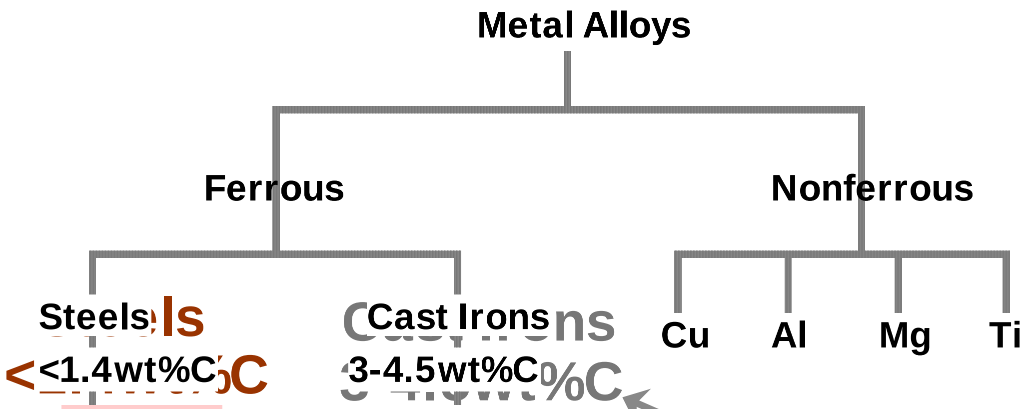
CHAPTER 11: METAL ALLOYS APPLICATIONS AND PROCESSING

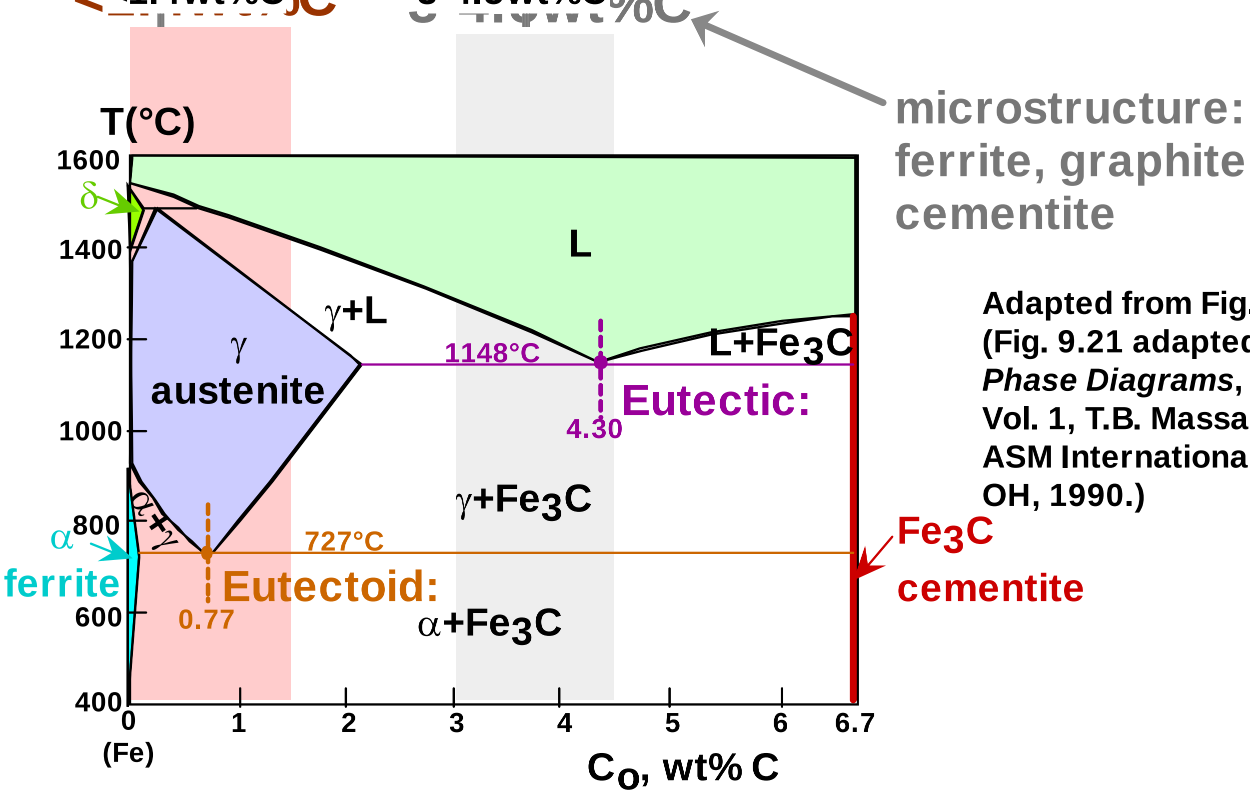
ISSUES TO ADDRESS...

- **How are metal alloys classified and how are they used?**
- **What are some of the common fabrication techniques?**
- **How do properties vary throughout a piece of material that has been quenched, for example?**
- **How can properties be modified by post heat treatment?**

TAXONOMY OF METALS



Adapted from Fig. 11.1, *Callister 6e*.



Adapted from Fig. 9.21, *Callister 6e*. (Fig. 9.21 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

STEELS

Low Alloy | **High Alloy**

low carbon	med carbon	high carbon
<0.25wt%C	0.25-0.6wt%C	0.6-1.4wt%C

Name	plain	HSLA	plain	heat treatable	plain	tool	austentitic stainless
Additions	none	Cr,V Ni, Mo	none	Cr, Ni Mo	none	Cr, V, Mo, W	Cr, Ni, Mo
Example	1010	4310	1040	4340	1095	4190	304
Hardenability	0	+	+	++	++	+++	0
TS	-	0	+	++	+	++	0
EL	+	+	0	-	-	--	++
Uses	auto struc. sheet	bridges towers press. vessels	crank shafts bolts hammers blades	pistons gears wear applic.	wear applic.	drills saws dies	high T applic. turbines furnaces V. corros. resistant

increasing strength, cost, decreasing ductility

Based on data provided in Tables 11.1(b), 11.2(b), 11.3, and 11.4, *Callister 6e*.

NONFERROUS ALLOYS

NonFerrous Alloys

- **Cu Alloys**

Brass: Zn is subst. impurity (costume jewelry, coins, corrosion resistant)

Bronze: Sn, Al, Si, Ni are subst. impurity (bushings, landing gear)

Cu-Be: precip. hardened for strength

- **Al Alloys**

-lower ρ: 2.7g/cm^3
-Cu, Mg, Si, Mn, Zn additions
-solid sol. or precip. strengthened (struct. aircraft parts & packaging)

- **Mg Alloys**

-very low ρ: 1.7g/cm^3
-ignites easily
-aircraft, missles

- **Ti Alloys**

-lower ρ: 4.5g/cm^3 vs 7.9 for steel
-reactive at high T
-space applic.

- **Noble metals**

-Ag, Au, Pt
-oxid./corr. resistant

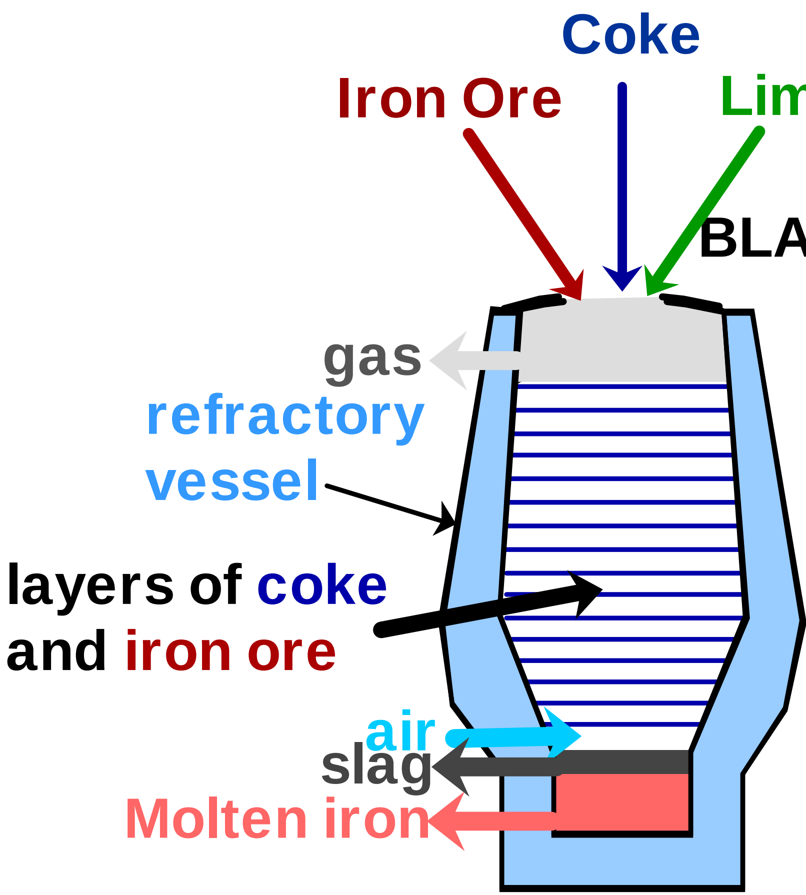
- **Refractory metals**

-high melting T
-Nb, Mo, W, Ta

Based on discussion and data provided in Section 11.3, *Callister 6e*.

REFINEMENT OF STEEL FROM ORE

BLAST FURNACE



heat generation

$$C + O_2 \rightarrow CO_2$$

reduction of iron ore to metal

$$CO_2 + C \rightarrow 2CO$$

$$3CO + Fe_2O_3 \rightarrow 2Fe + 3CO_2$$

purification

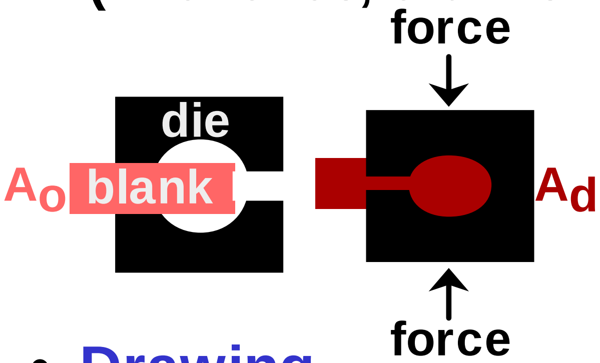
$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + SiO_2 + Al_2O_3 \rightarrow slag$$

METAL FABRICATION METHODS-I

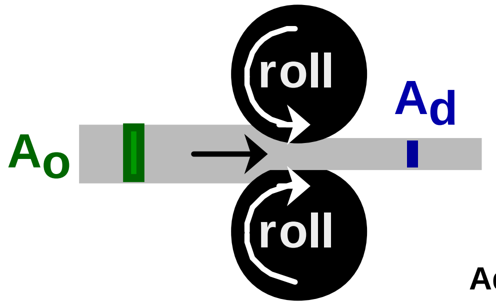
FORMING CASTING JOINING

- **Forging**
  (wrenches, crankshafts)



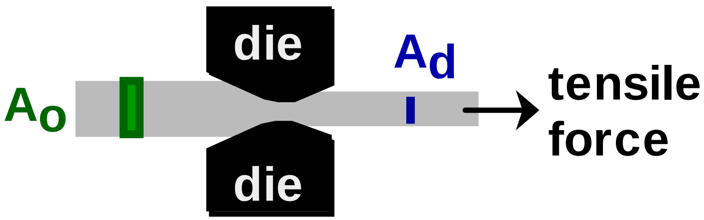
often at elev. T

- **Rolling**
  (I-beams, rails)

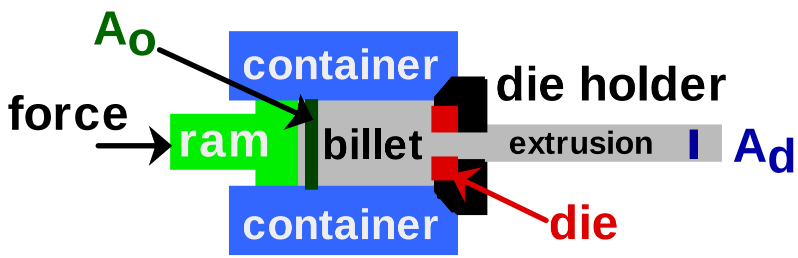


Adapted from Fig. 11.7, *Callister 6e.*

- **Drawing**
  (rods, wire, tubing)



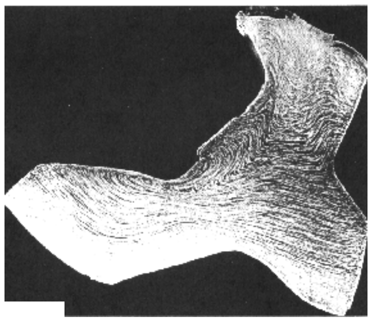
- **Extrusion**
  (rods, tubing)



FORMING TEMPERATURE

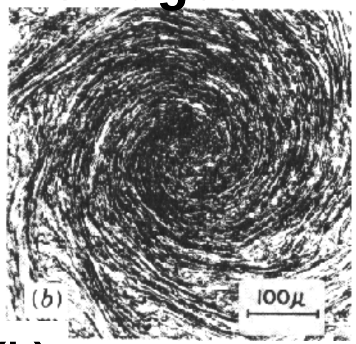
- **Hot working**
  - --recrystallization
  - --less energy to deform
  - --oxidation: poor finish
  - --lower strength
- **Cold working**
  - --more energy to deform
  - --oxidation: good finish
  - --higher strength
- **Cold worked microstructures**
  - --generally are very anisotropic!

--Forged



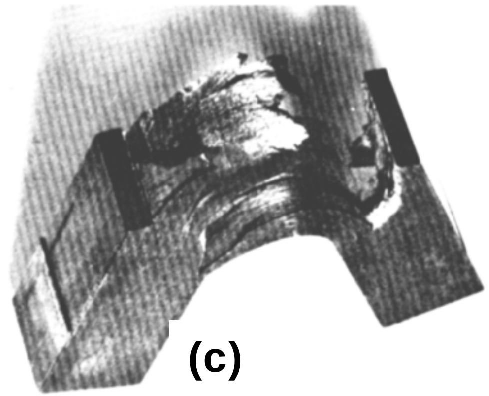
(a)

--Swaged



(b)

--Fracture resistant!



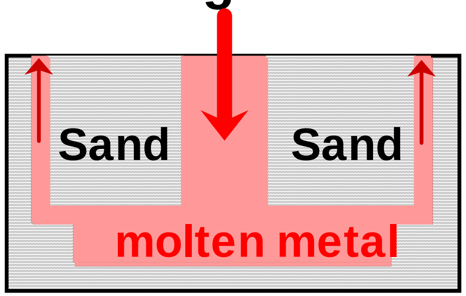
(c)

Reprinted w/ permission from R.W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials", (4th ed.), John Wiley and Sons, Inc., 1996. (a) Fig. 10.5, p. 410 (micrograph courtesy of G. Vander Voort, Car Tech Corp.); (b) Fig. 10.6(b), p. 411 (Orig. source: J.F. Peck and D.A. Thomas, *Trans. Metall. Soc. AIME*, 1961, p. 1240); (c) Fig. 10.10, p. 415 (Orig. source: A.J. McEvily, Jr. and R.H. Bush, *Trans. ASM* **55**, 1962, p. 654.)

METAL FABRICATION METHODS-II

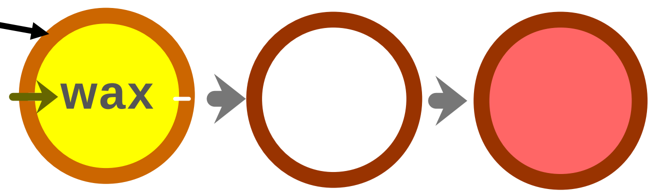
FORMING | **CASTING** | JOINING

- **Sand Casting**
  (large parts, e.g., auto engine blocks)

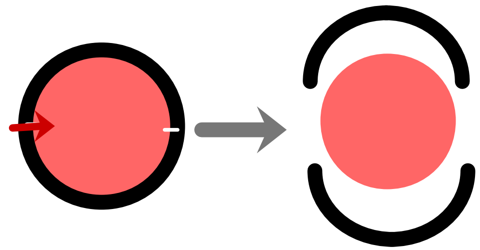


- **Investment Casting**
  (low volume, complex shapes e.g., jewelry, turbine blades)

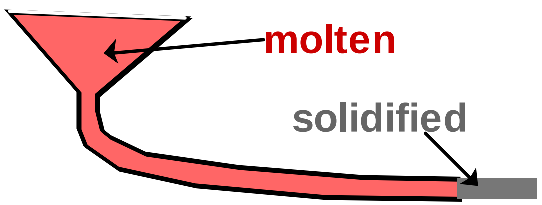
plaster die formed around wax prototype



- **Die Casting**
  (high volume, low T alloys)



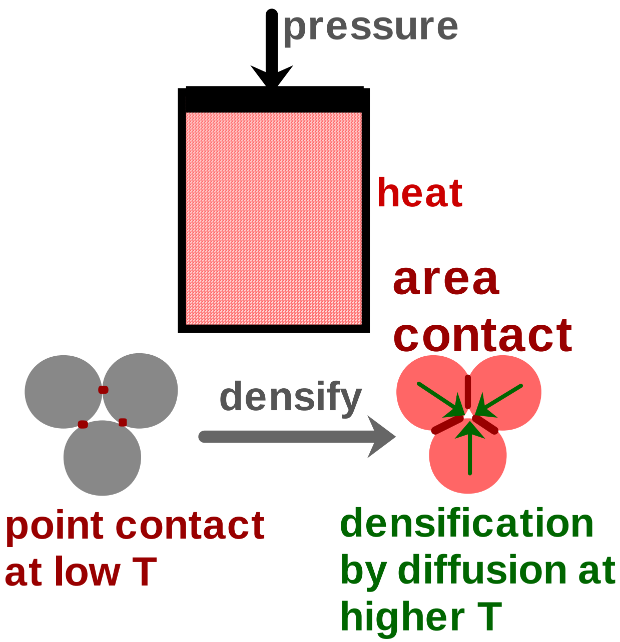
- **Continuous Casting**
  (simple slab shapes)



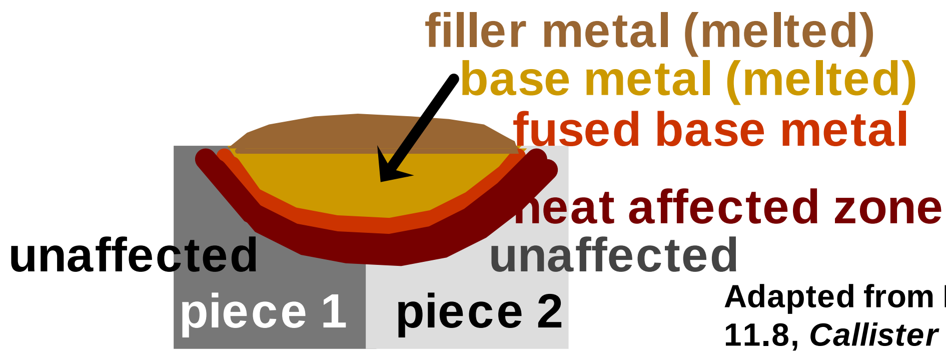
METAL FABRICATION METHODS-III

FORMING | CASTING | **JOINING**

- **Powder Processing**
  (materials w/low ductility)



- **Welding**
  (when one large part is impractical)



Adapted from Fig. 11.8, *Callister 6e*. (Fig. 11.8 from *Iron Castings Handbook*, C.F. Walton and T.J. Opar (Ed.), 1981.)

- **Heat affected zone:**
  (region in which the microstructure has been changed).

THERMAL PROCESSING OF METALS

Annealing: Heat to T_{anneal}, then cool slowly.

Types of Annealing

- **Stress Relief: Reduce stress caused by:**
  - -plastic deformation
  - -nonuniform cooling
  - -phase transform.

- **Spheroidize (steels):** Make very soft steels for good machining. Heat just below T_E & hold for 15-25h.

- **Full Anneal (steels):** Make soft steels for good forming by heating to get γ, then cool in furnace to get coarse P.

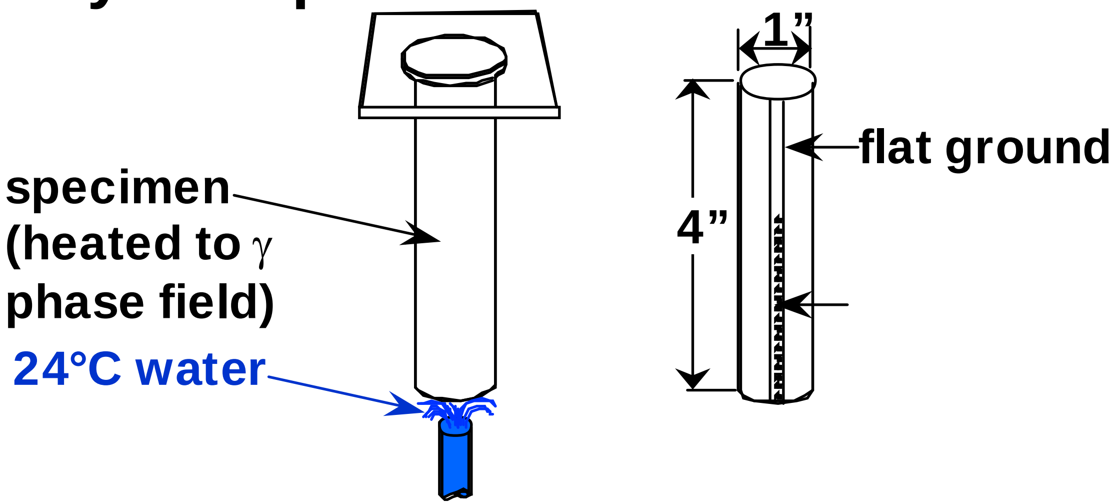
- **Process Anneal:** Negate effect of cold working by (recovery/ recrystallization)

- **Normalize (steels):** Deform steel with <u>large</u> grains, then normalize to make grains small.

Based on discussion in Section 11.7, *Callister 6e*.

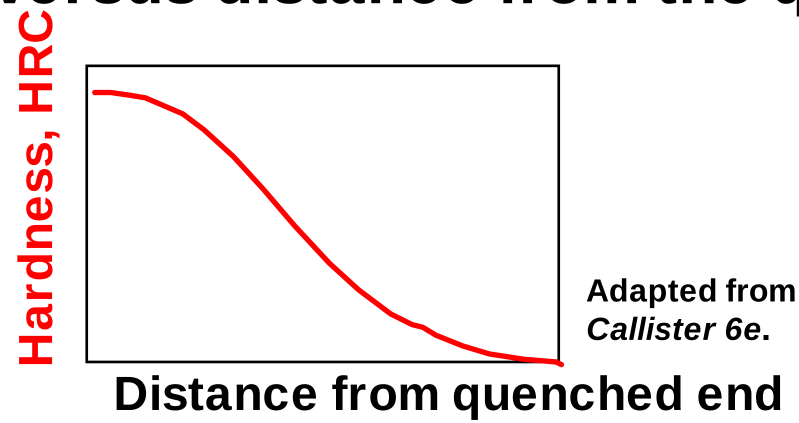
HARDENABILITY--STEELS

- Ability to form martensite
- Jominy end quench test to measure hardenability.



Adapted from Fig. 11.10, *Callister 6e*. (Fig. 11.10 adapted from A.G. Guy, *Essentials of Materials Science*, McGraw-Hill Book Company, New York, 1978.)

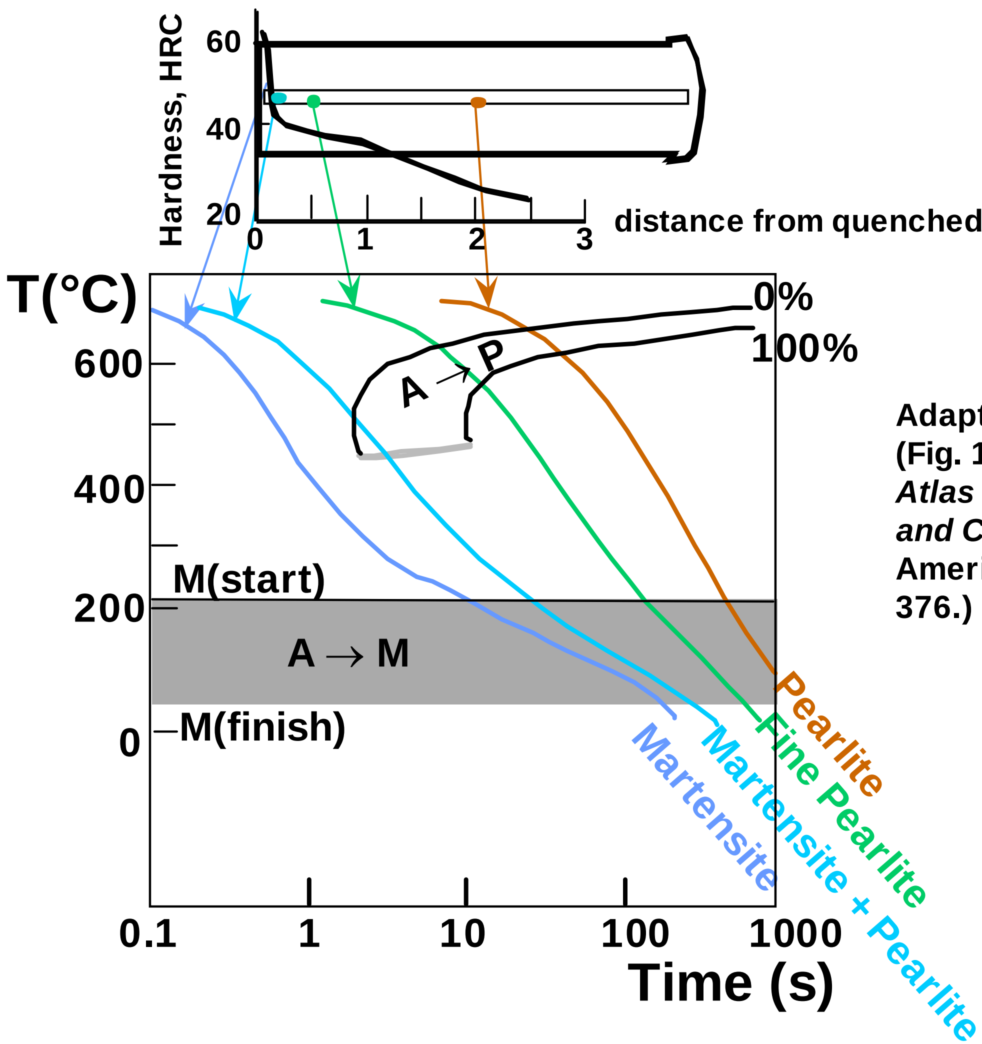
- Hardness versus distance from the quenched end.



Adapted from Fig. 11.11, *Callister 6e*.

WHY HARDNESS CHANGES W/POSITION

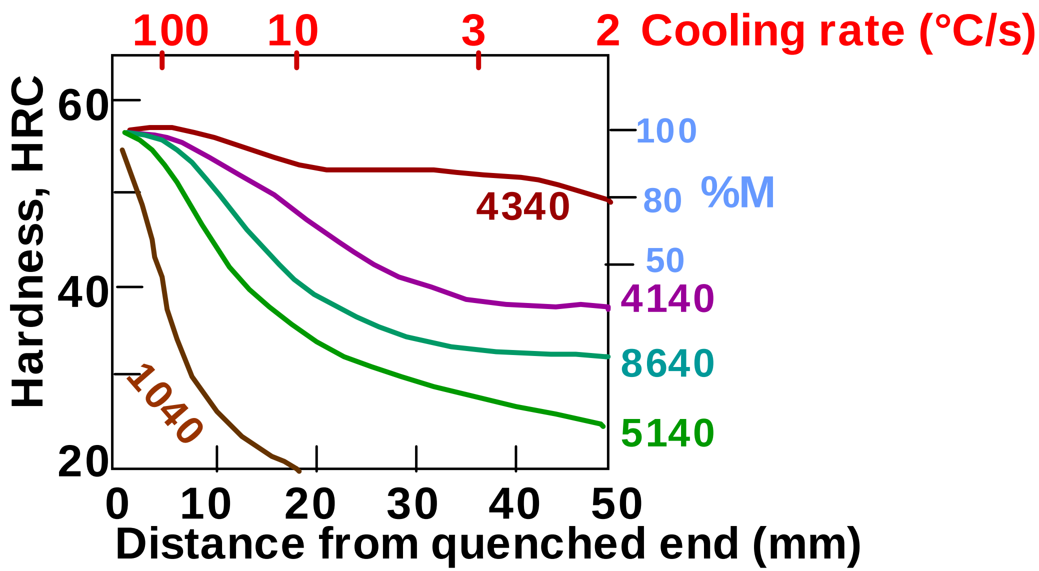
- The cooling rate varies with position.



Adapted from Fig. 11.12, *Callister 6e*. (Fig. 11.12 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1977, p. 376.)

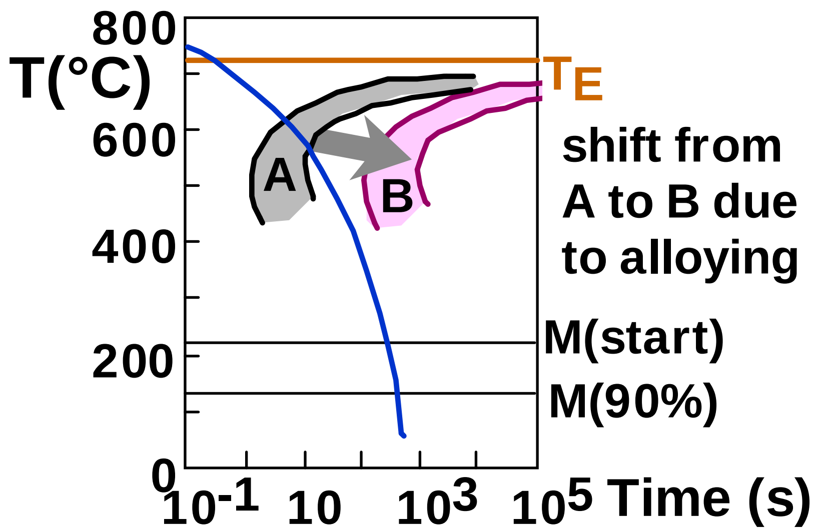
HARDENABILITY VS ALLOY CONTENT

- **Jominy end quench results, C = 0.4wt%C**



Adapted from Fig. 11.13, *Callister 6e*. (Fig. 11.13 adapted from figure furnished courtesy Republic Steel Corporation.)

- **"Alloy Steels"**
  (4140, 4340, 5140, 8640)
  --contain Ni, Cr, Mo
  (0.2 to 2wt%)
  --these elements shift the "nose".
  --martensite is easier to form.



QUENCHING MEDIUM & GEOMETRY

- **Effect of quenching medium:**

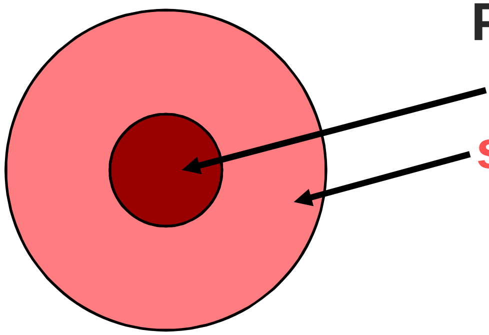
Medium	Severity of Quench	Hardness
air	small	small
oil	moderate	moderate
water	large	large

- **Effect of geometry:**

When surface-to-volume ratio increases:

--cooling rate increases

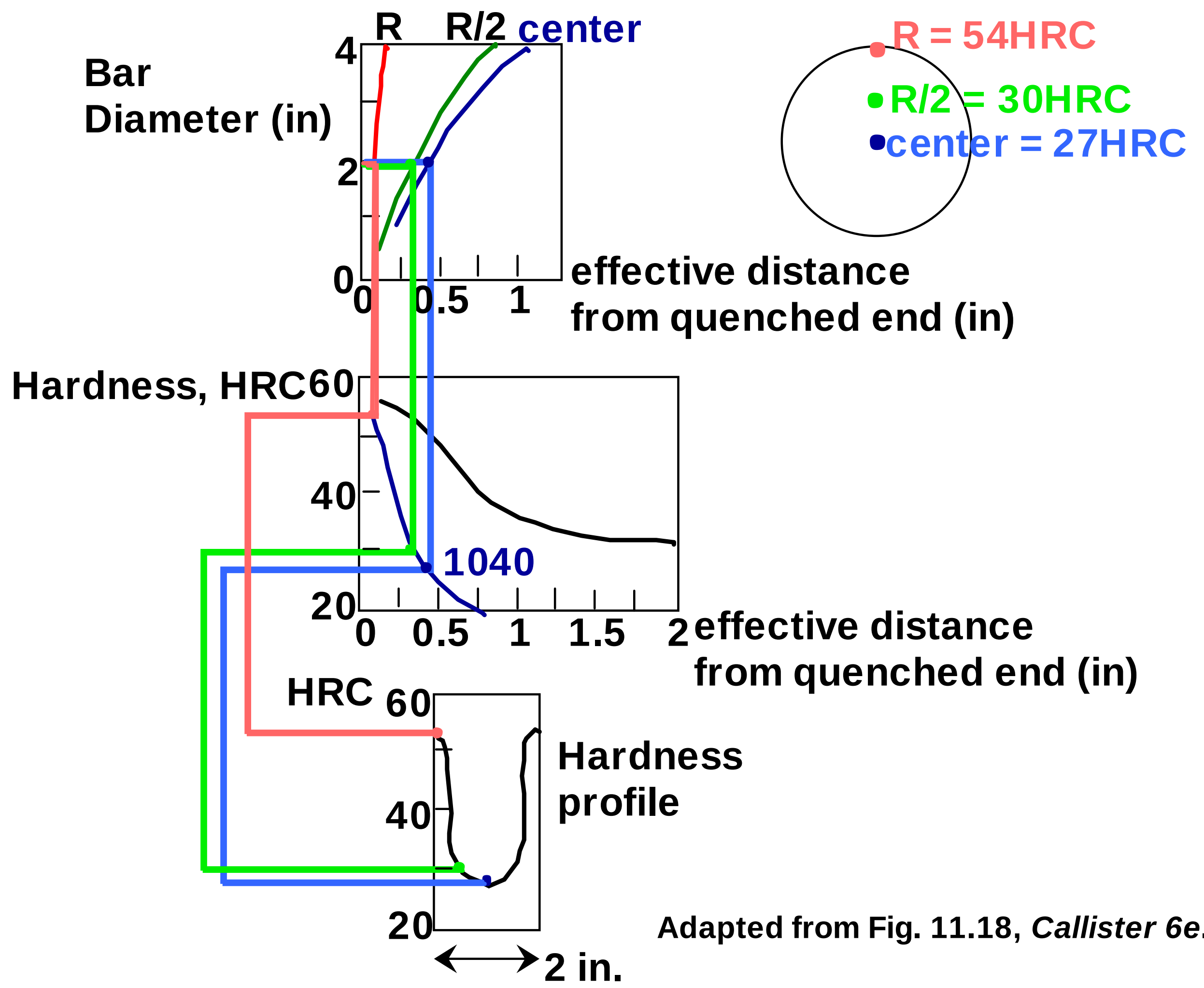
--hardness increases



Position	Cooling rate	Hardness
center	small	small
surface	large	large

PREDICTING HARDNESS PROFILES

- Ex: Round bar, 1040 steel, water quenched, 2" diam.



Adapted from Fig. 11.18, *Callister 6e*.

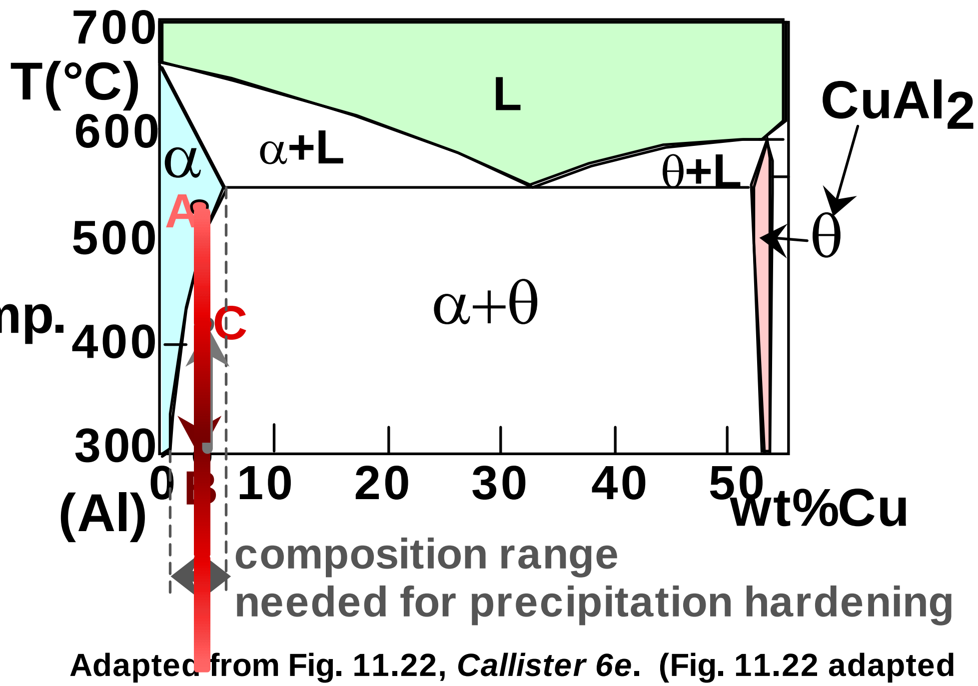
PRECIPITATION HARDENING

- Particles impede dislocations.
- Ex: Al-Cu system
- Procedure:

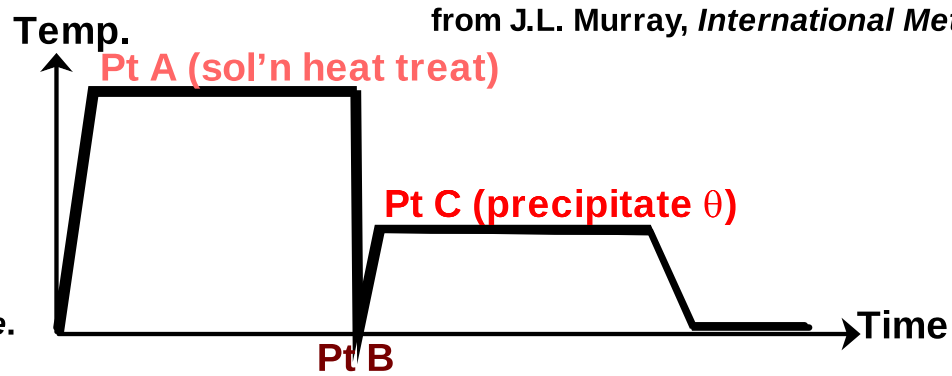
  --Pt A: solution heat treat (get α solid solution)

  --Pt B: quench to room temp.

  --Pt C: reheat to nucleate small θ crystals within α crystals.
- Other precipitation systems:
  - Cu-Be
  - Cu-Sn
  - Mg-Al



Adapted from Fig. 11.22, *Callister 6e*. (Fig. 11.22 adapted from J.L. Murray, *International Metals Review* **30**, p.5, 1985.)



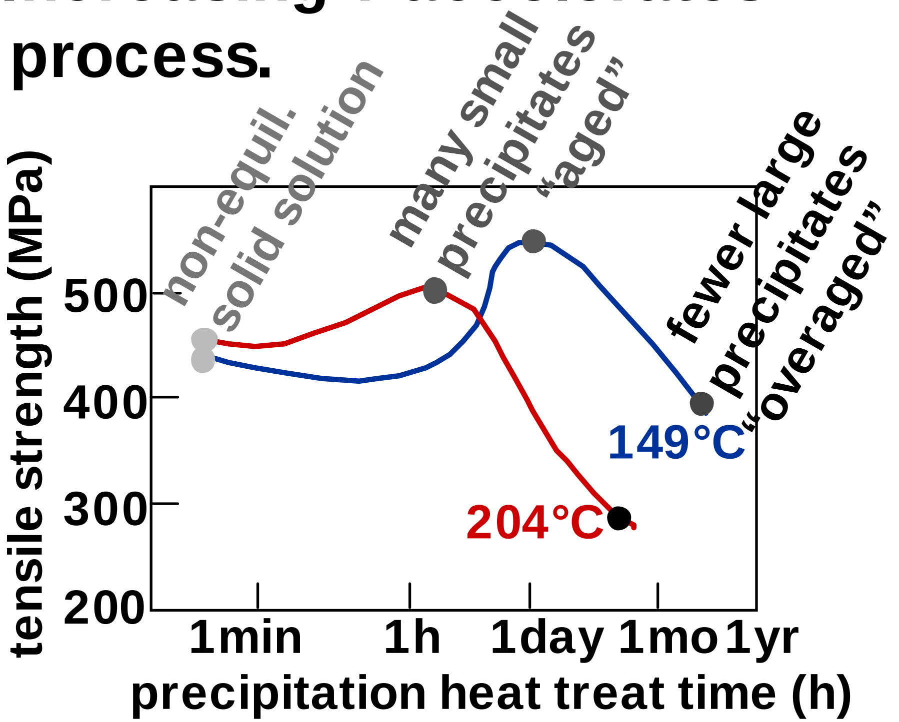
Adapted from Fig. 11.20, *Callister 6e*.

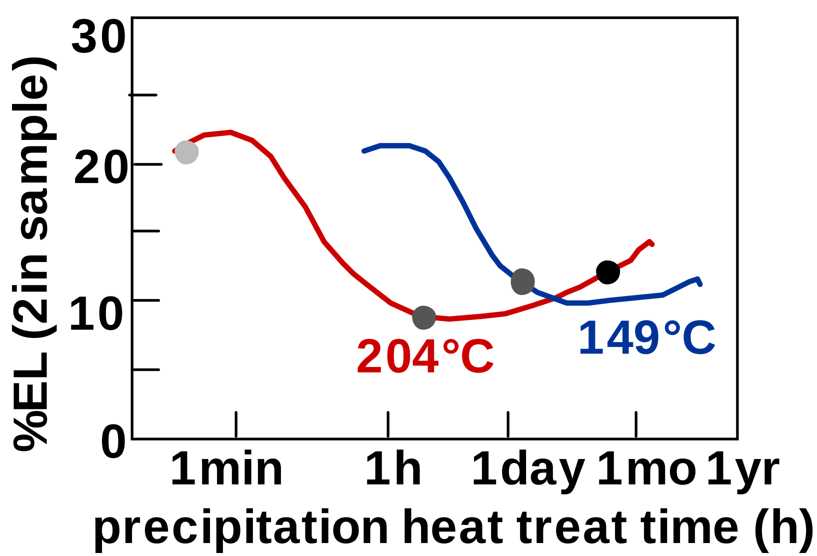
PRECIPITATE EFFECT ON TS, %EL

- 2014 Al Alloy:

- TS peaks with precipitation time.
- Increasing T accelerates process.

- %EL reaches minimum with precipitation time.

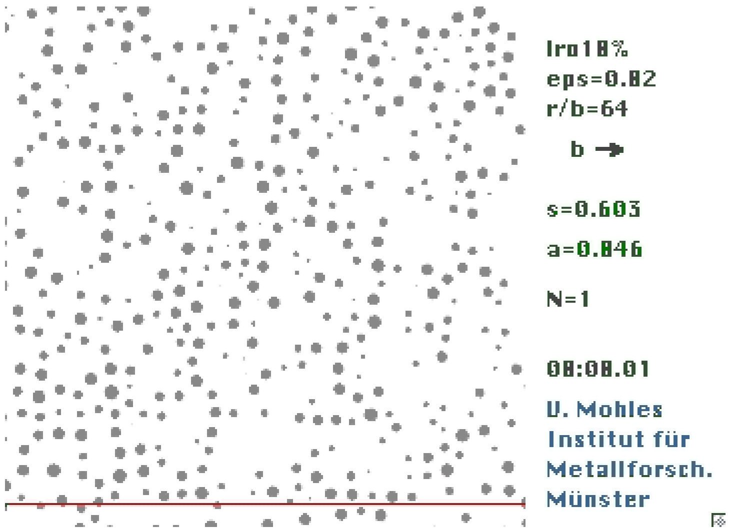




Adapted from Fig. 11.25 (a) and (b), *Callister 6e*. (Fig. 11.25 adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker (Managing Ed.), American Society for Metals, 1979. p. 41.)

SIMULATION: DISLOCATION MOTION PEAK AGED MATERIAL

• **Peak-aged**
  --avg. particle size = 64b
  --closer spaced particles
    efficiently stop dislocations.



Simulation courtesy
of Volker Mohles,
Institut für Materialphysik der
Universitåt, Münster, Germany
(http://www.
uni-munster.de/physik
/MP/mohles/). Used with
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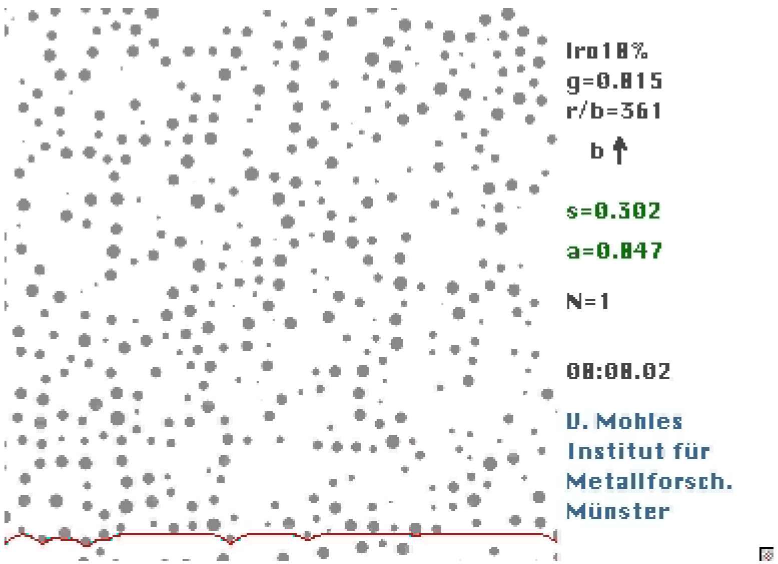
SIMULATION: DISLOCATION MOTION OVERAGED MATERIAL

- **Over-aged**
  --avg. particle size = 361b
  --more widely spaced particles not as effective.



Simulation courtesy of Volker Mohles, Institut für Materialphysik der Universitåt, Münster, Germany (http://www. uni-munster.de/physik /MP/mohles/). Used with permission.

SUMMARY

- Steels: increase TS, Hardness (and cost) by adding
  --C (low alloy steels)
  --Cr, V, Ni, Mo, W (high alloy steels)
  --ductility usually decreases w/additions.
- Non-ferrous:
  --Cu, Al, Ti, Mg, Refractory, and noble metals.
- Fabrication techniques:
  --forming, casting, joining.
- Hardenability
  --increases with alloy content.
- Precipitation hardening
  --effective means to increase strength in
  Al, Cu, and Mg alloys.