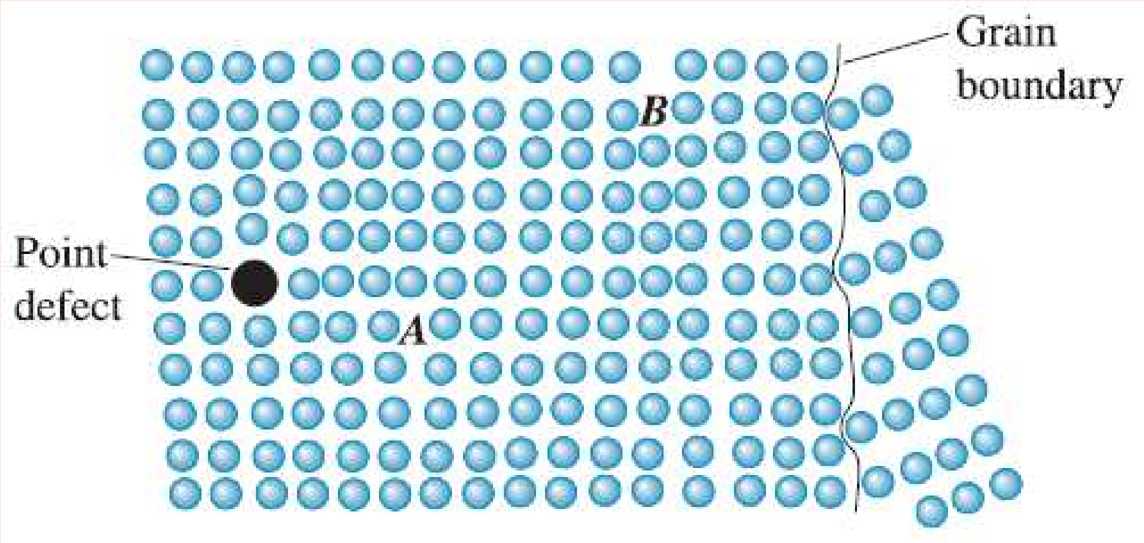
PLAYING WITH PROPERTIES

Sub-topics

Strengthening mechanisms
Heat treatment
Hot working

CAN SLIP PROCESS BE CONTROLLED?



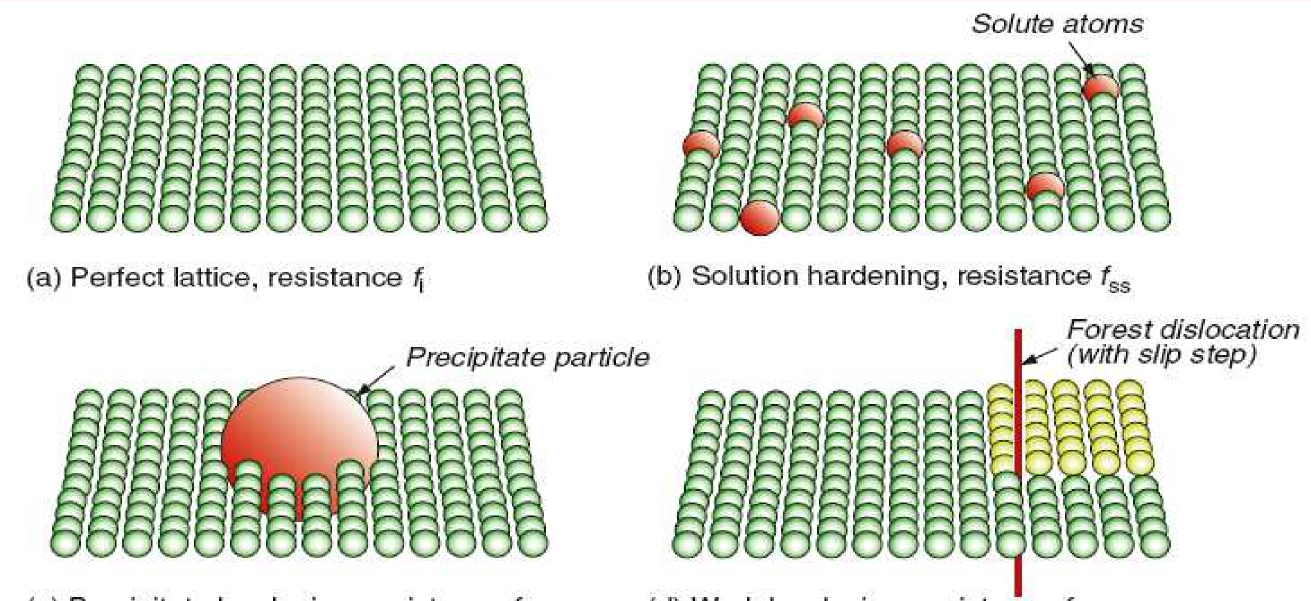
If the dislocation at point A moves to the left, it is blocked by the **point defect.**
If the dislocation moves to the right, it interacts with the disturbed lattice near the **second dislocation** at point B.
If the dislocation moves farther to the right, it is blocked by a **grain boundary.**

Defects in materials, such as dislocations, point defects, and grain boundaries, serve as "stop signs" for dislocations.

Manipulating Strength

The way to strengthen crystalline materials is to make it harder for dislocations to move

$$\tau b = f$$

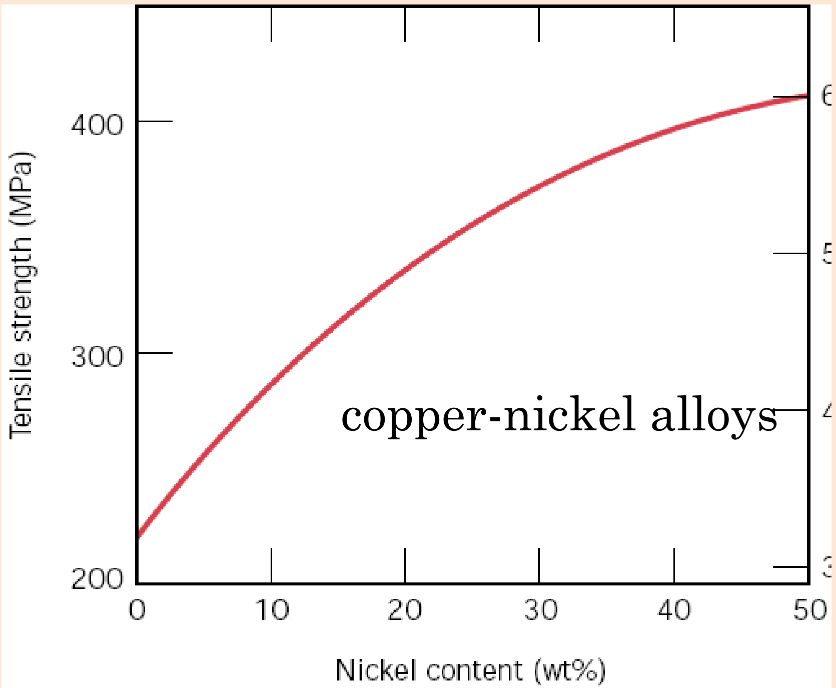


(a) Perfect lattice, resistance f_i
(b) Solution hardening, resistance f_{ss}
(c) Precipitate hardening, resistance f_{ppt}
(d) Work hardening, resistance f_{wh}

STRENGTHENING METALS

By intentionally introducing substitutional or interstitial atoms, we cause **solid-solution strengthening**

Increasing the **concentration of the impurities** results in an attendant **increase in tensile and yield strengths**



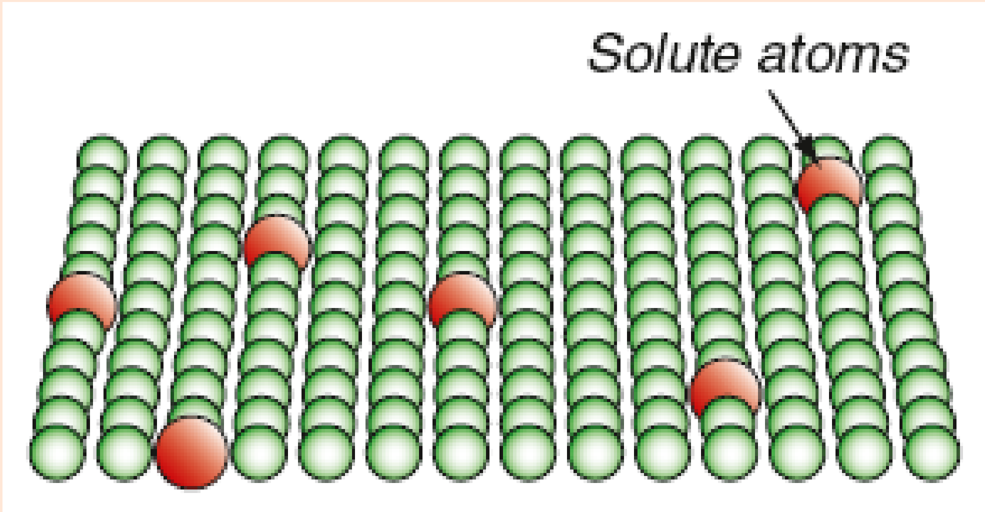
Lattice strain field interactions between dislocations and impurity atoms result in dislocation movement restriction.

- Why do alloys usually stronger than pure metals?

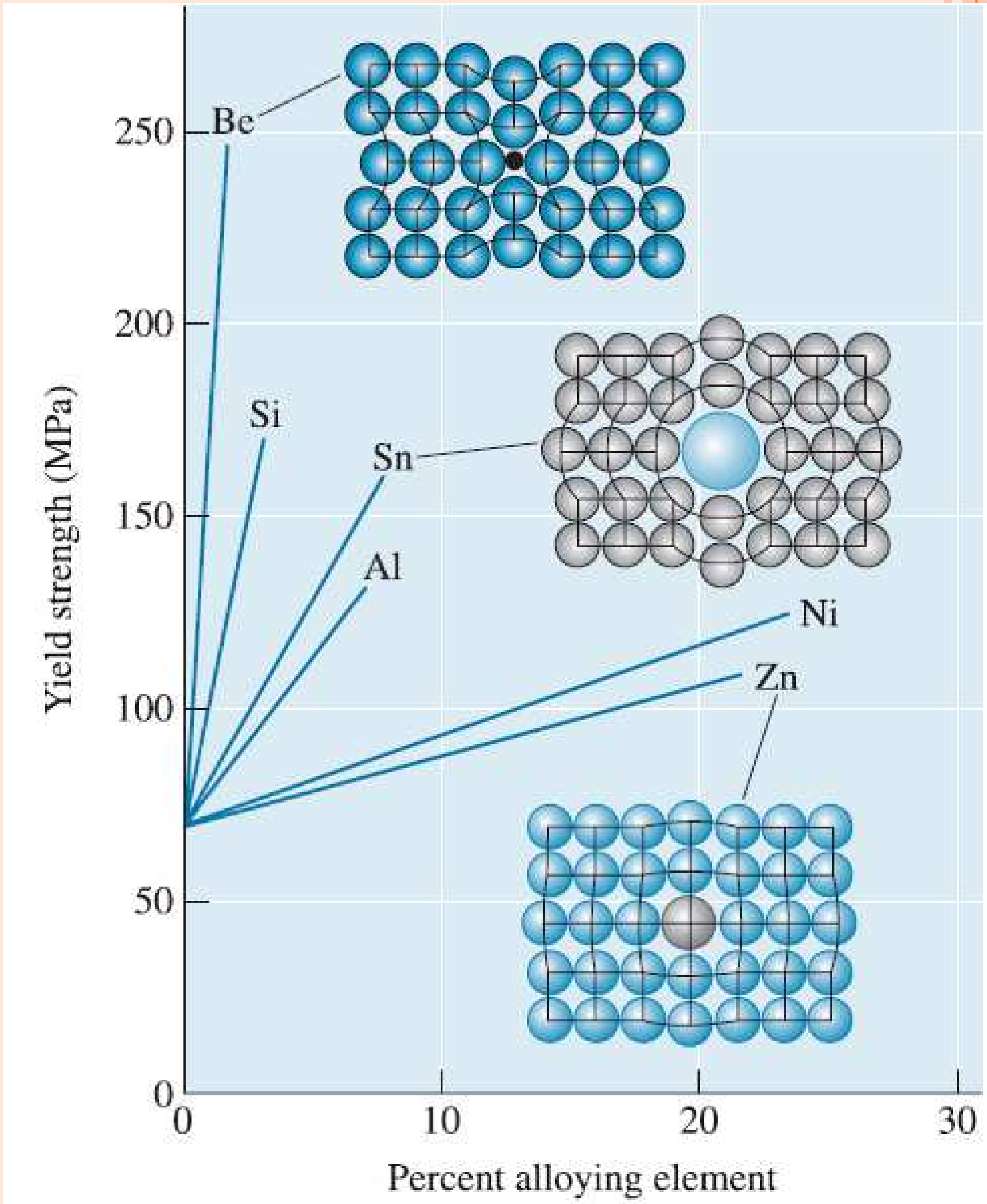
Solution hardening

Strengthening of a metal by alloying – deliberate additions of dopants

Alloying elements are generally bigger than those of the host material, making it harder for dislocations to move



THE EFFECTS OF ALLOYING ELEMENTS ON THE YIELD STRENGTH OF COPPER.



DISLOCATION-POINT DEFECT INTERACTIONS

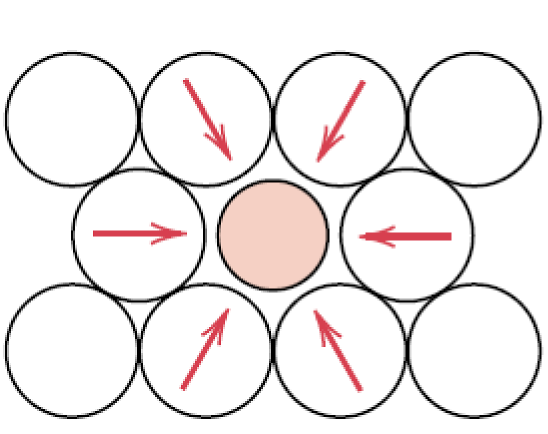
Point defect and dislocation will interact elastically and exert forces on each other.

If the solute atom is larger than the solvent atom *($\varepsilon > 1$)*	➡ *The atom will be repelled from the compressive side of a positive edge dislocation and will be attracted to the tension side.*
If the solute atom is smaller than the solvent atom *($\varepsilon < 1$)*	➡ *The atom will be attracted to the compression side.*

Solute atoms tend to diffuse to and segregate around dislocations in a way so as **to reduce the overall strain energy**, that is to **cancel the strain** in the lattice surrounding a dislocation

- Vacancies will be attracted to regions of compression.
- Interstitials will be collected at regions of tension.

Solution hardening

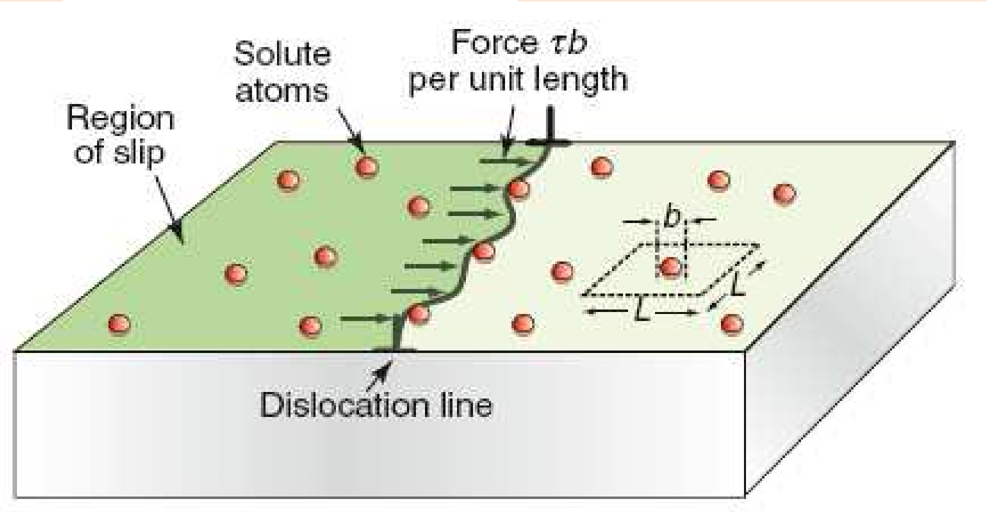


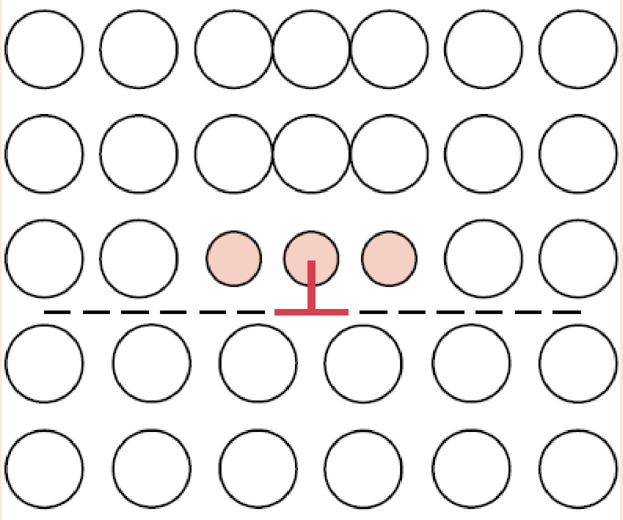
Representation of tensile lattice strains imposed on host atoms by a smaller substitutional impurity atom.

Possible locations of smaller impurity atoms relative to an edge dislocation such that there is partial cancellation of impurity–dislocation lattice strains.

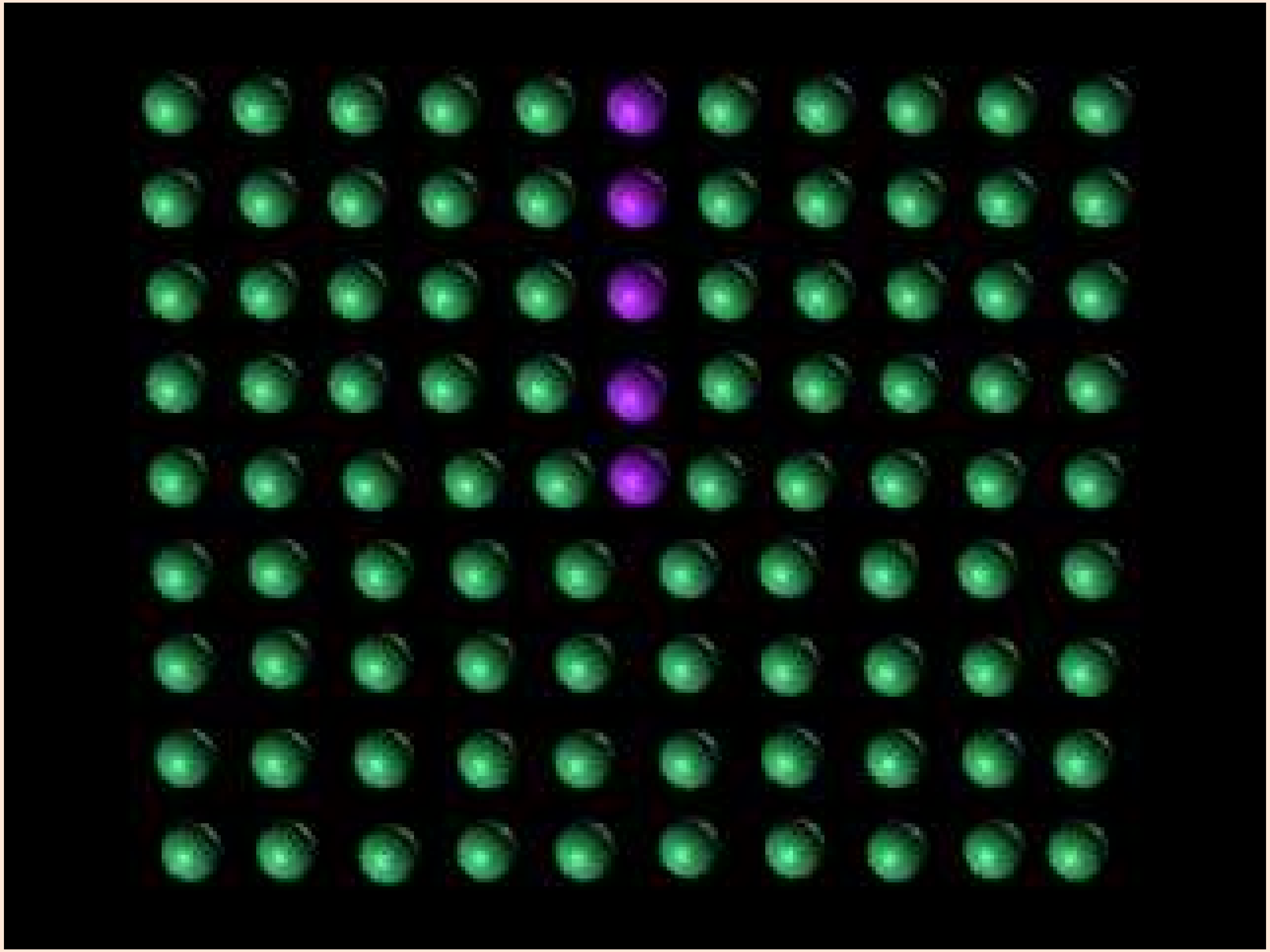
$$\tau_{ss} = \alpha E c^{1/2}$$

Contribution of solid solution to the shear strength required to move the dislocation

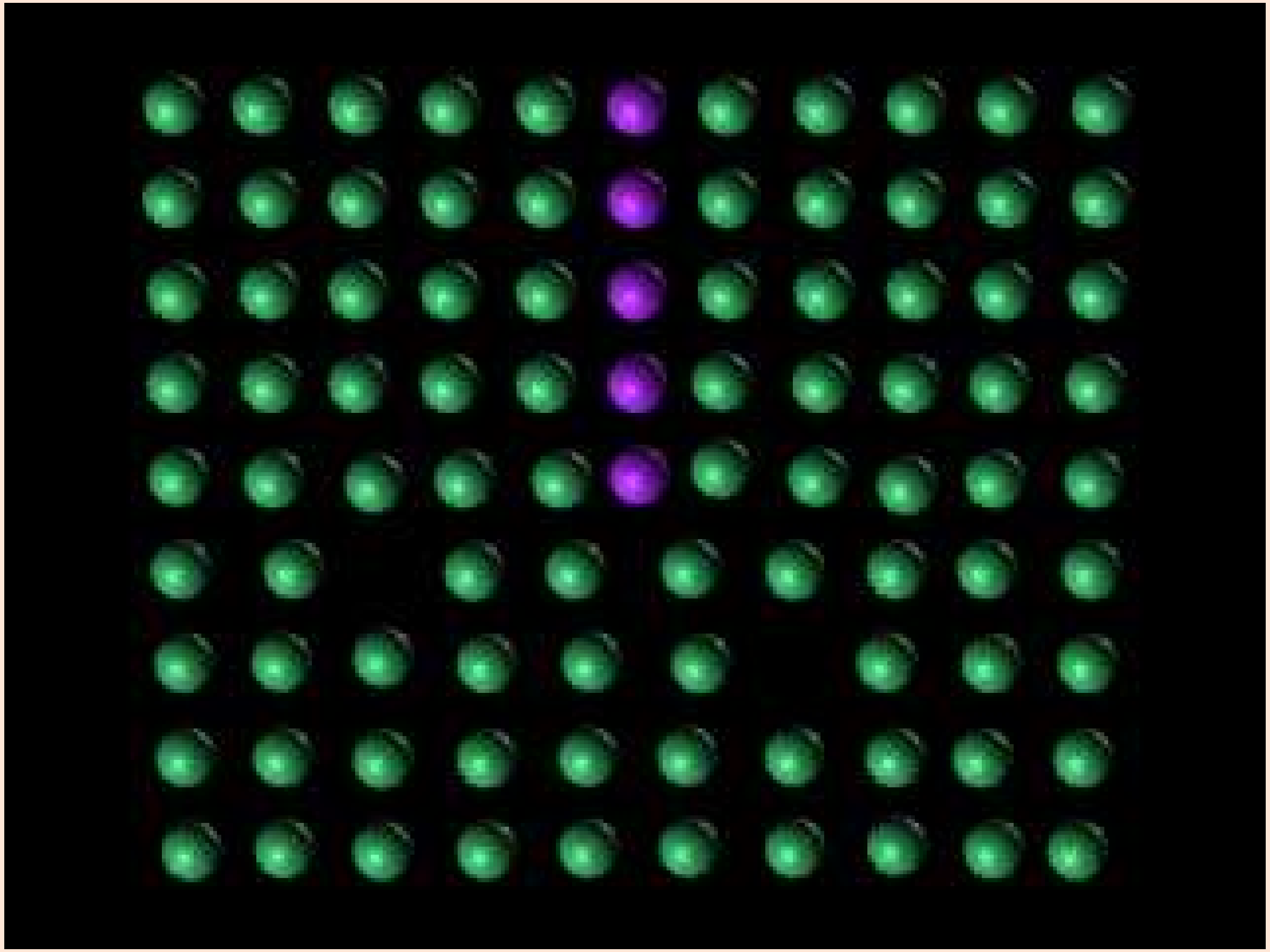




Solid-solution strengthening – substitutional atom



SOLID-SOLUTION STRENGTHENING – INTERSTITIAL ATOM



PROBLEM

The lattice resistance of copper, like that of most FCC metals, is small.
When 10% of nickel is dissolved in copper to make a solid solution, the strength of the alloy is 150 MPa.

➢ What would you expect the strength of an alloy with 20% nickel to be?

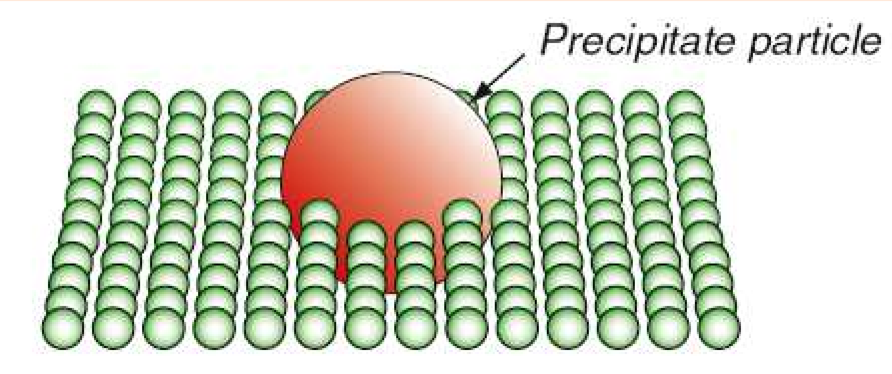
The contribution of solid solution to the yield strength

$$\sigma_y \approx 3\tau_{ss}$$

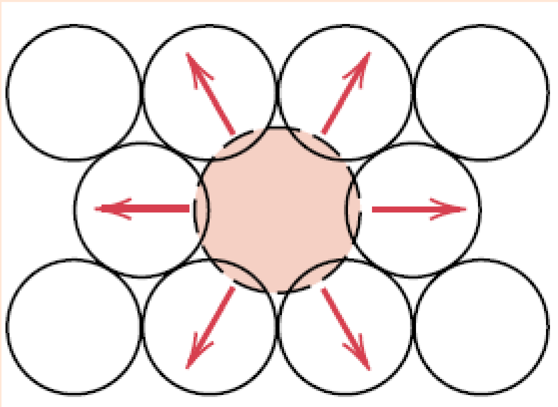
$$\tau_{ss} = \alpha E c^{1/2}$$

DISPERSION AND PRECIPITATE STRENGTHENING

If the **solubility** limit is exceeded, a different strengthening mechanism, **dispersion strengthening**, may come in to play.
In dispersion strengthening, the **interface** between the host phase and guest phase resists dislocation motion and contributes to strengthening.

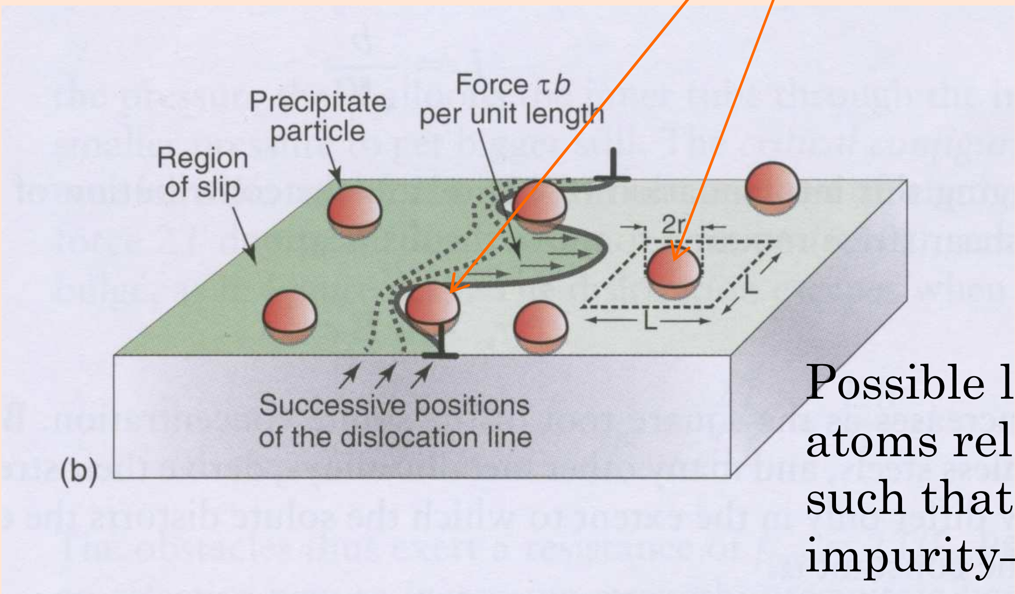


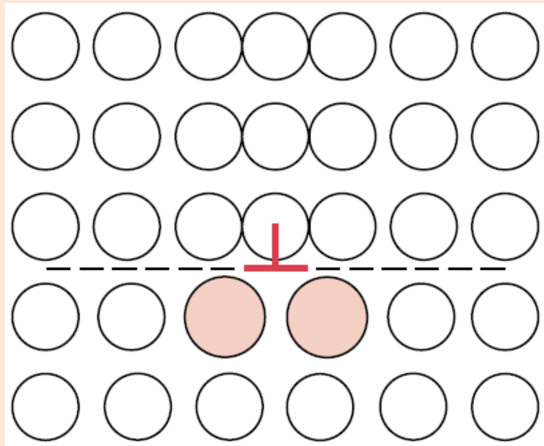
PRECIPITATION HARDENING



Representation of compressive strains imposed on host atoms by a larger substitutional impurity atom

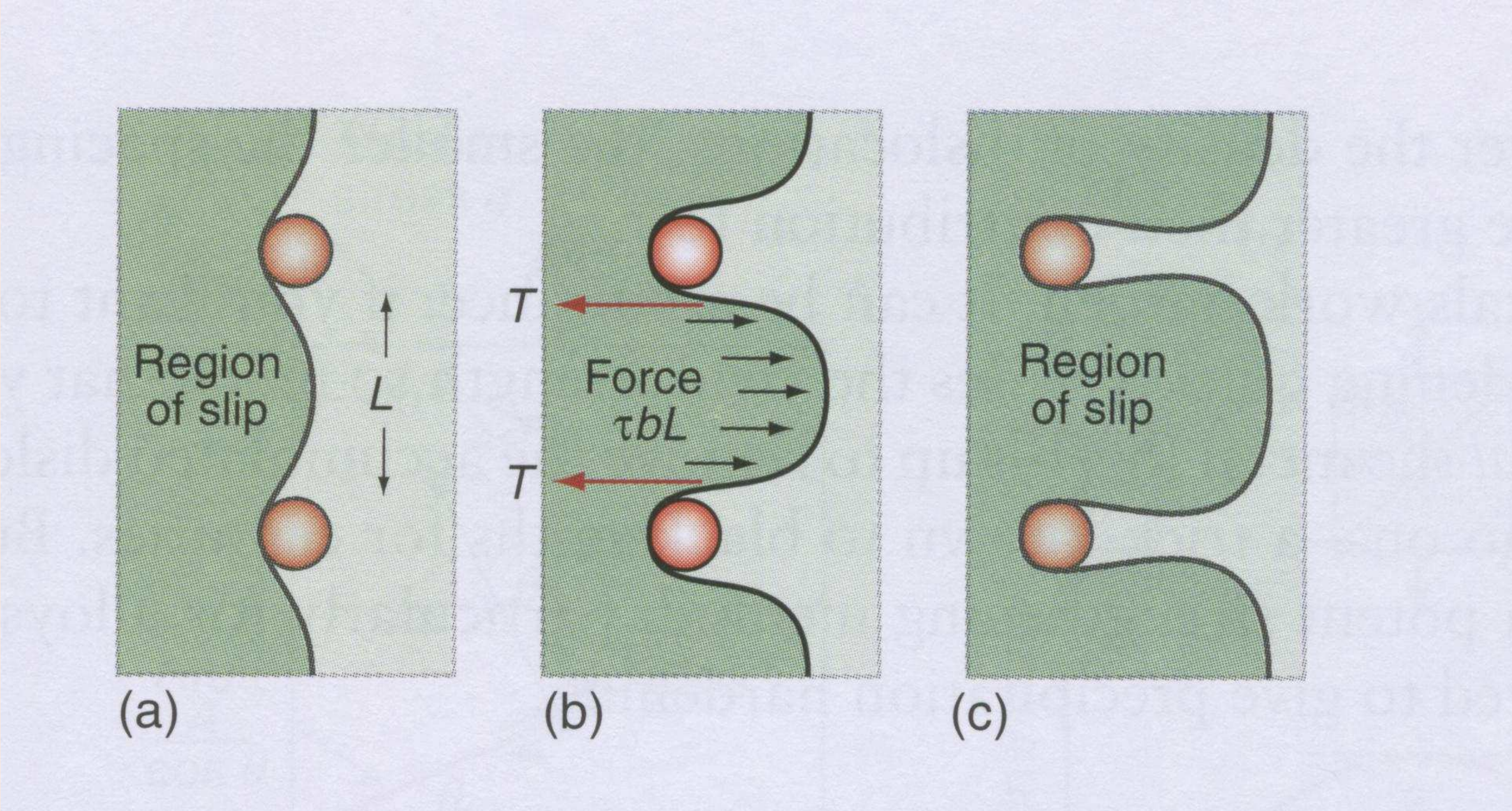
Particles obstruct the dislocation motion



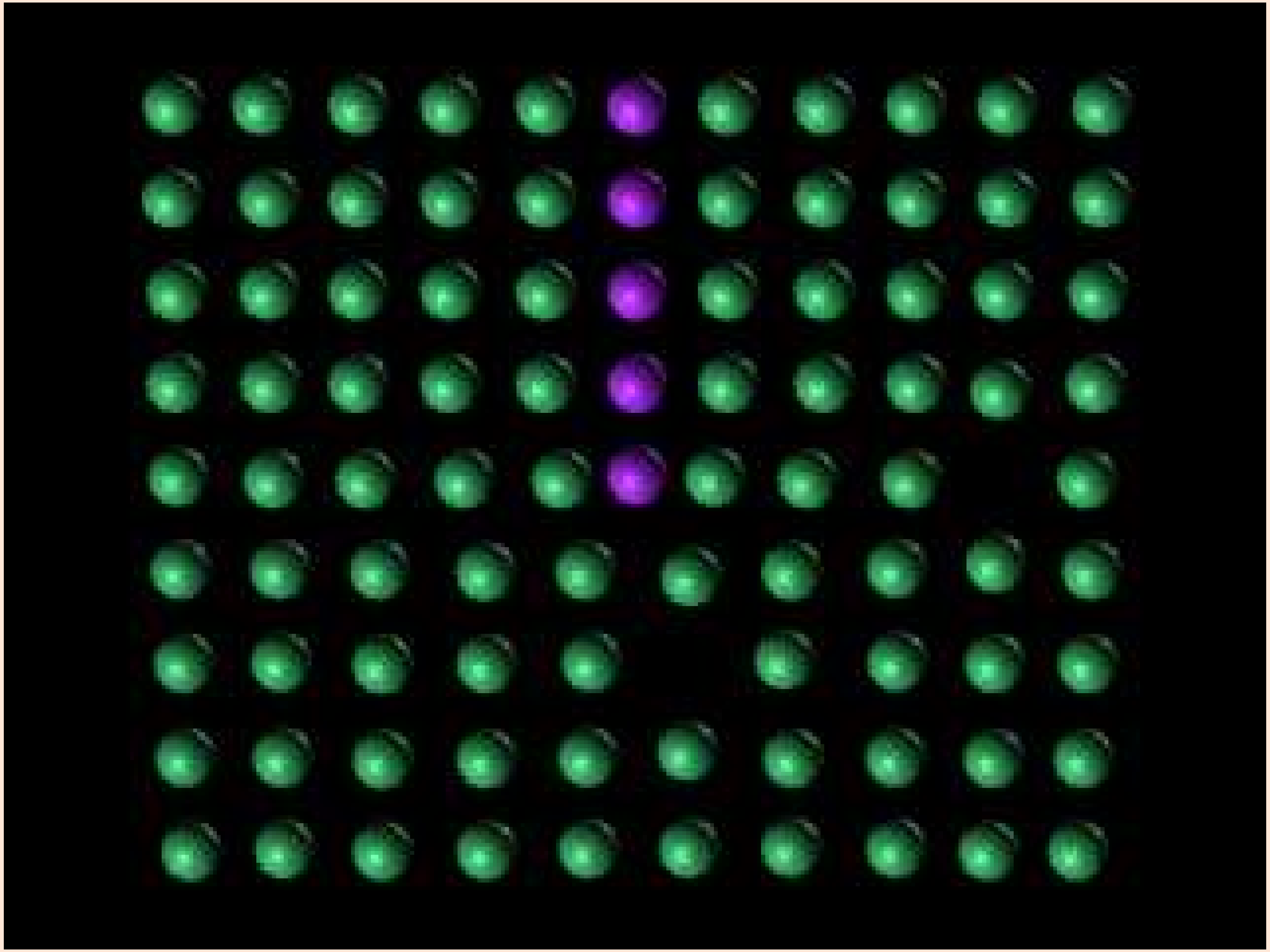


Possible locations of larger impurity atoms relative to an edge dislocation such that there is partial cancellation of impurity–dislocation lattice strains.

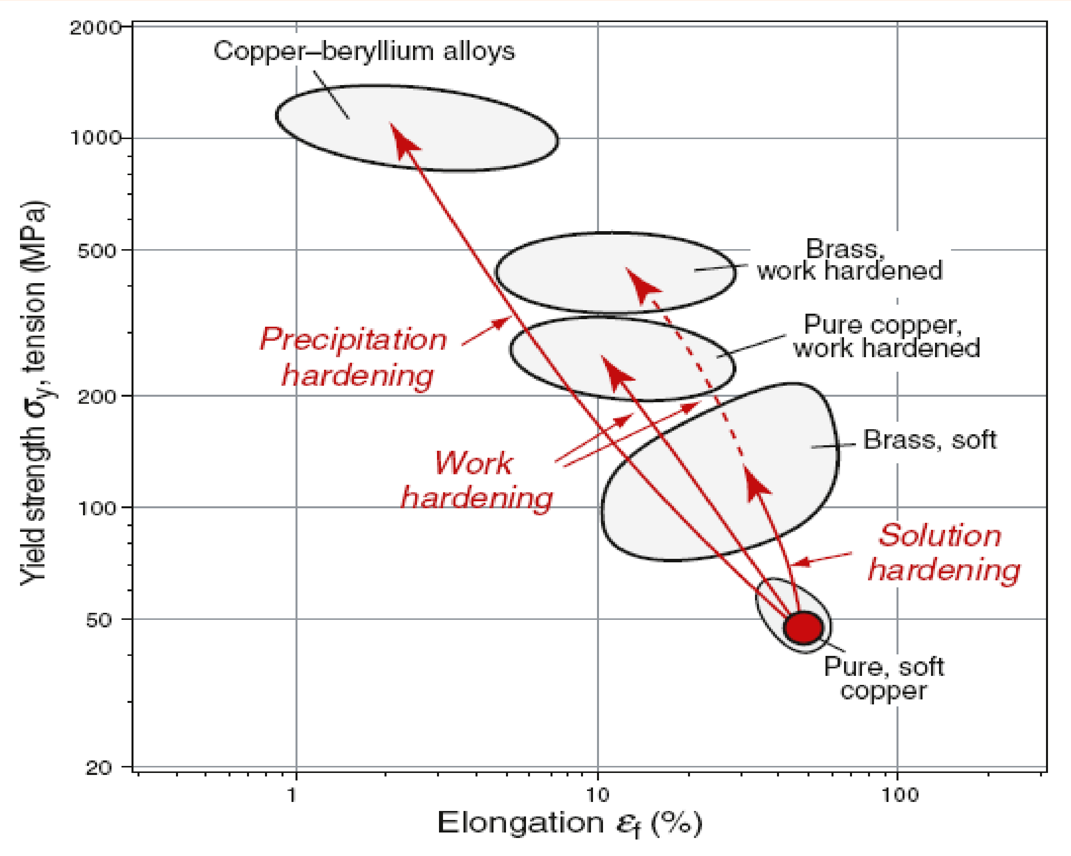
DISLOCATION MOVEMENT



SOLID-SOLUTION STRENGTHENING



STRENGTHENING MECHANISMS



an increase in strength
will often lower the ductility

Brass –
a copper rich
copper – zinc
alloy

DESIGN PROBLEM

You have to produce a bracket to hold ceramic bricks in place in a heat-treating furnace. The bracket should maintain most of its strength up to 600 C.

- Design the material for bracket, considering various possibility to strengthen material.

In order to serve up to 600°C, the bracket should not be produced from a polymer material. Instead, a metal or ceramic would be considered.

How to make an aluminum can.

ANNEALING PROCESSES

The term annealing refers to a **heat treatment** in which a material is exposed to an elevated temperature for an extended time period and then slowly cooled.

Ordinarily, annealing is carried out to
(1)relieve stresses;
(2)increase softness, ductility, and toughness;
(3)produce a specific microstructure.

Any annealing process consists of three stages:
(1) **heating** to the desired temperature,
(2**) holding** or "soaking" at that temperature, and
(3) **cooling**, usually to room temperature.

Annealing

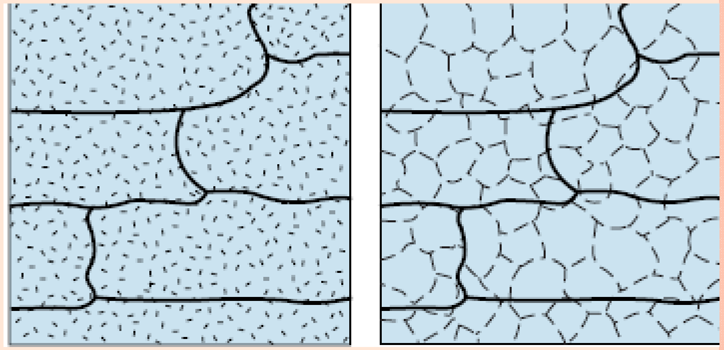
- **Annealing** is a heat treatment used to eliminate some or all of the effects of cold working.
- Annealing at a <u>low temperature</u> may be used to eliminate the residual stresses produced during cold working without affecting the mechanical properties of the finished part.
- Annealing may be used to <u>completely eliminate</u> the strain hardening achieved during cold working. In this case, the final part is soft and ductile but still has a good surface finish and dimensional accuracy.
- After annealing, <u>additional</u> cold work could be done, since the ductility is restored;
- By combining repeated cycles of cold working and annealing, large total deformations may be achieved.

RECOVERY

The original cold-worked microstructure is composed of deformed grains containing a large number of dislocations ➡

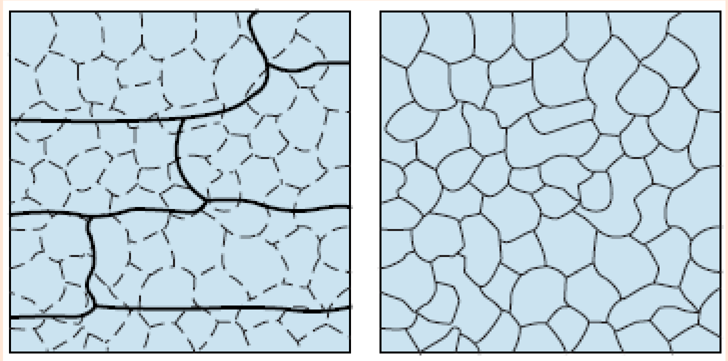
Stored **strain energy** ➡ **residual stresses**

During **recovery**,



some of the stored internal strain energy is relieved by dislocation motion (in the absence of an externally applied stress), as a result of **enhanced atomic diffusion at the elevated temperature** ➡ some **reduction** in the number of dislocations; and **dislocation configurations** are produced having **low strain energies**.

RECRYSTALLIZATION

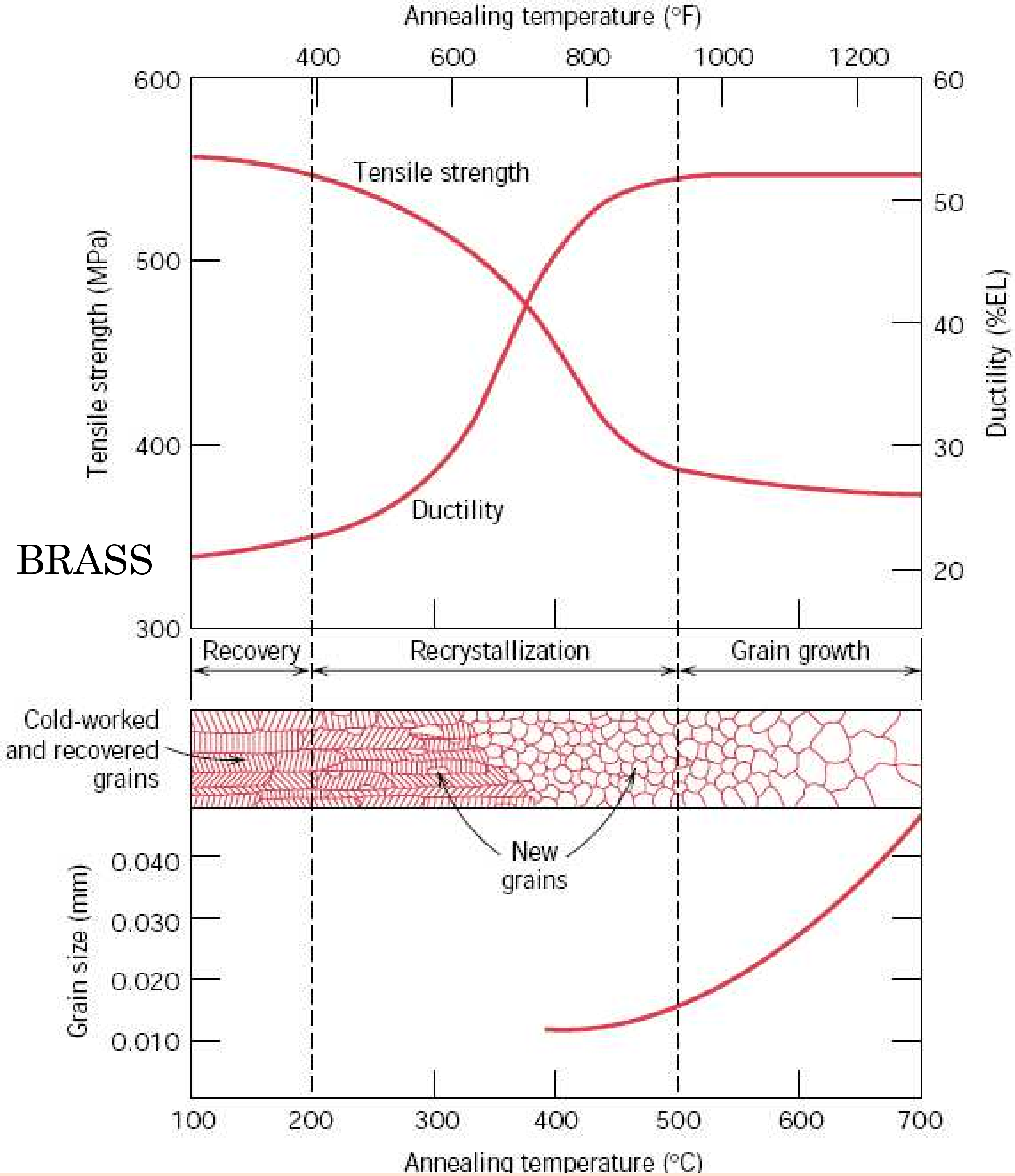


- Even after recovery is complete in a relatively high strain energy state.
- **Recrystallization** is the formation of a new set of **strain-free and equiaxed grains** that have low dislocation densities and are characteristic of the pre-cold-worked condition.
- The **driving force** to produce this new grain structure is the difference in internal energy between the strained and unstrained material.
- The **new grains** form as very small nuclei and grow until they completely replace the parent material. Processes involve <u>short-range diffusion</u>.

RECRYSTALLIZATION

- During recrystallization, the mechanical properties that were changed as a result of cold working, are restored to their **pre-cold-worked** values.
- The metal becomes softer, weaker, yet more ductile.
- Some heat treatments are designed to allow recrystallization to occur with these modifications in the mechanical characteristics.

- **Recrystallization** is a process, the extent of which **depends on both time and temperature**.



BRASS

What temperature is needed for recrystallization?

For **pure metals**, the recrystallization temperature is normally

$0.3T_m$,

where Tm is the absolute melting temperature;

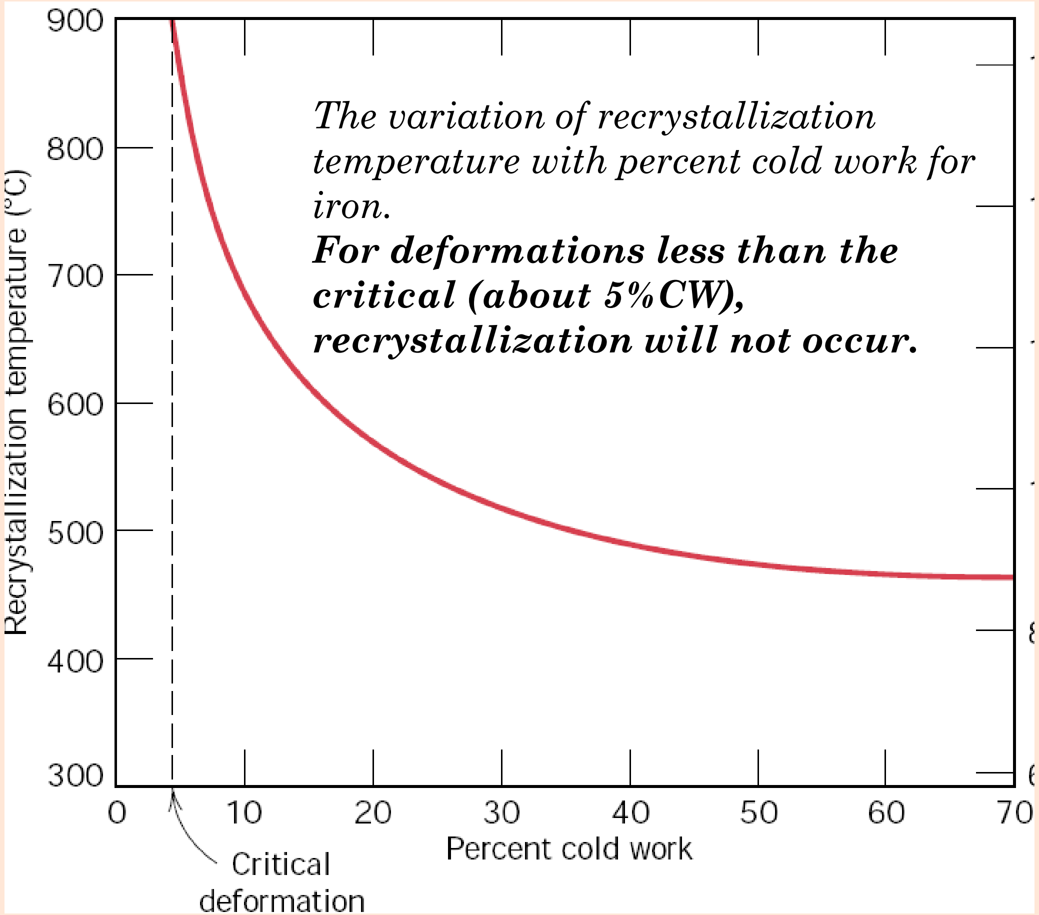
for some commercial **alloys** it may run as high as **0.7 Tm.**

Recrystallization temperature

- The temperature at which a microstructure of new grains that have very low dislocation density appears is known as the **recrystallization temperature**.

- The temperature at which recrystallization just reaches completion in 1 hour.

RECRYSTALLIZATION IN METALS



The variation of recrystallization temperature with percent cold work for iron.
For deformations less than the critical (about 5%CW), recrystallization will not occur.

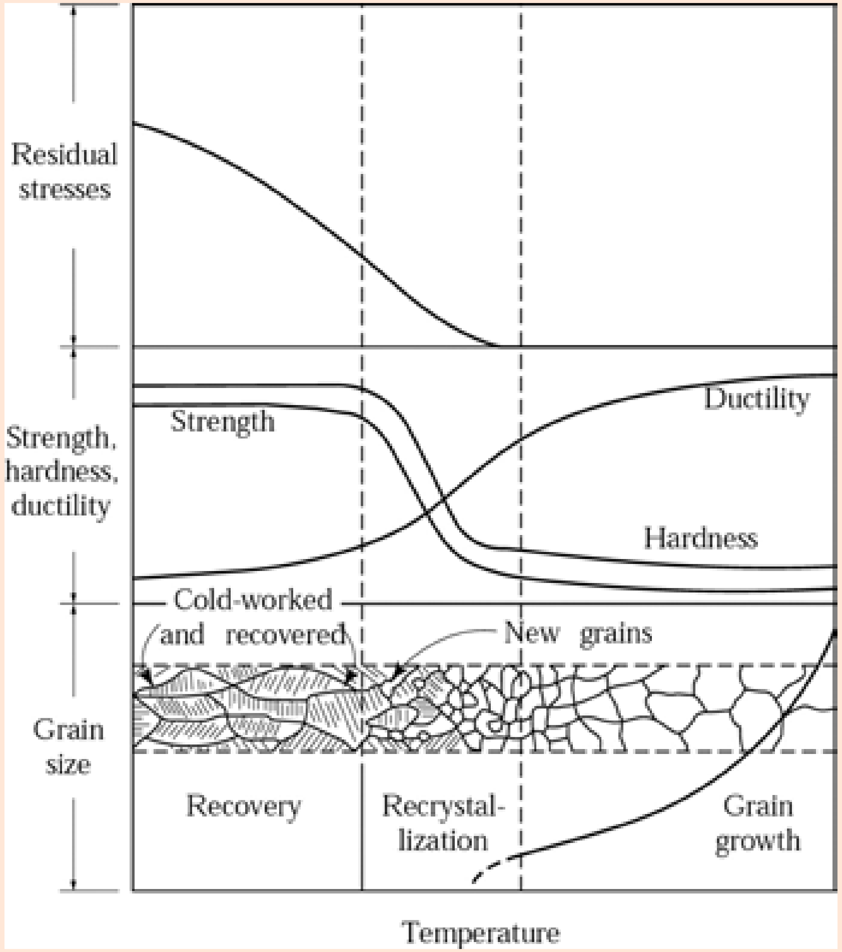
Rate of recrystallization increases with amount of cold work

- require a **critical amount of coldwork** to cause recrystallization (5 - 40%)
- recrystallization is easier in pure metals than in alloys and occurs at lower T:
  0.3Tm versus ~0.7Tm

- A smaller original cold-worked grain size **reduces** the recrystallization temperature;
- Increasing the **annealing time** reduces the recrystallization temperature

Recrystallization temperature depends on many variables and is not a fixed temperature similar to melting temperature of elements and compounds.

ANNEALING - RECRYSTALLIZATION IN METALS



Schematic illustration of the effects of recovery, recrystallization, and grain growth on mechanical properties and on the shape and size of grains.

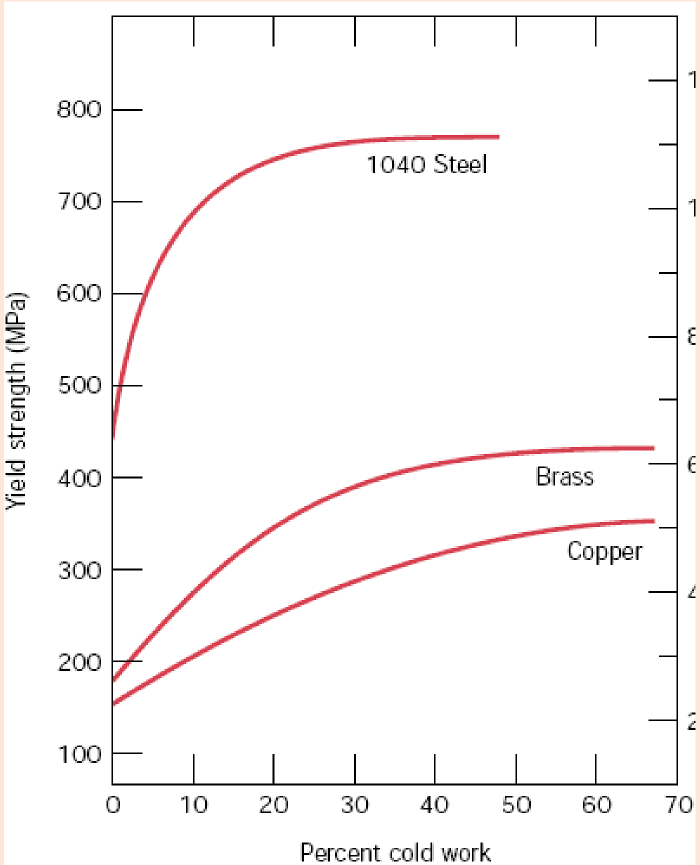
- Recrystallization can be exploited in **manufacturing**
- Heating a metal to its recrystallization temperature prior to deformation allows a **greater amount of straining.** **Lower forces** and **power** are required to perform the process

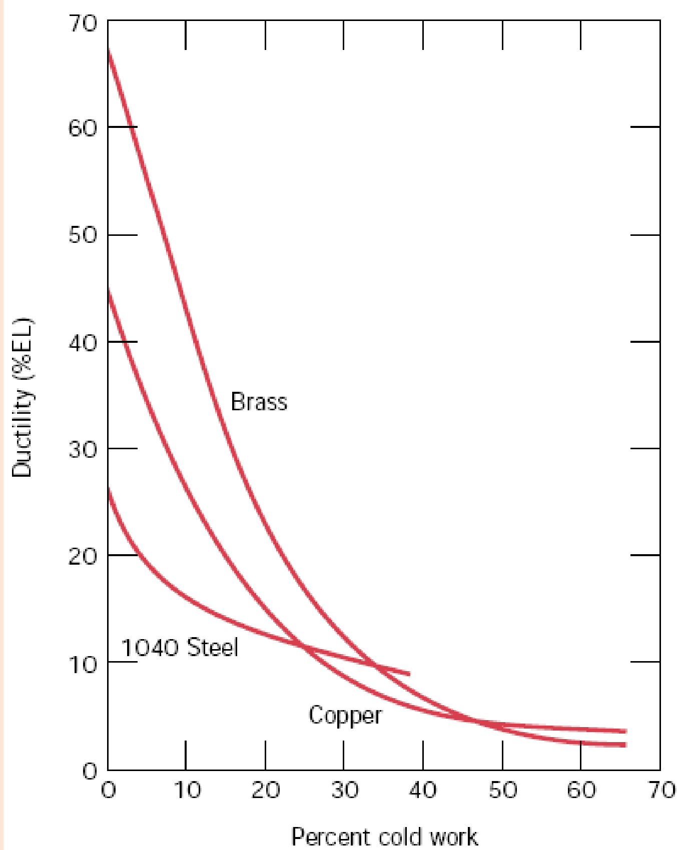
DESIGN PROBLEM

A cylindrical rod of noncold-worked brass having an initial diameter of 6.4 mm is to be cold worked by drawing such that the cross-sectional area is reduced.

It is required to have a cold-worked yield strength of at least 345 Mpa and a ductility in excess of 20%EL; in addition, a final diameter of 5.1 mm is necessary.

- Describe the manner in which this procedure may be carried out.





RECOVERY AND RECRYSTALLIZATION (SUMMARY)

Recovery

• occurs during heating at elevated temperatures below the recrystallization temperature

• dislocations reconfigure due to diffusion and relieve the *lattice strain energy*

• electrical and thermal properties are recovered to their pre-cold worked state

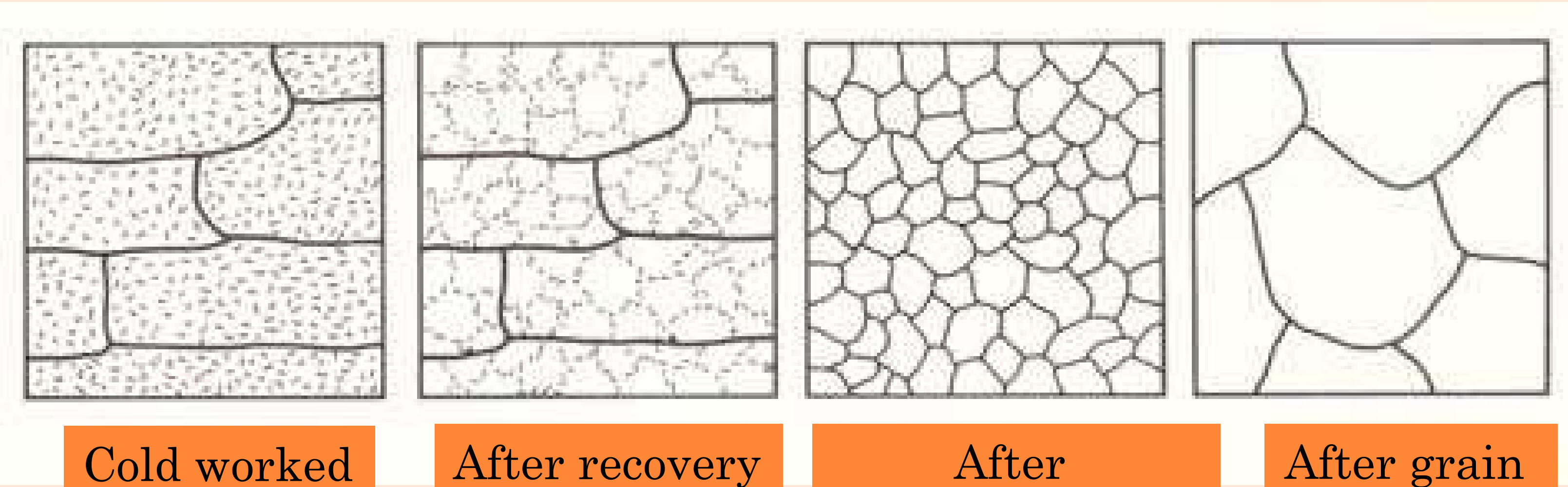
Recrystallization

• recrystallization results in the nucleation and growth of new *strain-free, equiaxed grains*

• contain low dislocation density equivalent to the pre-cold worked condition → *annealed state*

• restoration of mechanical properties → softening

EFFECT OF ANNEALING ON MICROSTRUCTURE



Cold worked

After recovery

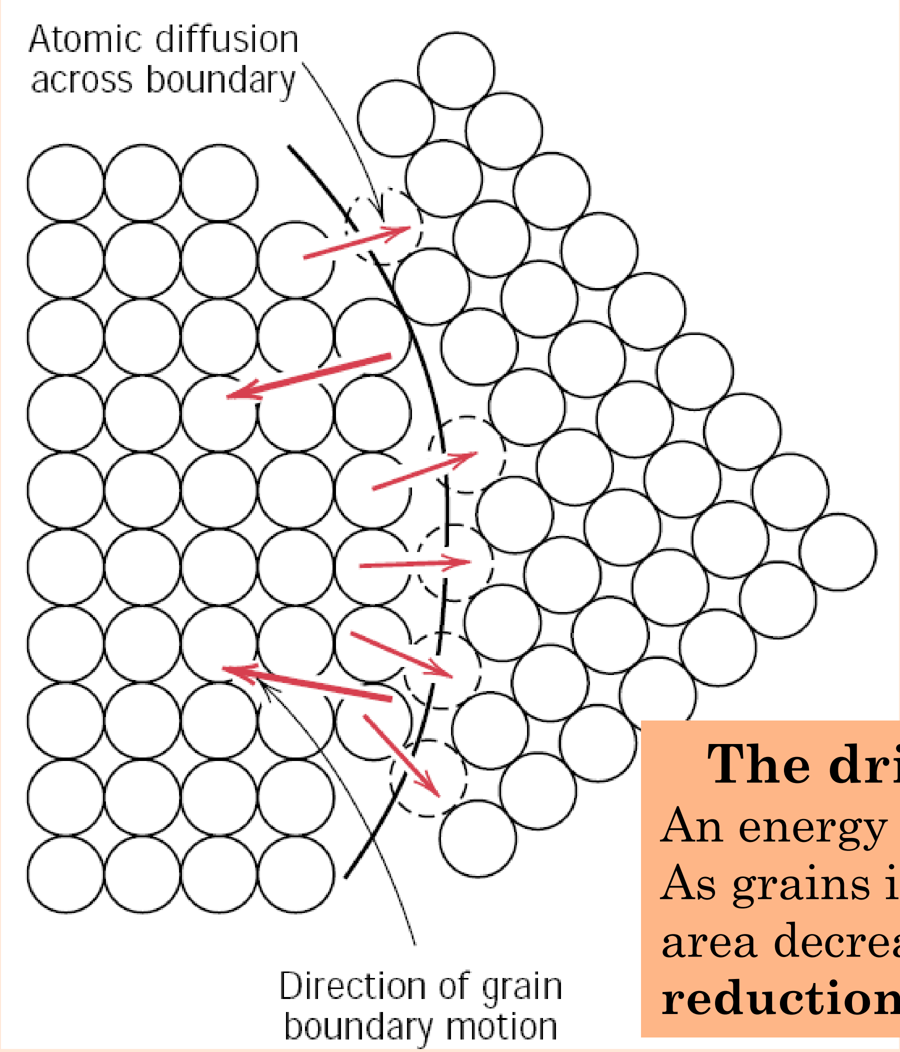
After Recrystallization

After grain growth

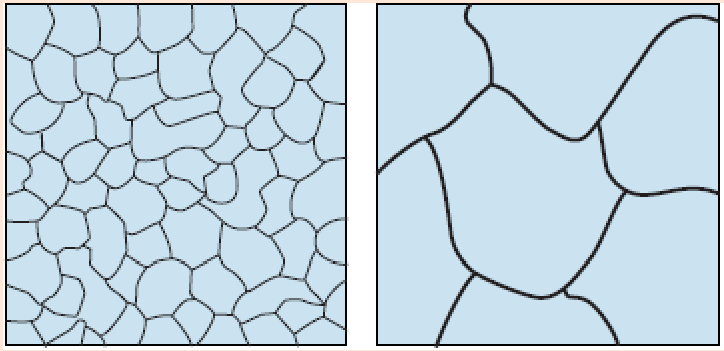
Time is an important parameter in these procedures

Grain growth

Schematic representation of grain growth via atomic diffusion.



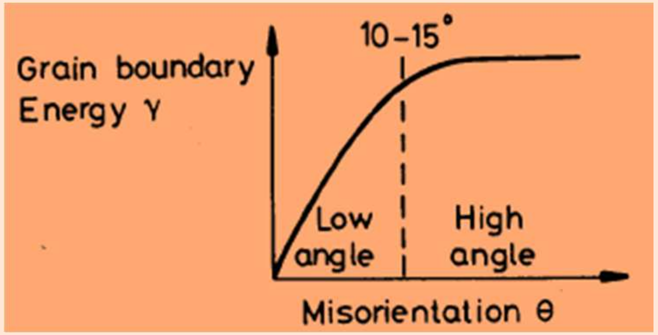
After recrystallization is complete, the strain-free grains will continue to grow if the metal specimen is left at the elevated temperature



Grain growth occurs by the **migration of grain boundaries**

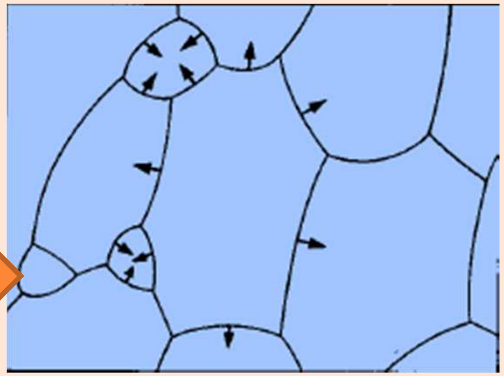
The driving force for grain growth.
An energy is associated with grain boundaries. As grains increase in size, the total boundary area decreases, yielding an attendant **reduction in the total energy.**

FEATURES OF GRAIN GROWTH



- Growth of new grains will continue at high temperature
- does not require recovery and recrystallization
- occurs in both metals and ceramics at elevated temperature
- involves the migration of grain boundaries
- large grains grow at expense of small ones
- reduction of grain boundary area

(driving force)



How large are grains?

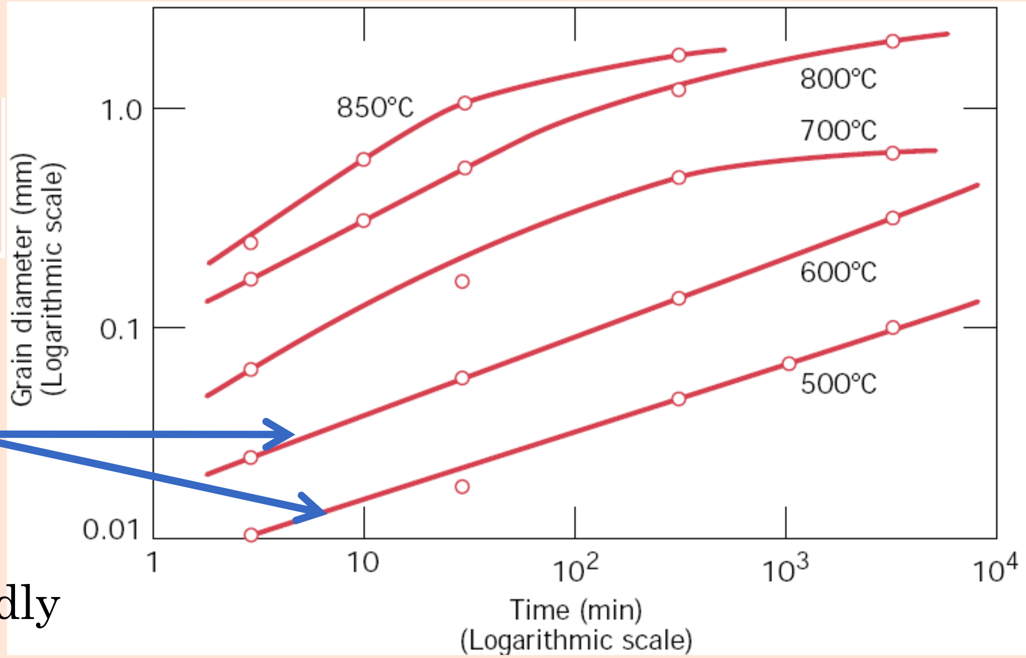
For many polycrystalline materials, the grain diameter ***d** varies with time **t*** according to the relationship

time-independent constants

$$d^n - d_0^n = Kt$$

the initial grain diameter

At lower temperatures the curves are linear.



Grain growth proceeds more rapidly as temperature increases.

- Why?

=> the enhancement of diffusion rate with rising temperature.

The logarithm of grain diameter versus the logarithm of time for grain growth in brass at several T.

HOT WORKING - BASIC

- Deformation is performed above a metals recrystallization temperature.
- Continuous recrystallization occurs during hot working.
- No strengthening occurs during deformation by hot working.

Why hot working?

- Plastic deformation operations are often carried out at temperatures above the recrystallization temperature.

- The material remains relatively soft and ductile during deformation because it does not strain harden, and thus large deformations are possible.

- During hot working the material is continually recrystallized.

HOT WORKING – INDUSTRIAL APPLICATIONS

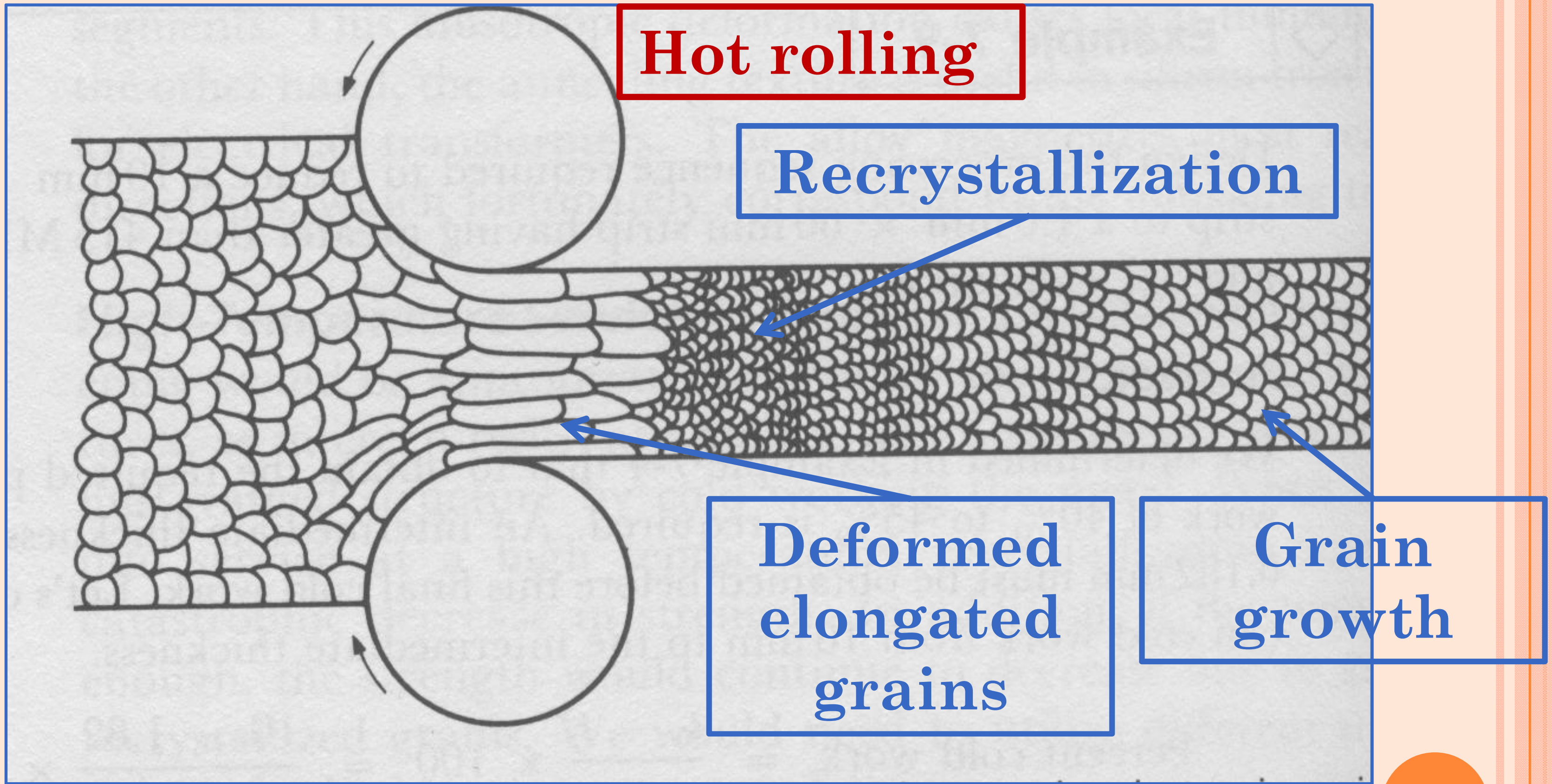
❖The plastic deformation experienced by the metal as it is pulled through the die tends to increase hardness and reduce ductility. It takes a great deal of force to push solid metal through a die but if it's heated up close to its melting point it deforms more readily.

❖It needs less force to extrude the metal when it's hot but the "extrudate," (the technical term for the material that has been extruded,) is not as strong as when it's been extruded cold.

CHARACTERISTICS OF THE HOT WORKING PROCESS

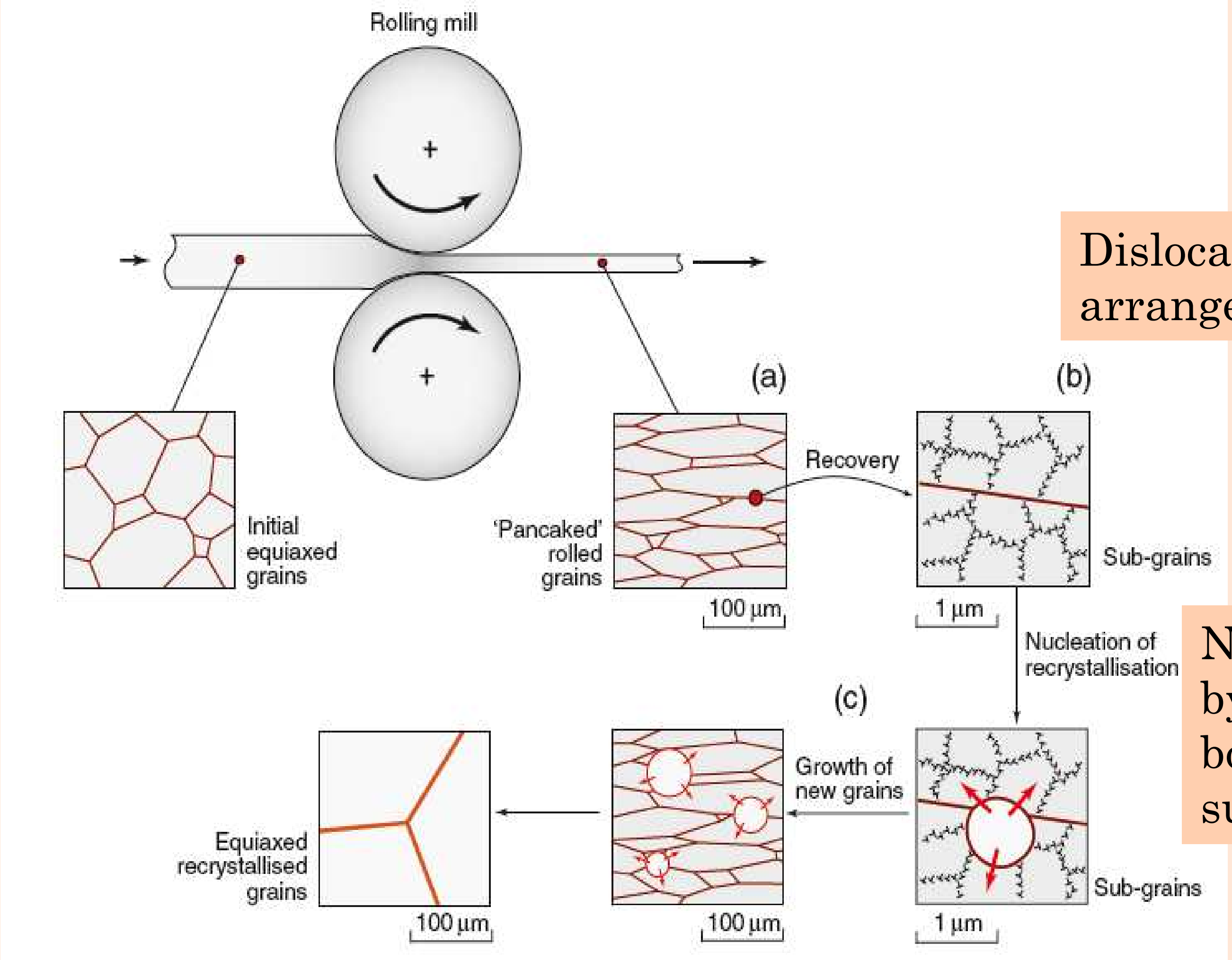
- No strengthening occurs during deformation => the amount of plastic deformation is almost unlimited.
- Hot working is well suited for forming large parts.
- Some imperfections may be eliminated or their effect minimized.
- The surface finish is usually poorer than that obtained by cold working. Oxygen may react with the metal at the surface => oxides formation => sometimes the protective atmosphere is needed.
- The dimensional accuracy is more difficult to control – elastic strain must be considered, since the modulus of elasticity is low at T of hot working.

Structure of hot-worked material



If the hot working T is properly controlled, the fine product will have fine grain sizes.

GRAIN STRUCTURE EVOLUTION THROUGH DEFORMATION AND ANNEALING



Dislocations re-arrangement

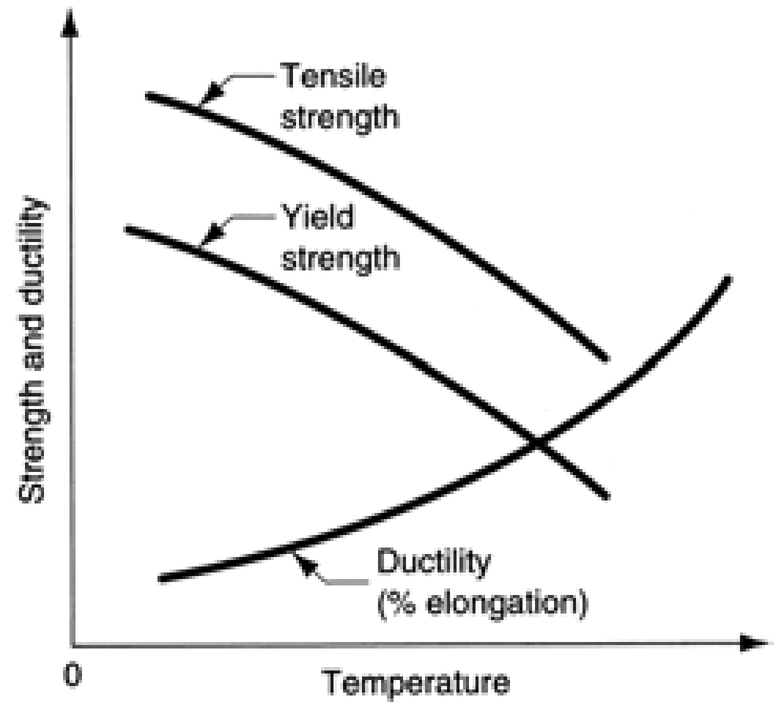
New grains formation by migration of boundaries from a few sub-grain nuclei

Hot working and annealing (summary)

- **Cold Working** - deforming of a metal at low temperatures and strengthening by dislocation formation.
- **Hot Working** - deforming a metal at high temperatures (above the metals recrystallization temperature). No strengthening.
- **Annealing** - a heat treatment that eliminates the effects of cold working.

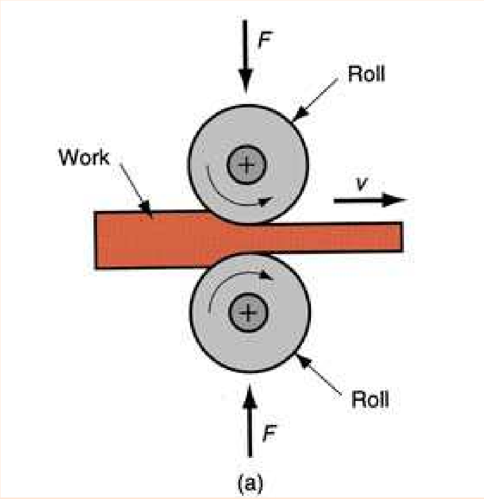
HOT ROLLING

FORMABILITY



Desirable material properties in metal forming:
Low yield strength and high ductility

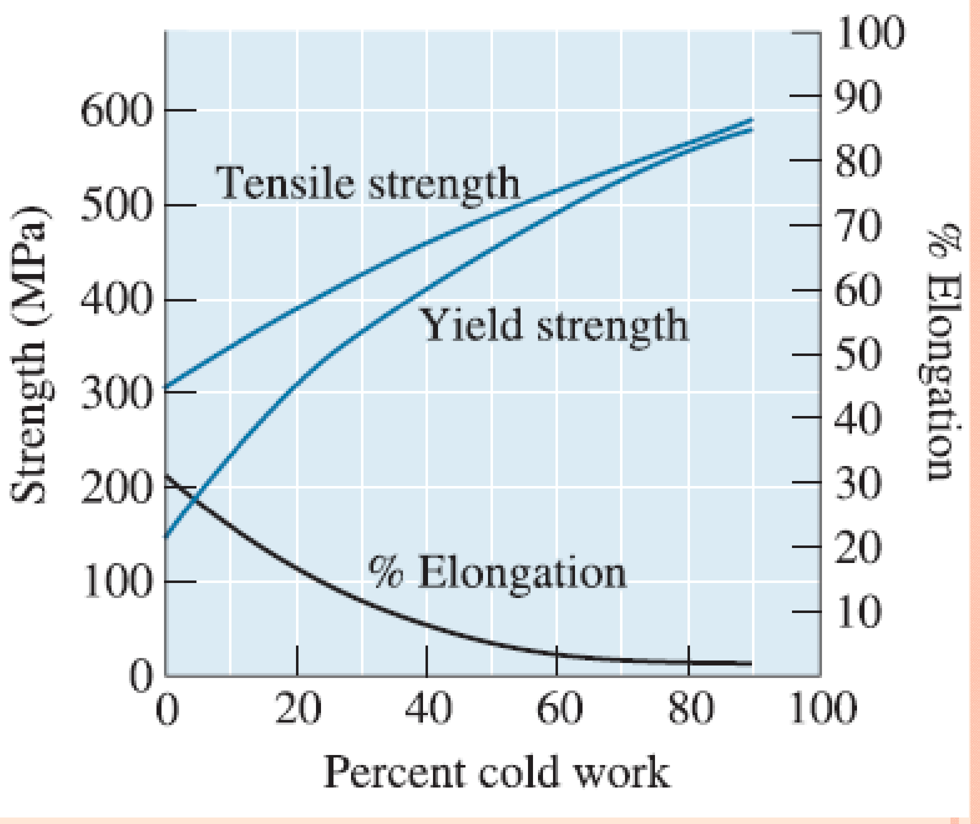
→ Any deformation operation can be accomplished with lower forces and power at elevated temperature



PROBLEM

➢ Design of a Process to Produce Copper Strip

You have to produce a **0.1-cm-thick**, **6-cm-wide** copper strip having at least **414 MPa** yield strength and at **least 5%** elongation. Only 6-cm-wide strips in thicknesses of 5 cm are available in the stock. Design a process to produce the product needed.



Steel making process

http://www.youtube.com/watch?v=9l7JqonyoKA&feature=related