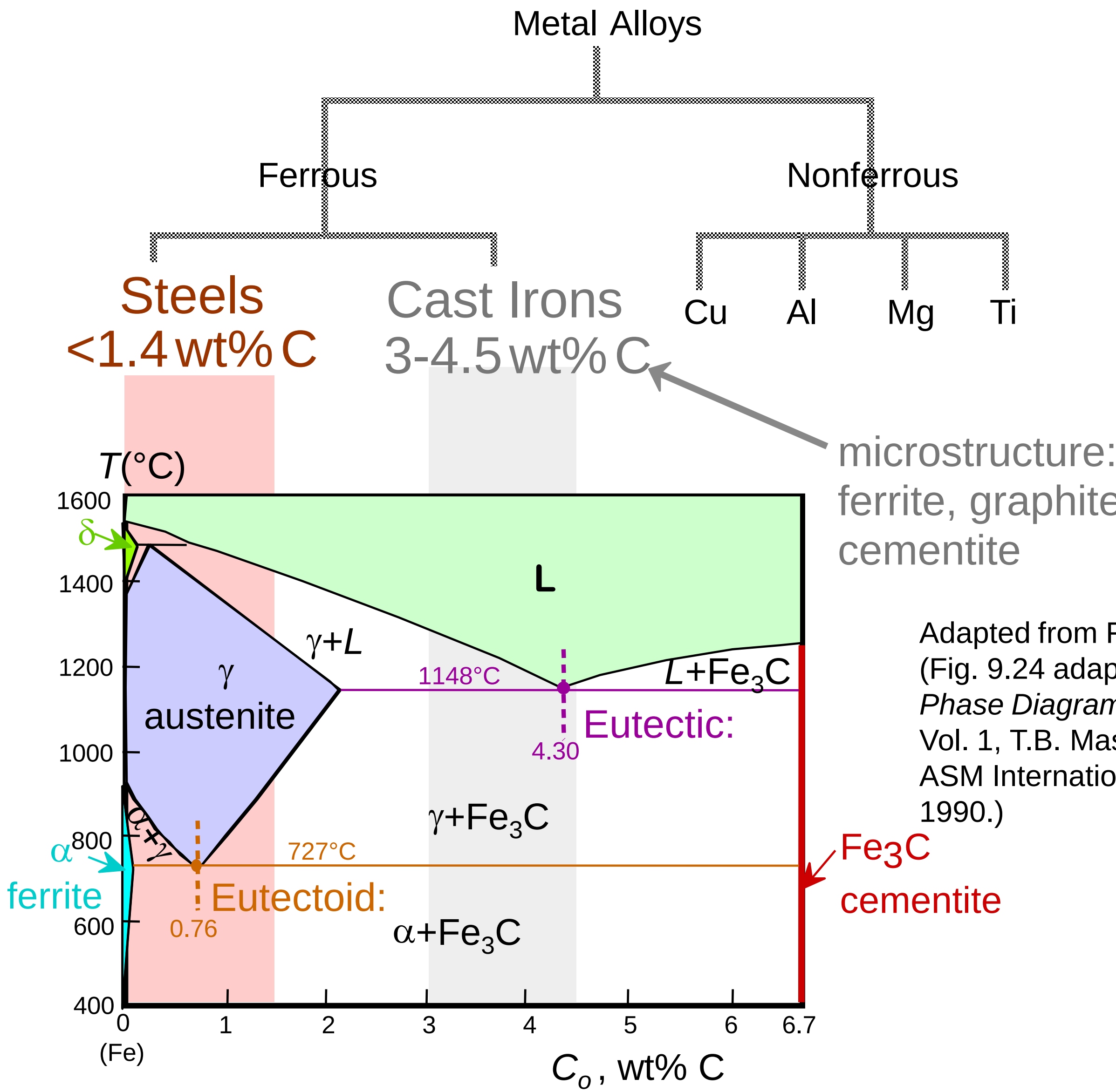
Chapter 11: Metal Alloys Applications and Processing

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 7e*.

Adapted from Fig. 9.24, *Callister 7e*. (Fig. 9.24 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

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

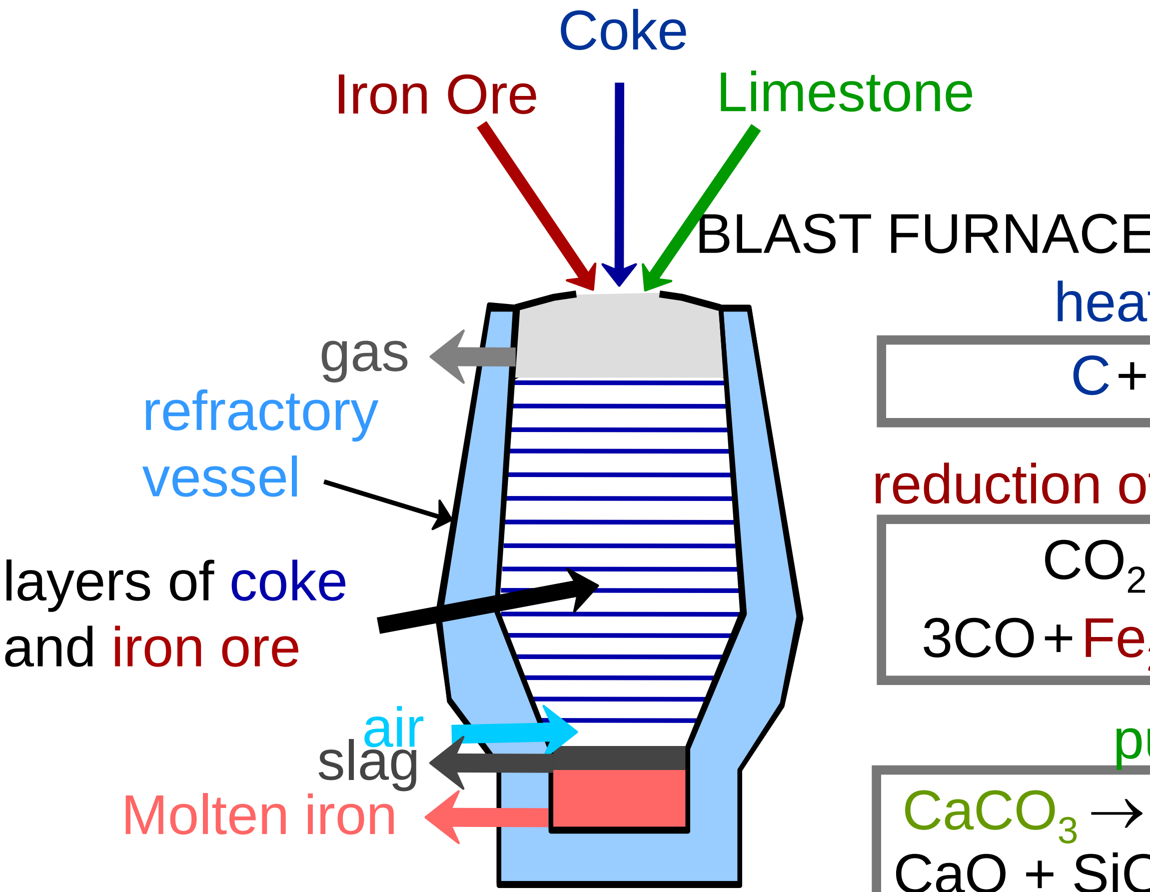
High Alloy

	low carbon <0.25 wt% C		Med carbon 0.25-0.6 wt% C		high carbon 0.6-1.4 wt% C		High Alloy
Name	plain	HSLA	plain	heat treatable	plain	tool	austenitic 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 7e*.

Refinement of Steel from Ore



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

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + SiO_2 + Al_2O_3 \rightarrow \text{slag}$$

Ferrous Alloys

Iron containing – Steels - cast irons

Nomenclature   AISI & SAE

- 10xx Plain Carbon Steels
- 11xx Plain Carbon Steels (resulfurized for machinability)
- 15xx Mn (10 ~ 20%)
- 40xx Mo (0.20 ~ 0.30%)
- 43xx Ni (1.65 - 2.00%), Cr (0.4 - 0.90%), Mo (0.2 - 0.3%)
- 44xx Mo (0.5%)

where xx is wt% C x 100

example: 1060 steel – plain carbon steel with 0.60 wt% C

Stainless Steel -- >11% Cr

Cast Iron

- Ferrous alloys with > 2.1 wt% C
  - more commonly 3 - 4.5 wt%C
- low melting (also brittle) so easiest to cast

- Cementite decomposes to ferrite + graphite

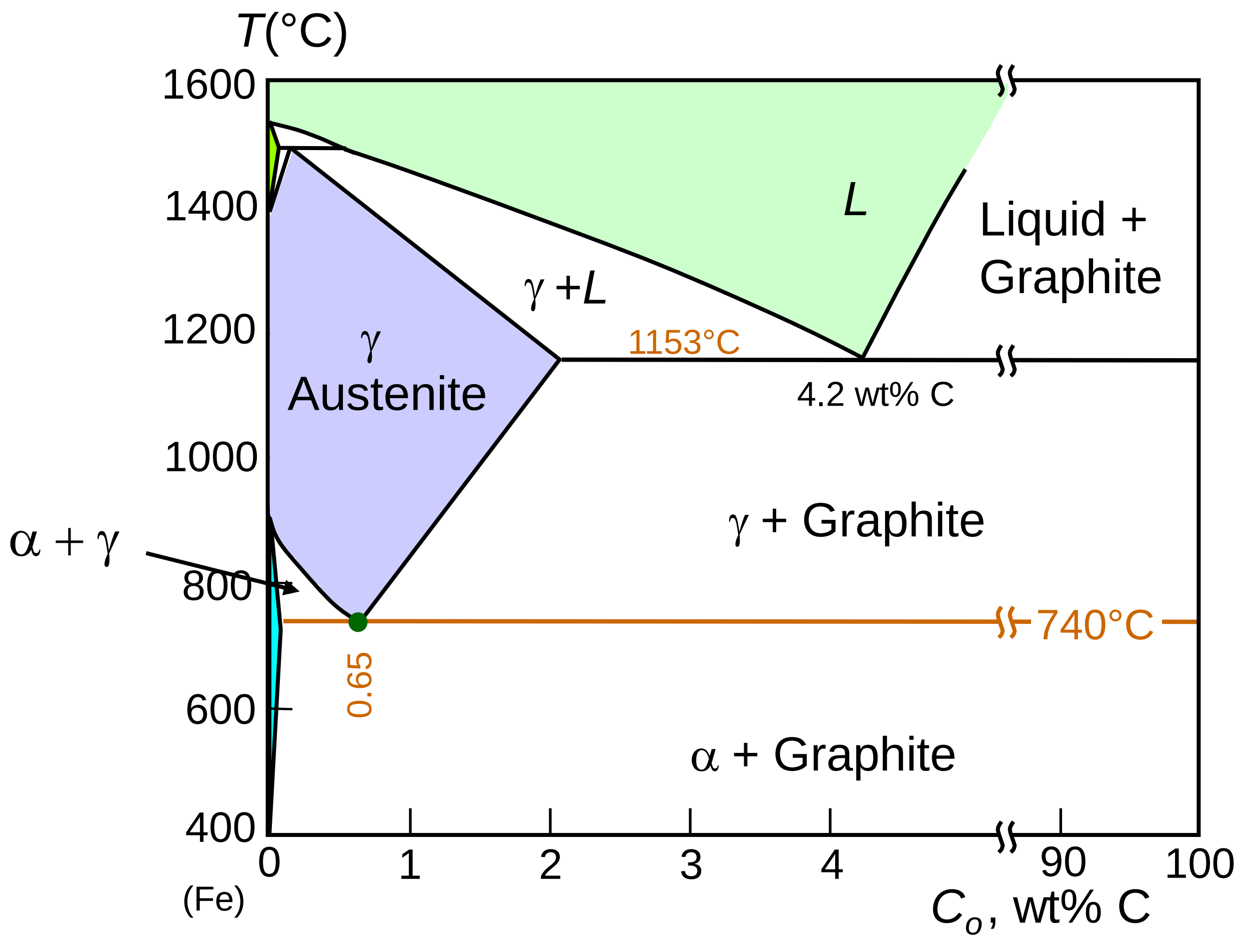
  $Fe_3C \rightarrow 3\ Fe\ (\alpha) + C\ (graphite)$

  - generally a slow process

Fe-C True Equilibrium Diagram

Graphite formation promoted by

- Si > 1 wt%
- slow cooling



Adapted from Fig. 11.2,*Callister 7e*. (Fig. 11.2 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

Types of Cast Iron

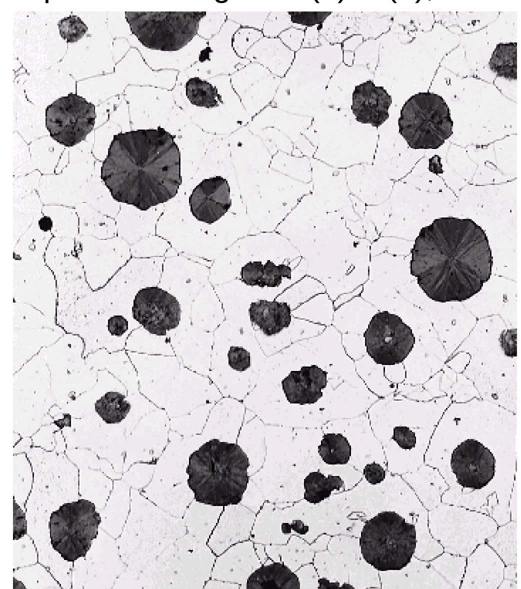
Gray iron

- graphite flakes
- weak & brittle under tension
- stronger under compression
- excellent vibrational dampening
- wear resistant

Ductile iron

- add Mg or Ce
- graphite in nodules not flakes
- matrix often pearlite - better ductility

Adapted from Fig. 11.3(a) & (b), *Callister 7e*.



Types of Cast Iron

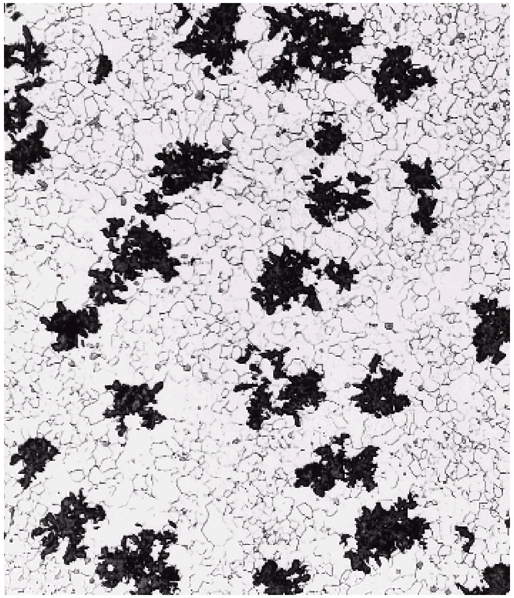
White iron

- <1wt% Si so harder but brittle
- more cementite

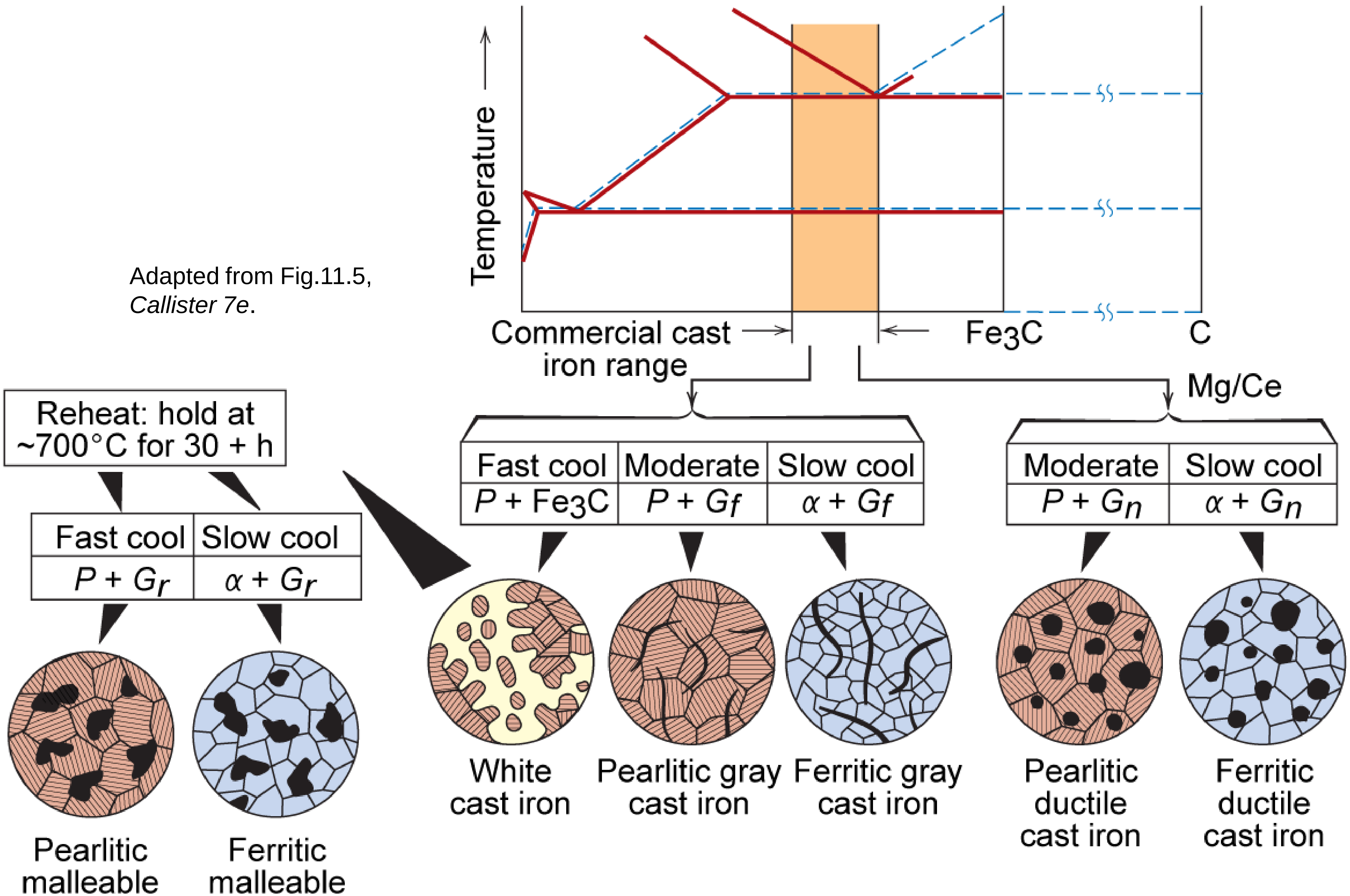
Adapted from Fig. 11.3(c) & (d), *Callister 7e*.

Malleable iron

- heat treat at 800-900ºC
- graphite in rosettes
- more ductile



Production of Cast Iron



Adapted from Fig.11.5, *Callister 7e*.

Limitations of Ferrous Alloys

1) Relatively high density
2) Relatively low conductivity
3) Poor corrosion resistance

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)

NonFerrous Alloys

- **Mg Alloys**

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

- **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 7e*.

Metal Fabrication

- How do we fabricate metals?
  – Blacksmith - hammer (forged)
  – Molding - cast

- Forming Operations
  – Rough stock formed to final shape

Hot working vs. Cold working

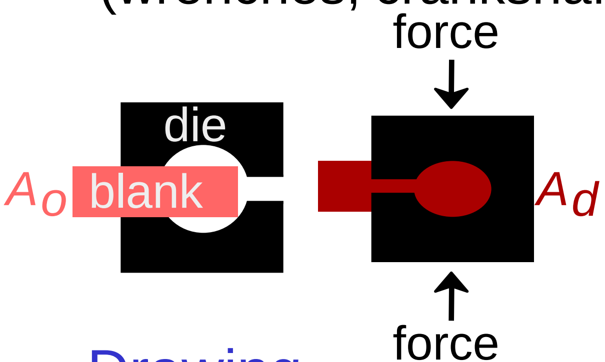
Hot working
- T high enough for recrystallization
- Larger deformations

Cold working
- well below T_m
- work hardening
- smaller deformations

Metal Fabrication Methods - I

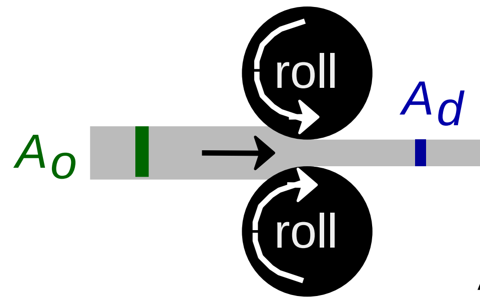
FORMING | CASTING | JOINING

- Forging (Hammering; Stamping)
  (wrenches, crankshafts)



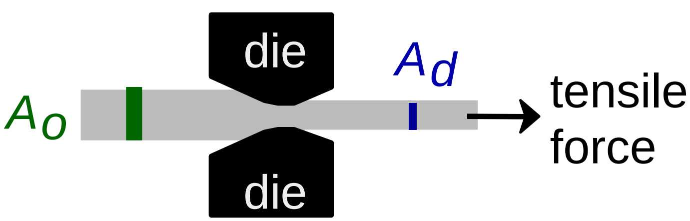
often at elev. *T*

- Rolling (Hot or Cold Rolling)
  (I-beams, rails, sheet & plate)



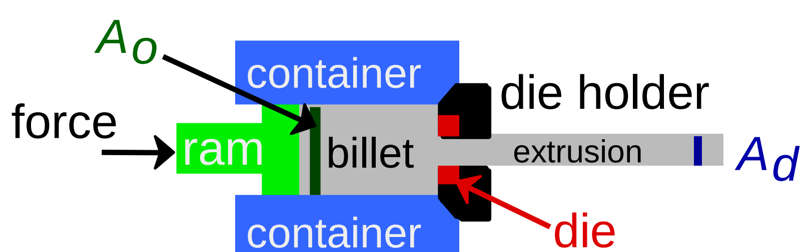
Adapted from Fig. 11.8, *Callister 7e*.

- Drawing
  (rods, wire, tubing)



die must be well lubricated & clean

- Extrusion
  (rods, tubing)



ductile metals, e.g. Cu, Al (hot)

Metal Fabrication Methods - II

FORMING CASTING JOINING

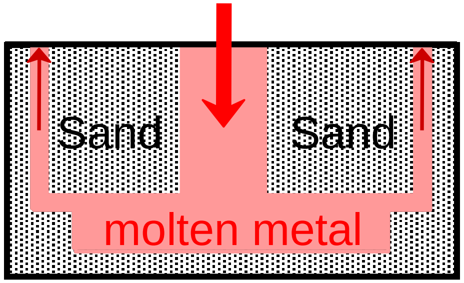
- Casting- mold is filled with metal
  - metal melted in furnace, perhaps alloying elements added. Then cast in a mold
  - most common, cheapest method
  - gives good production of shapes
  - weaker products, internal defects
  - good option for brittle materials

Metal Fabrication Methods - II

FORMING | CASTING | JOINING

- Sand Casting

(large parts, e.g., auto engine blocks)

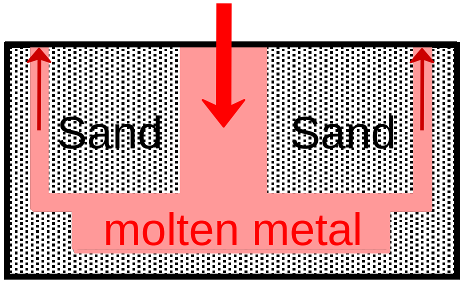


- trying to hold something that is hot
- what will withstand >1600ºC?
- cheap - easy to mold => sand!!!
- pack sand around form (pattern) of desired shape

Metal Fabrication Methods - II

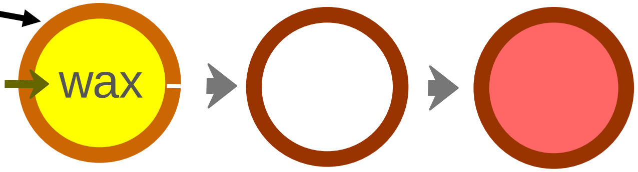
FORMING | **CASTING** | JOINING

- 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



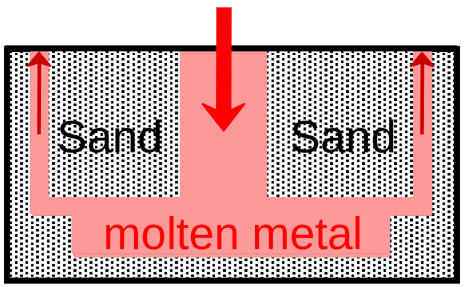
Investment Casting

- pattern is made from paraffin.
- mold made by encasing in plaster of paris
- melt the wax & the hollow mold is left
- pour in metal

Metal Fabrication Methods - II

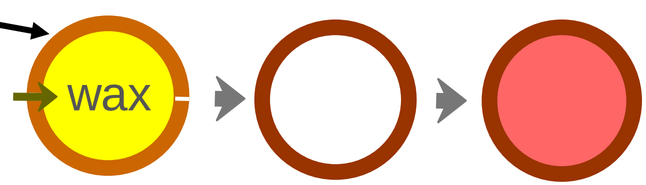
FORMING | **CASTING** | JOINING

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

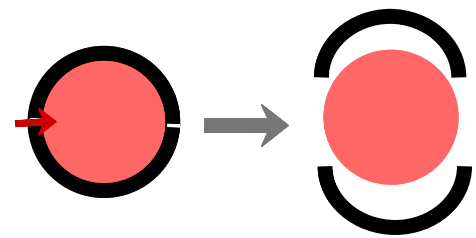


- Investment Casting
  (low volume, complex shapes
  e.g., jewelry, turbine blades)

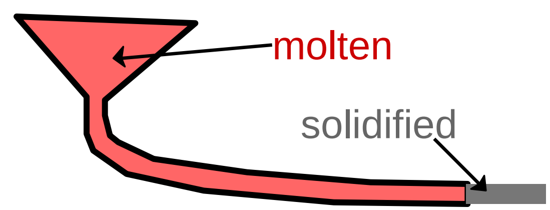
plaster
die formed
around wax
prototype



- Die Casting
  (high volume, low T alloys)



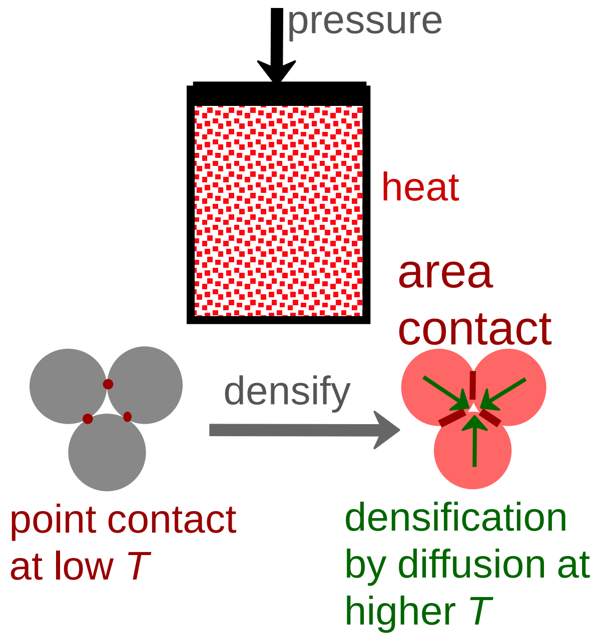
- Continuous Casting
  (simple slab shapes)



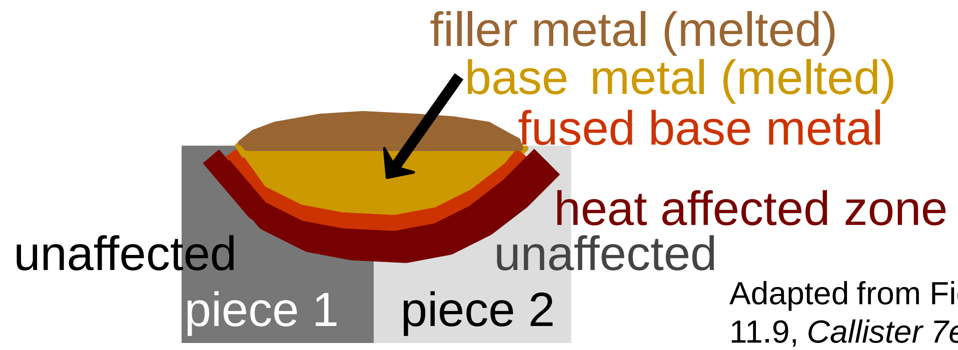
Metal Fabrication Methods - III

FORMING | CASTING | **JOINING**

- Powder Metallurgy
  (materials w/low ductility)



- Welding
  (when one large part is impractical)



Adapted from Fig. 11.9, *Callister 7e*. (Fig. 11.9 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 15-25 h.

- 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.

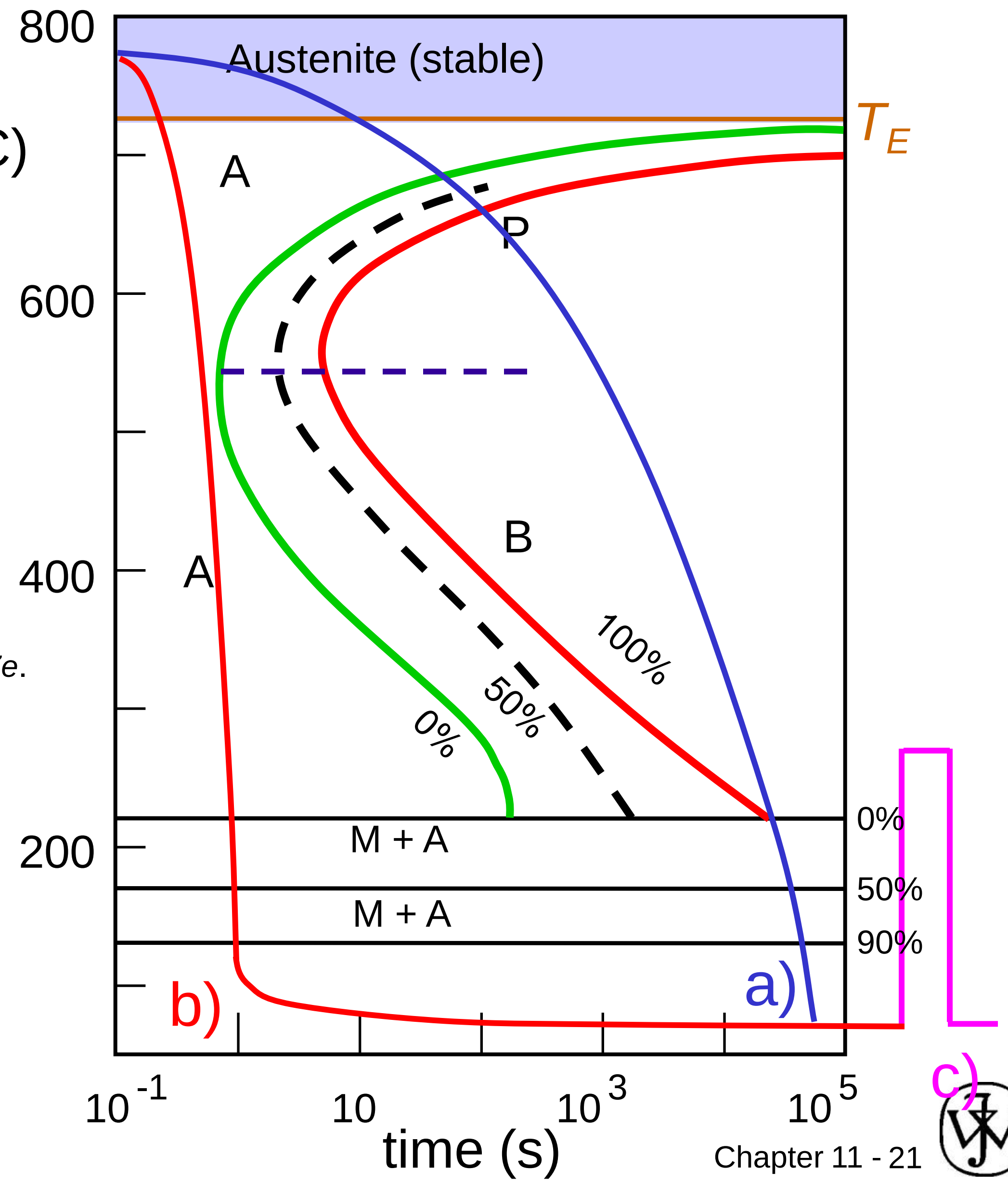
Based on discussion in Section 11.7, *Callister 7e*.

Heat Treatments

a) Annealing

b) Quenching

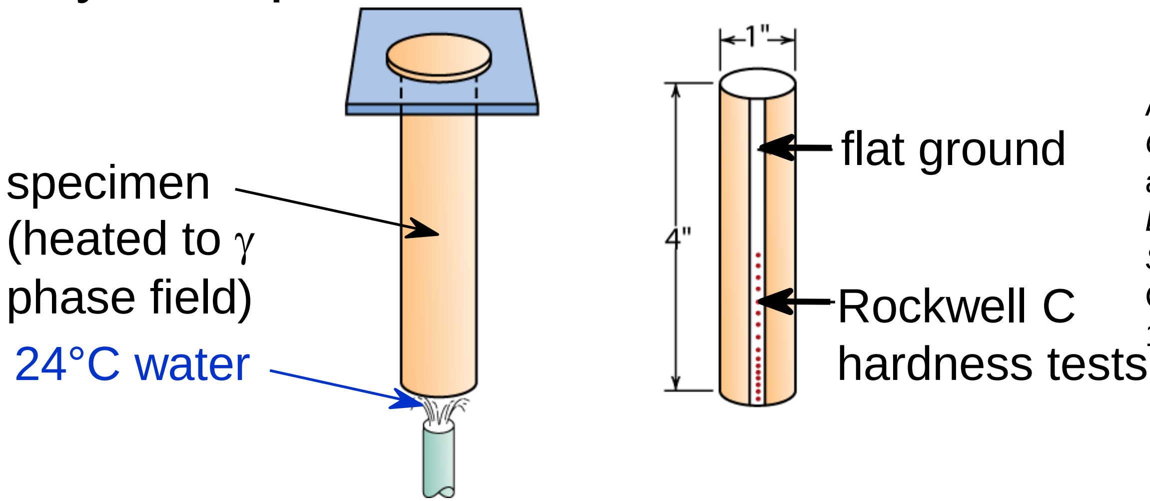
c) Tempered Martensite



Adapted from Fig. 10.22, *Callister 7e*.

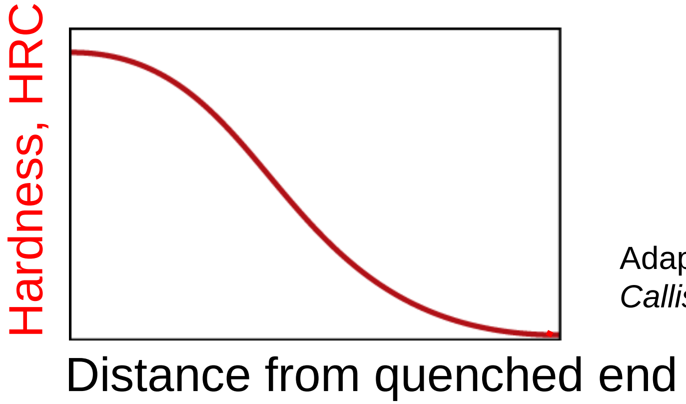
Hardenability--Steels

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



Adapted from Fig. 11.11, *Callister 7e*. (Fig. 11.11 adapted from A.G. Guy, *Essentials of Materials Science*, McGraw-Hill Book Company, New York, 1978.)

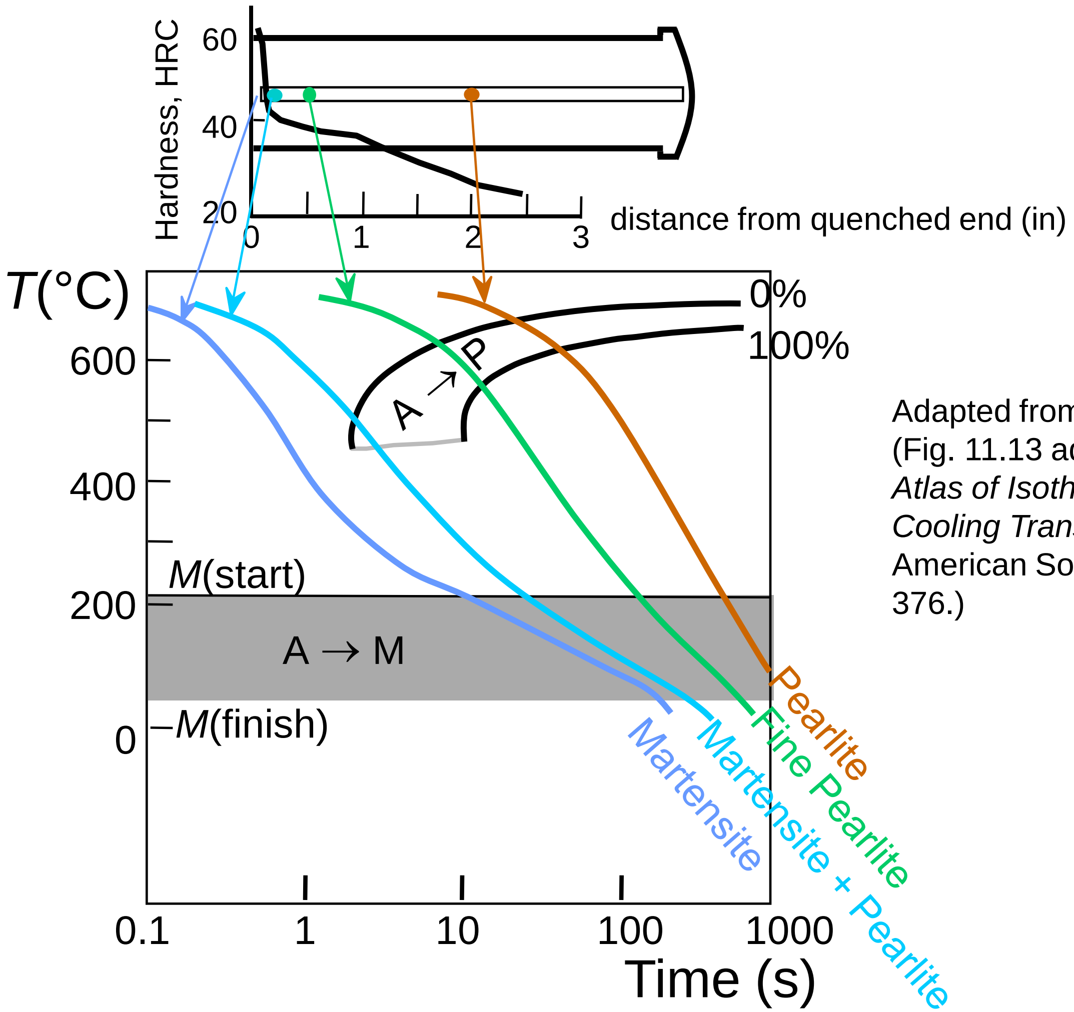
- Hardness versus distance from the quenched end.



Adapted from Fig. 11.12, *Callister 7e*.

Why Hardness Changes W/Position

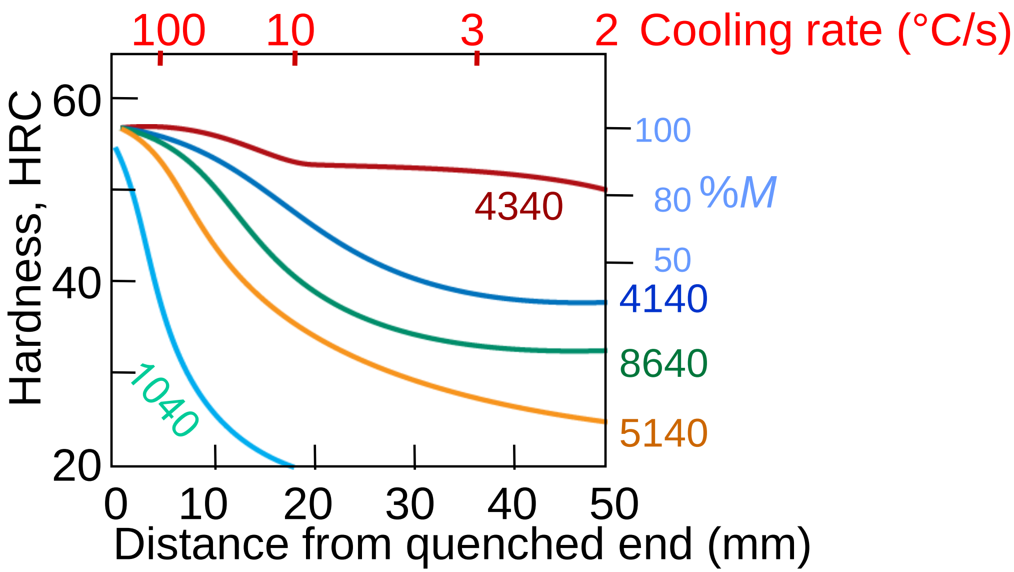
- The cooling rate varies with position.



Adapted from Fig. 11.13, *Callister 7e*. (Fig. 11.13 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1977, p. 376.)

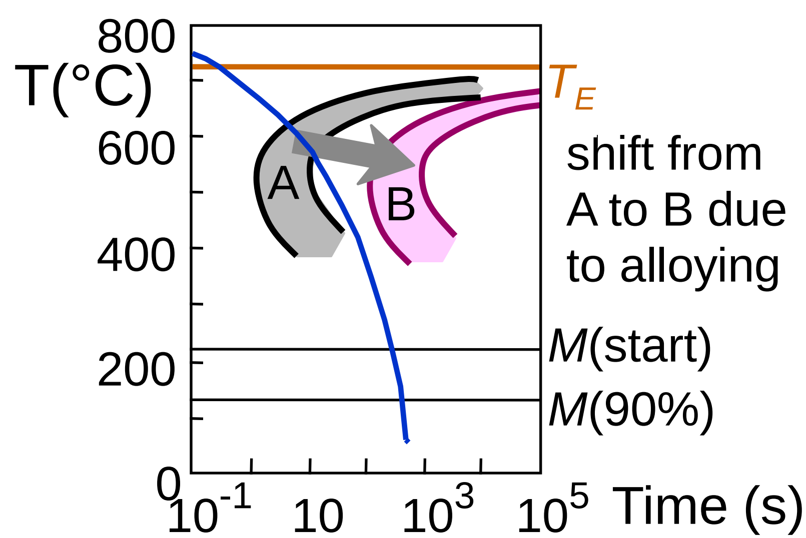
Hardenability vs Alloy Composition

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



Adapted from Fig. 11.14, *Callister 7e*.
(Fig. 11.14 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:

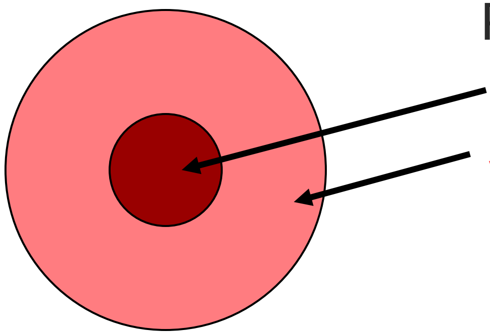
Medium	Severity of Quench	Hardness
air	low	low
oil	moderate	moderate
water	high	high

- Effect of geometry:

When surface-to-volume ratio increases:

--cooling rate increases

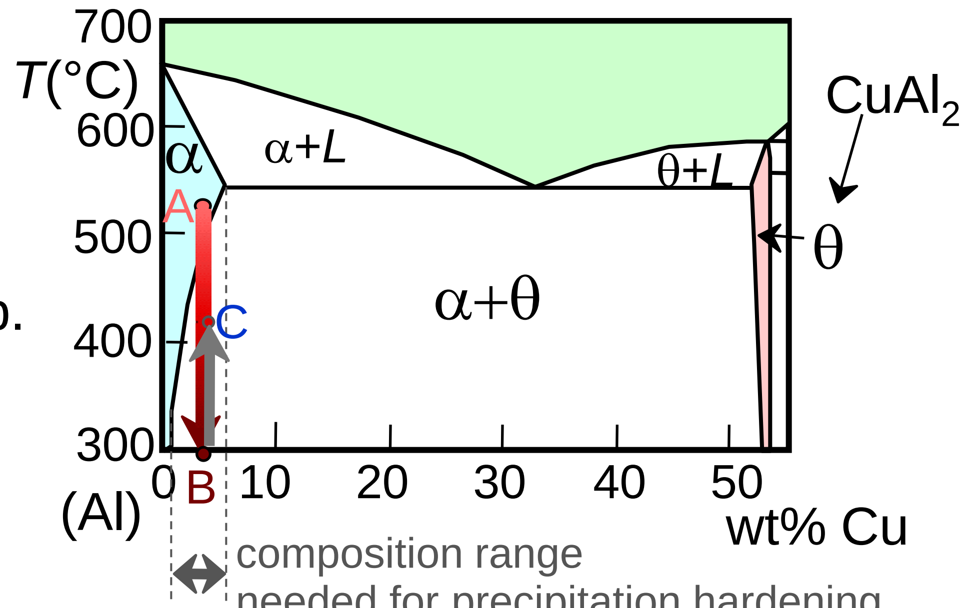
--hardness increases



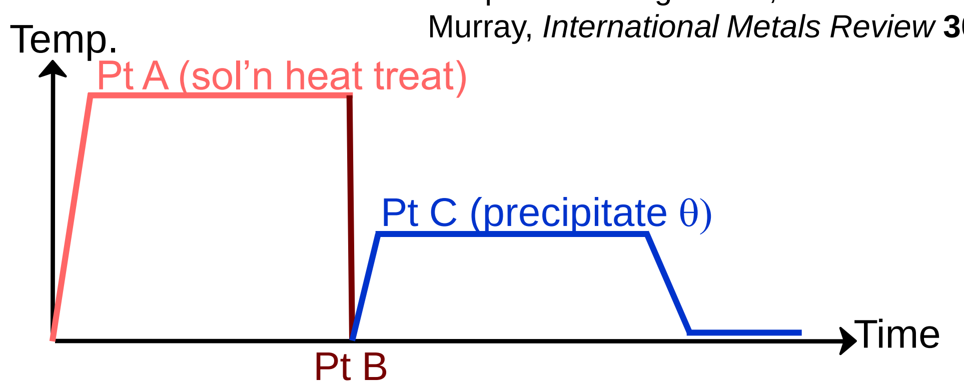
Position	Cooling rate	Hardness
center	low	low
surface	high	high

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. 11.24, *Callister 7e*. (Fig. 11.24 adapted from J.L. Murray, *International Metals Review* **30**, p.5, 1985.)



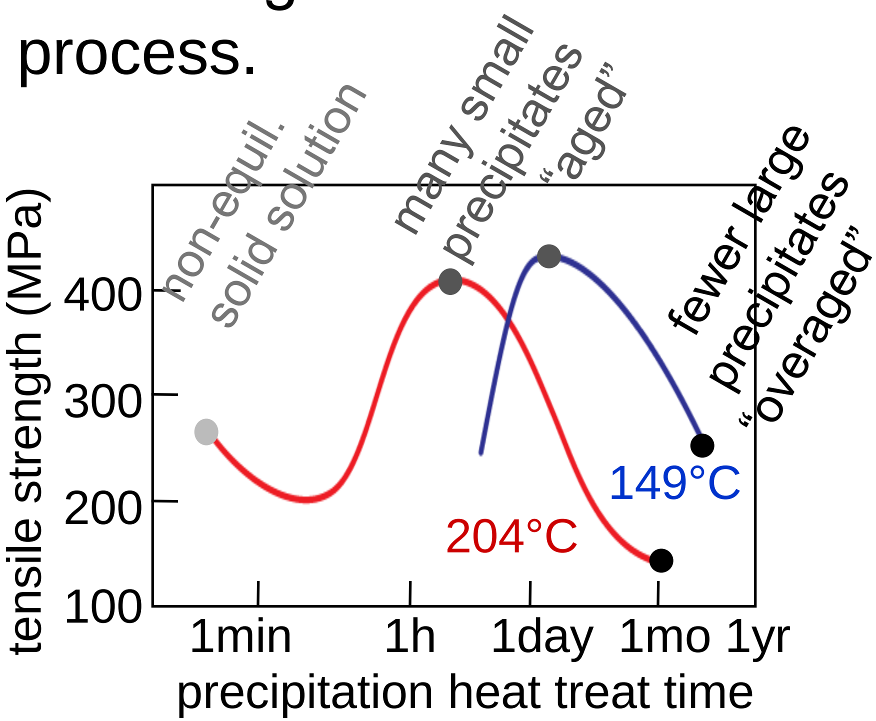
Adapted from Fig. 11.22, *Callister 7e*.

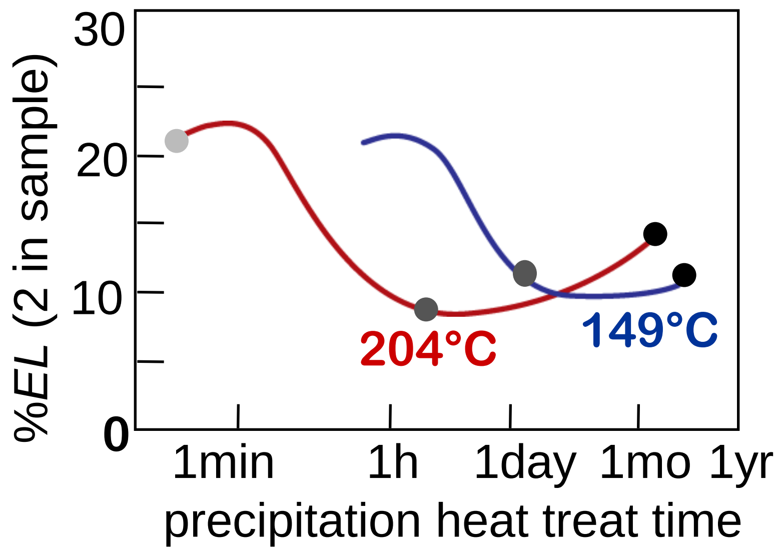
Precipitate Effect on *TS*, %*EL*

- 2014 Al Alloy:

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

- %*EL* reaches minimum with precipitation time.





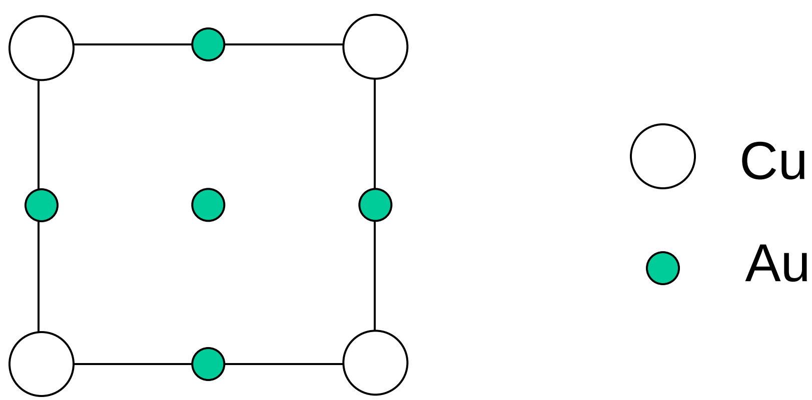
Adapted from Fig. 11.27 (a) and (b), *Callister 7e*. (Fig. 11.27 adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker (Managing Ed.), American Society for Metals, 1979. p. 41.)

Metal Alloy Crystal Stucture

Alloys

- substitutional alloys
  - – can be ordered or disordered
  - – disordered solid solution
  - – ordered - periodic substitution

example: CuAu FCC



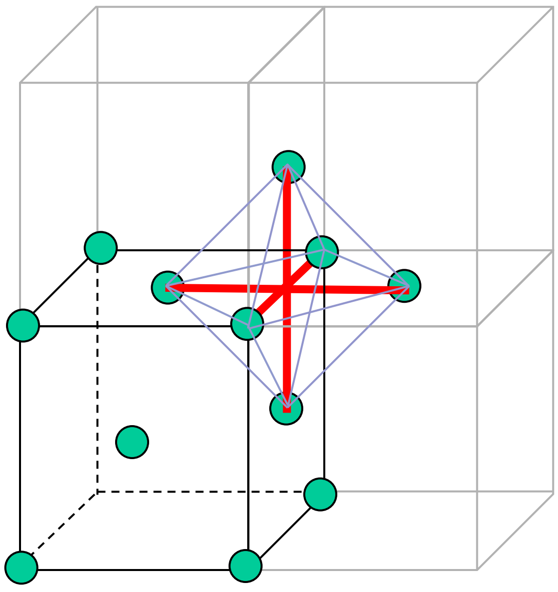
Metal Alloy Crystal Stucture

- Interstitial alloys (compounds)
  - one metal much larger than the other
  - smaller metal goes in ordered way into interstitial “holes” in the structure of larger metal
  - Ex: Cementite – Fe_3C

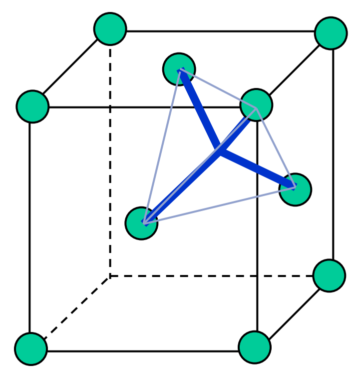
Metal Alloy Crystal Stucture

- Consider FCC structure --- what types of holes are there?

Octahedron - octahedral site = O_H



Tetrahedron - tetrahedral site = T_D

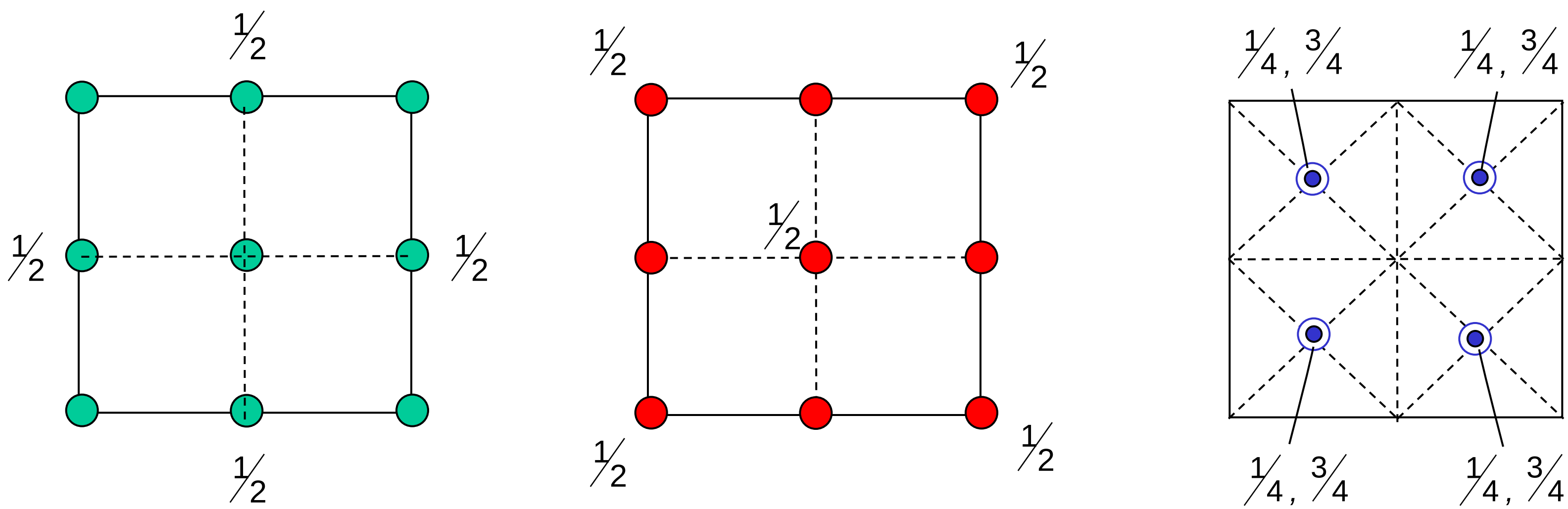


Metal Alloy Crystal Stucture

- Interstitials such as H, N, B, C
- FCC has 4 atoms per unit cell

4 O_H sites

8 T_D sites



metal atoms

O_H sites

T_D sites

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.

ANNOUNCEMENTS

Reading:

Core Problems:

Self-help Problems: