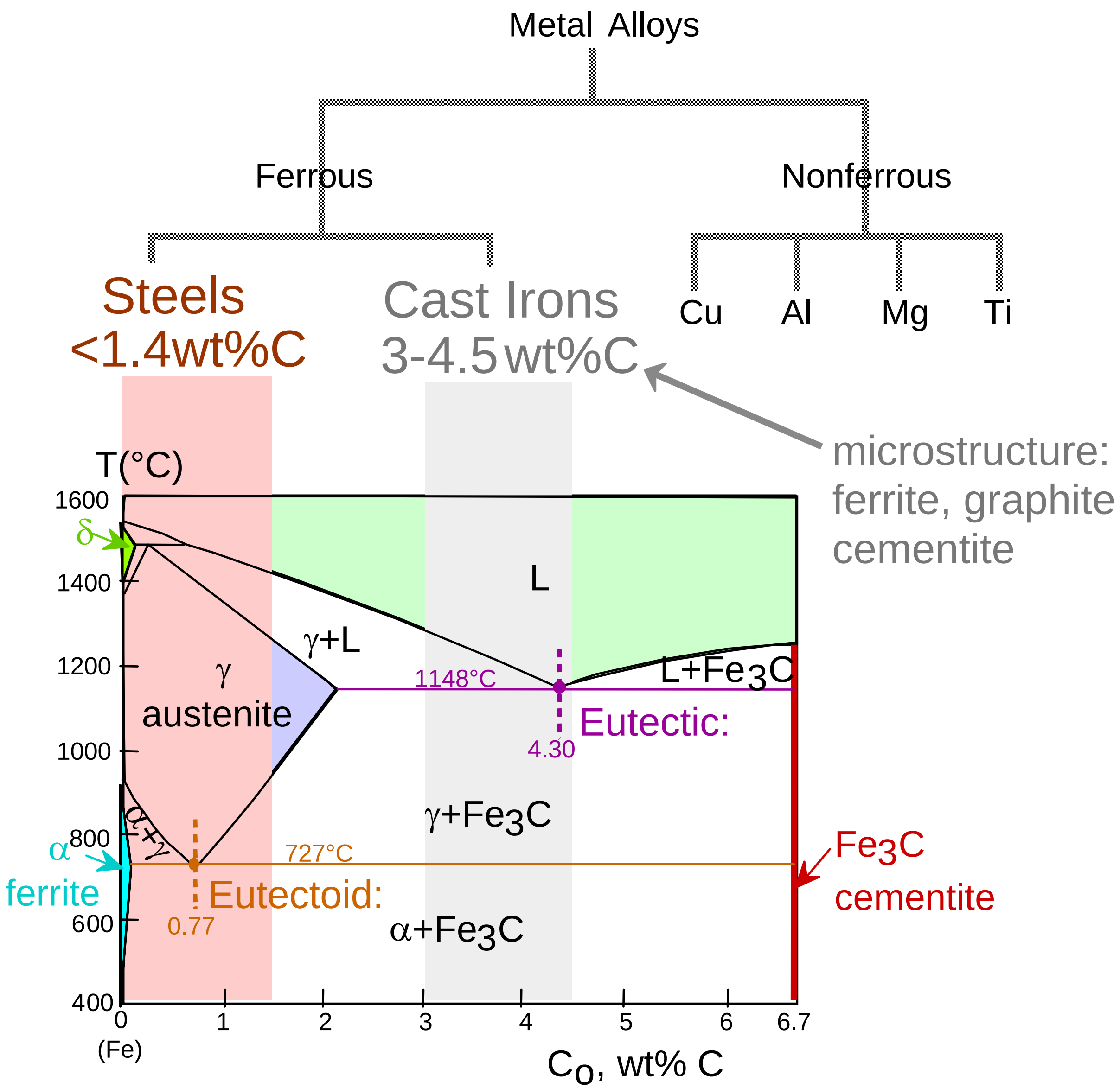
CHAPTER 11: METAL ALLOYS APPLICATIONS AND PROCESSING

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?

Alloy classification



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

Steels

Low Alloy

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

High Alloy

	Low Alloy: low carbon <0.25wt%C		Low Alloy: med carbon 0.25-0.6wt%C		Low Alloy: high carbon 0.6-1.4wt%C		High Alloy
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	43 40	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

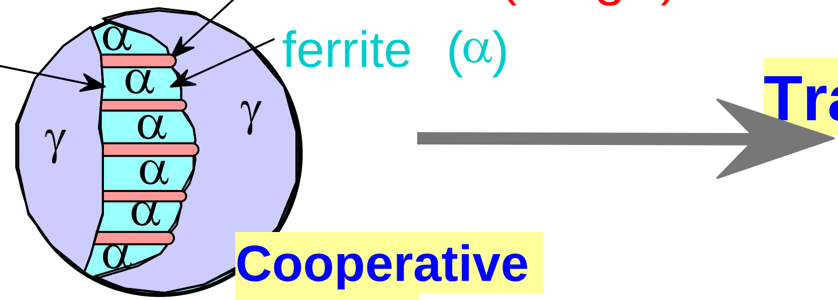
increasing strength, cost, decreasing ductility →

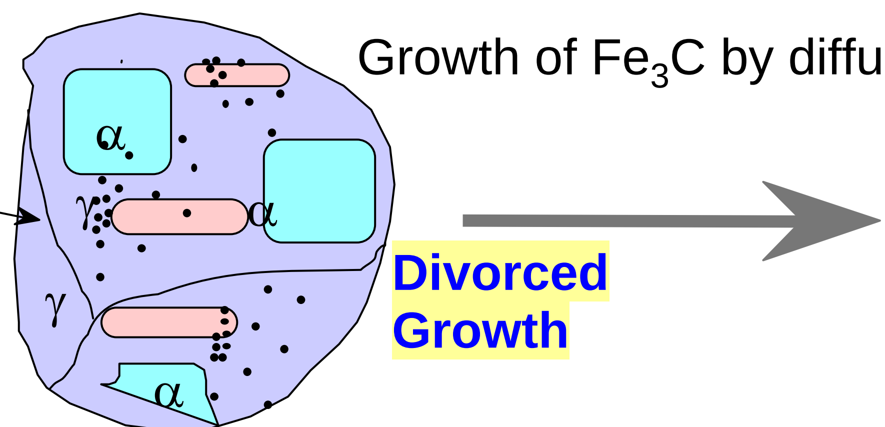
Example: Damascus Steels

- Produced from high carbon (hypereutectic) steel -1.5% C bloom, or cake (wootz – produced in India exported to Damascus)
- Characteristic surface pattern (damascene) produced by microstructure bands of Fe_3C
  - Band formations favored by some carbide forming elements, e.g, V, Mn, Cr, Nb, Mo
  - Vanadium and other carbide-forming impurities existed in iron ores from South India

http://www.tms.org/pubs/journals/JOM/9809/Verhoeven-9809.html

Divorced growth in hypereutectoid steels





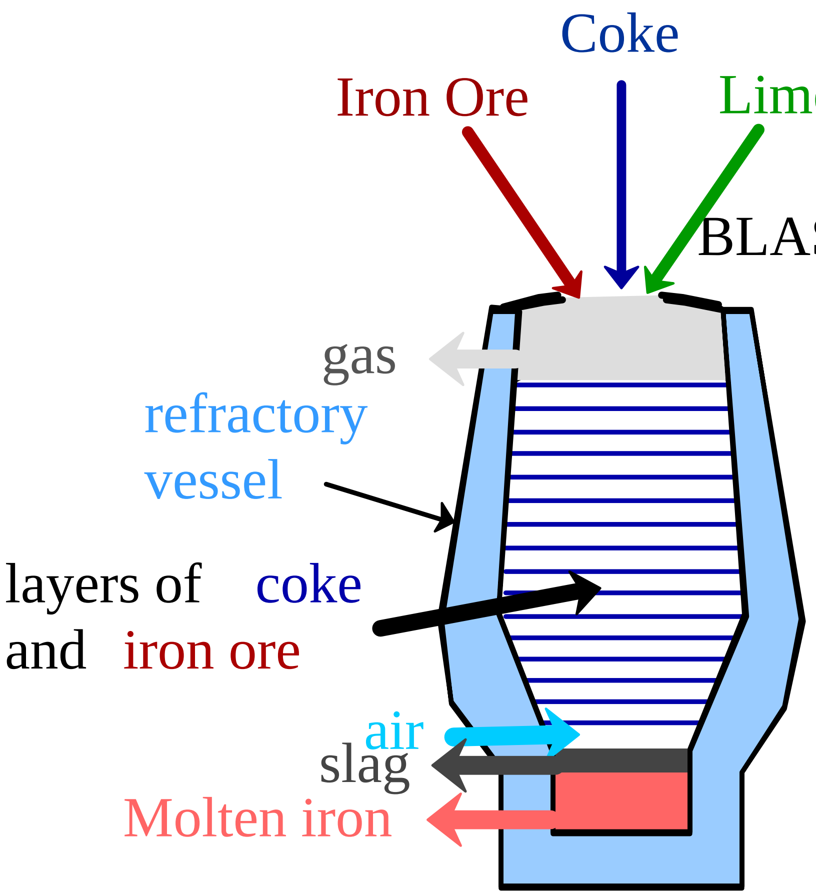
Cast Irons

2.5-4.0wt%C

	1.0-3.0wt%Si	Small Mg or Ce	<1.0wt%Si	
Name	Gray	Duct (nodular)	White	Malleable
Cooling	F M S	M S	F	S
Phases	$P+Fe_3C$, $P+G_f$, $\alpha+G_f$	$P+G_n$, $\alpha+G_n$	$P+G_r$,	$\alpha+G_r$
Example	SAE G1800	ASTM A536	32510	45006
TS	--	+	-	++
EL	--	+	-	+
Uses	Base struct of machining Equipment Engine casting Cylinders, pistons	crank shafts gears valves Pump bodies	Rolling mill rollers	Transmission gears Connecting rod Pipe fittings, flanges

increasing cost →

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

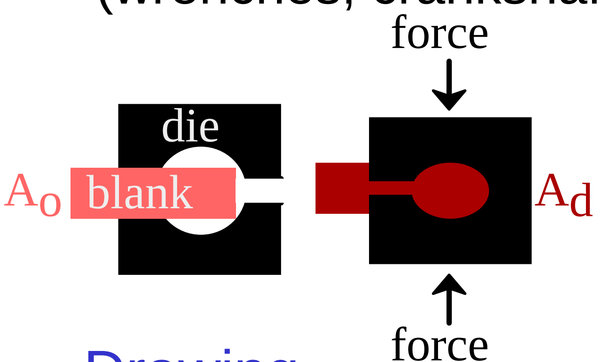
$$CaCO_3 \rightarrow CaO + CO_2$$

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

Metal fabrication methods-I

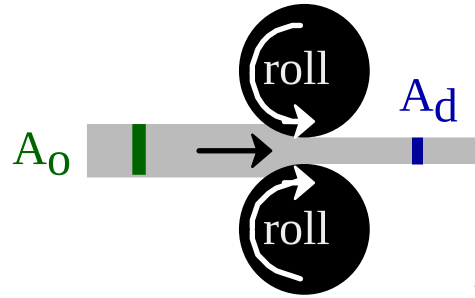
FORMING | CASTING | JOINING

- Forging
  (wrenches, crankshafts)



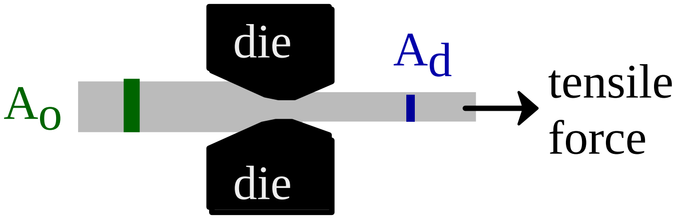
often at elev. T

- Rolling
  (I-beams, rails)

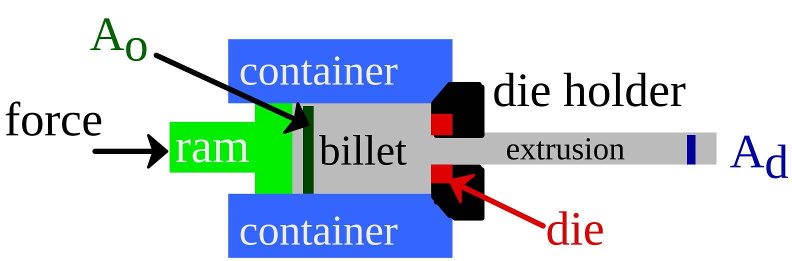


Adapted from Fig. 11.7, *Callister 6e*.

- Drawing
  (rods, wire, tubing)



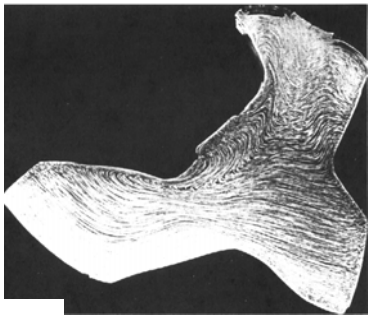
- Extrusion
  (rods, tubing)



Forming temperature

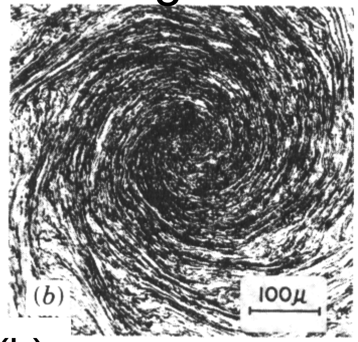
- Hot working
  - --recrystallization
  - --less energy to deform
  - --oxidation: poor finish
  - --lower strength
- Cold working
  - -- no recrystallization
  - -- more energy to deform
  - -- oxidation: good finish
  - -- higher strength
- Cold worked microstructures
  - --generally are very anisotropic!

--Forged



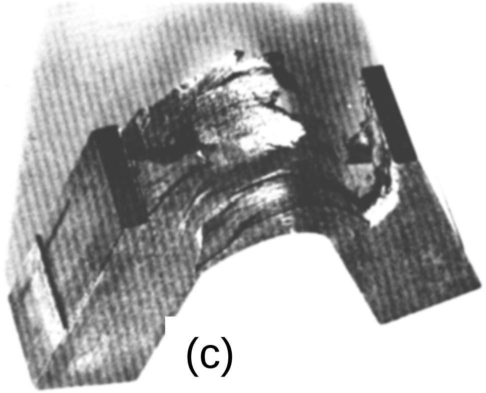
(a)

--Swaged



(b)

--Fracture resistant!



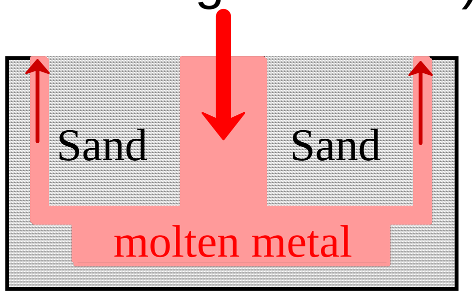
(c)

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

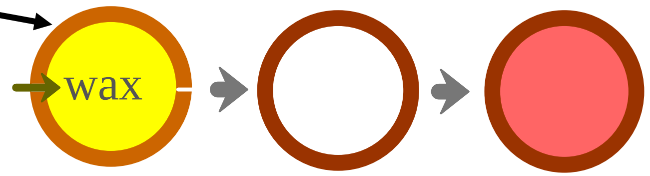
FORMING | **CASTING** | JOINING

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

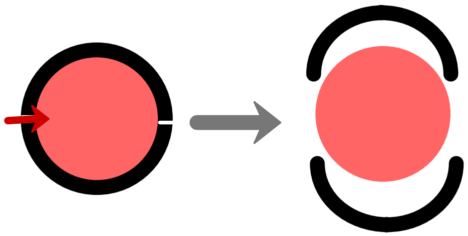


- Investment Casting
  (low volume, complex shapes e.g., jewelry, turbine blades)

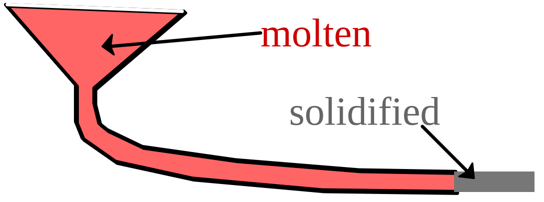
plaster die formed around wax prototype



- Die Casting
  (high volume, low T alloys)



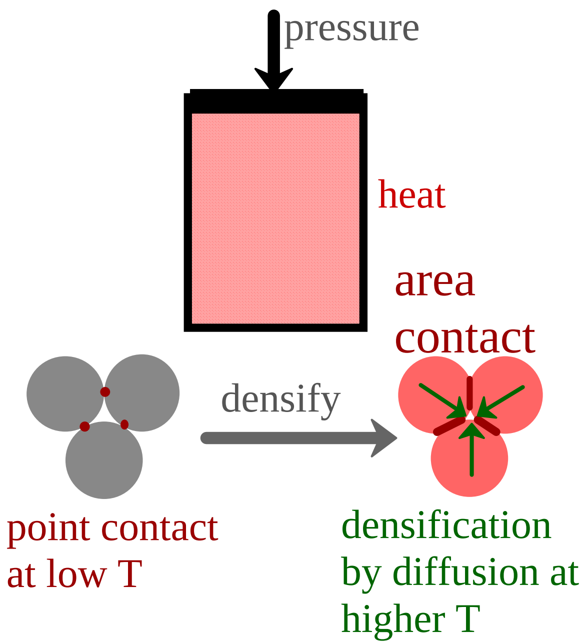
- Continuous Casting
  (simple slab shapes)



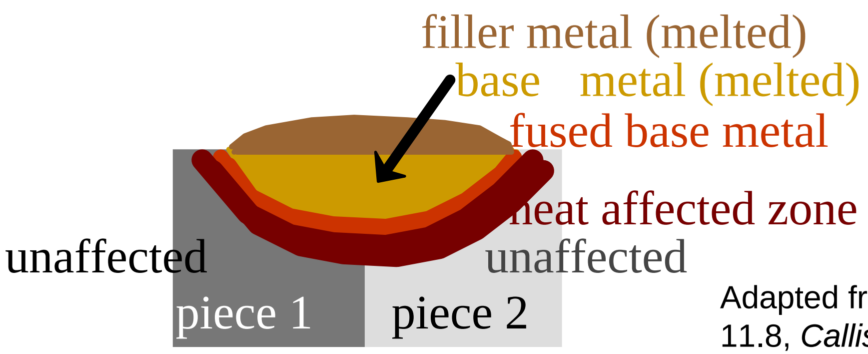
Metal fabrication methods-III

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).

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

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.

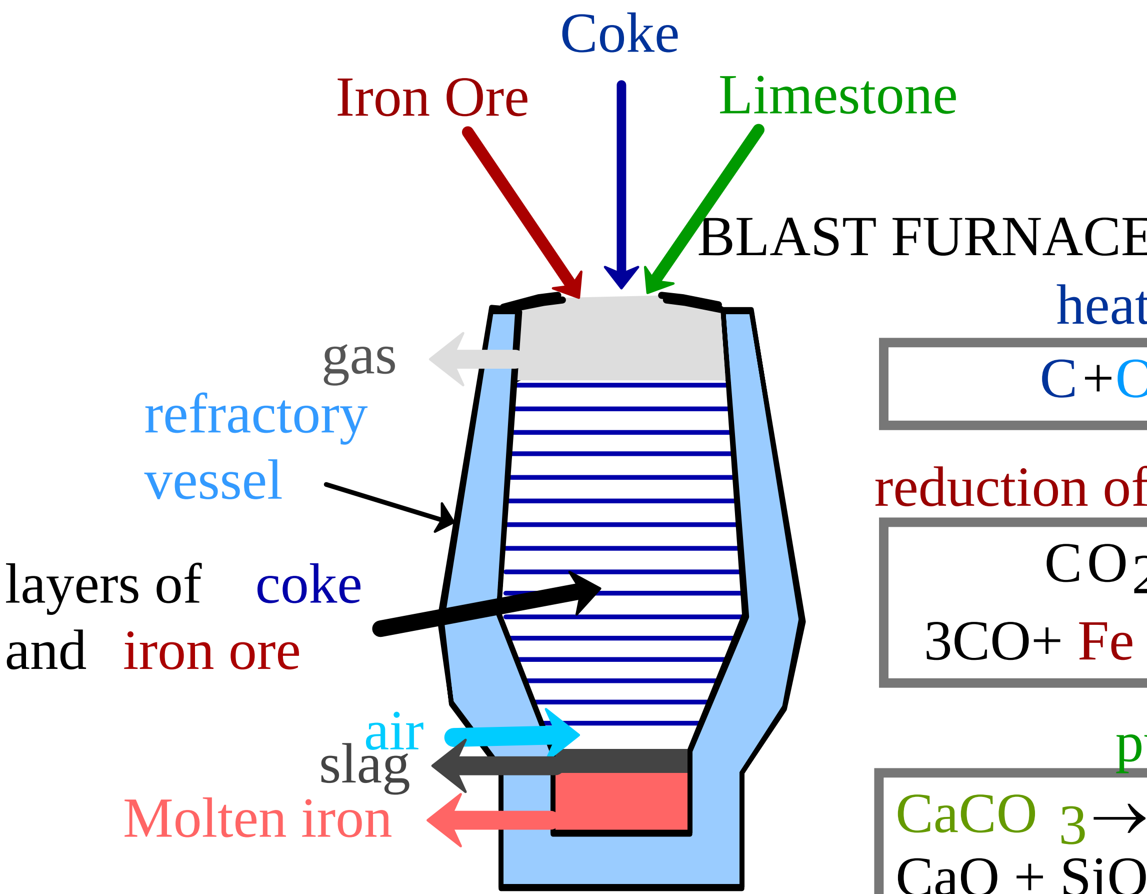
- Spheroidize (steels): Make very soft steels for good machining. Heat just below T_E & hold for 15-25h.

- 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 large grains, then normalize to make grains small.

Refinement of steel from ore



heat generation

$$C + O_2 \rightarrow CO_2$$

reduction of iron ore to metal

$$CO_2 + C \rightarrow 2CO$$

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purification

$$CaCO_3 \rightarrow CaO + CO_2$$

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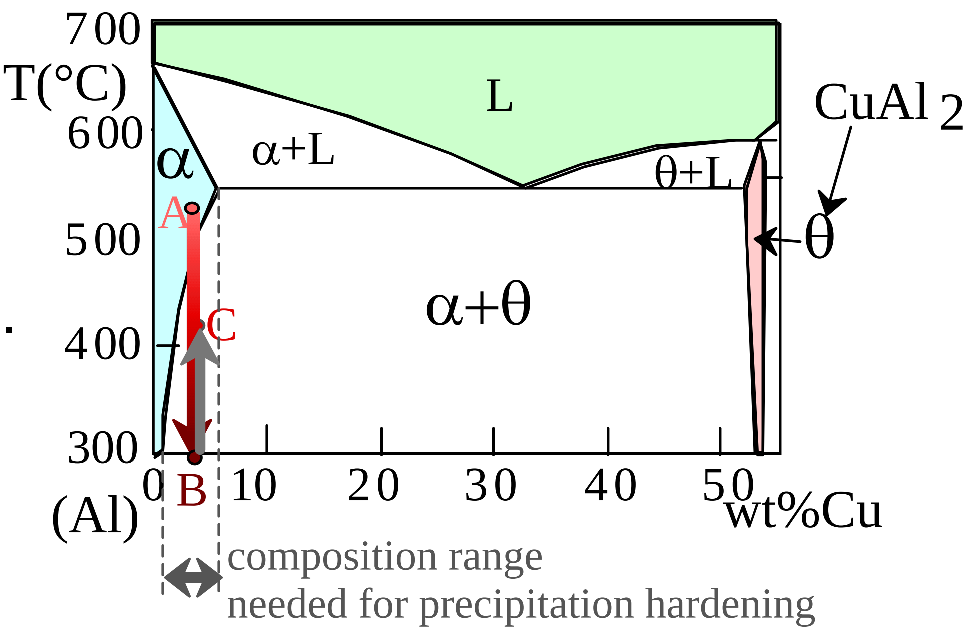
Precipitation hardening

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

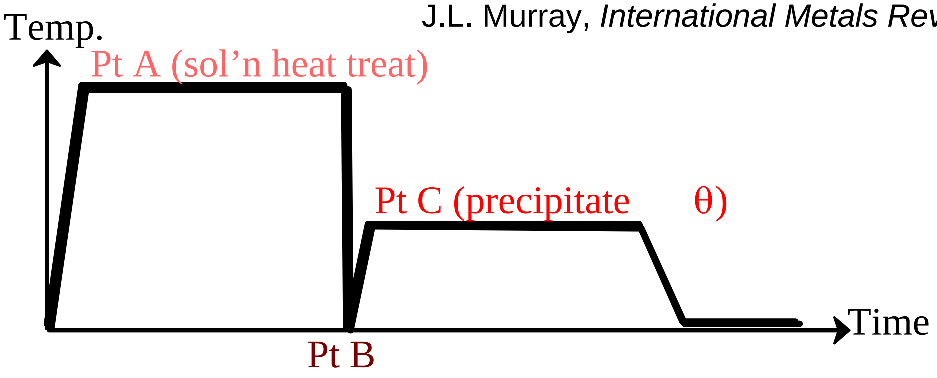
  --Pt A: solution heat treat (get α solid solution)

  --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



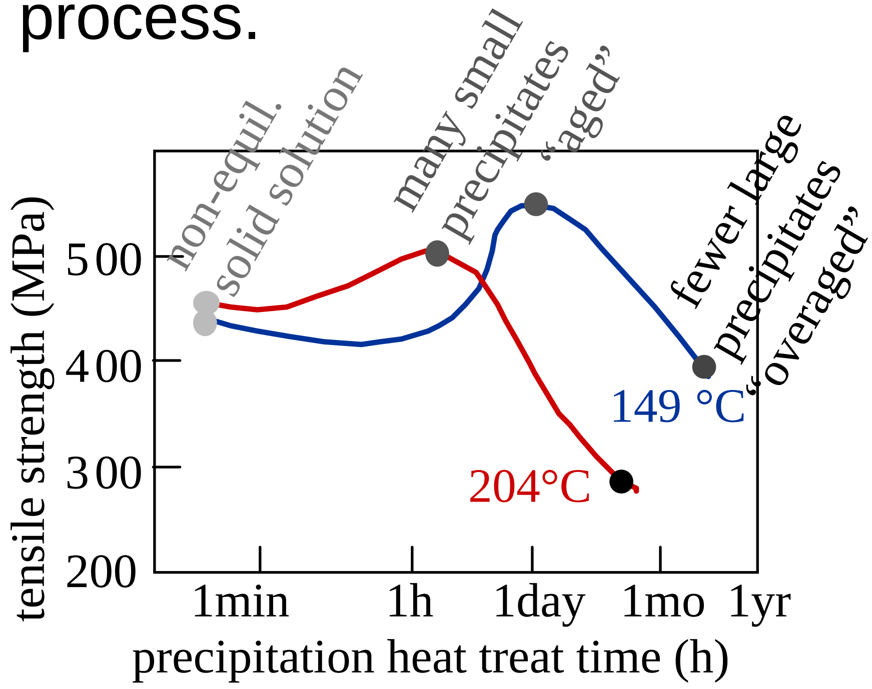
Adapted from Fig. 11.22, *Callister 6e*. (Fig. 11.22 adapted from J.L. Murray, *International Metals Review* **30**, p.5, 1985.)



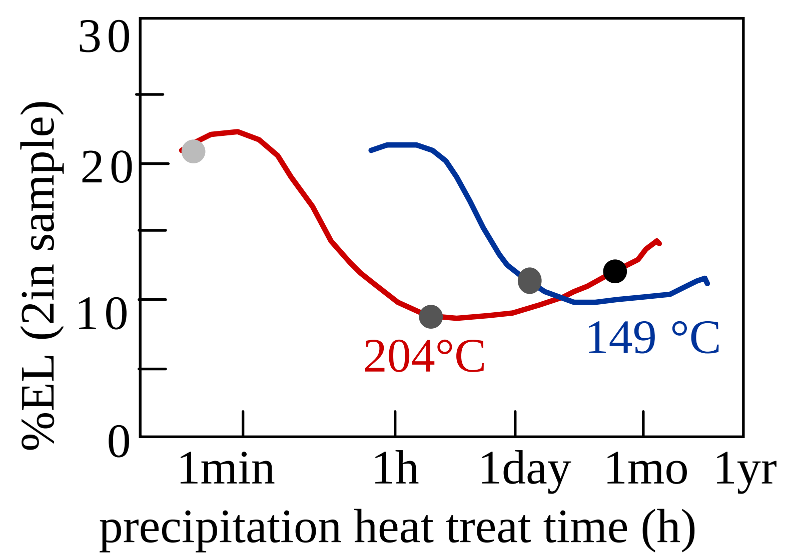
Adapted from Fig. 11.20, *Callister 6e*.

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.)

Heat treatment of Al alloys

- Heat treatable Al alloys: 2xxx, 6xxx, 7xxx series (e.g. –T4, -T6, -T7, -T651)

- -T6511

Standard heat-treat designation 4, 6, 7, 8
- 4 Naturally peak-aged
- 6 Artificially peak-aged
- 7 Overaged
- 8 Overaged

Material has been stress relieved after quench and before aging

Stretched to accomplish stress-relief. It is 2 if compressive methods are used

Minor straightening after stretching

Precipitate formation

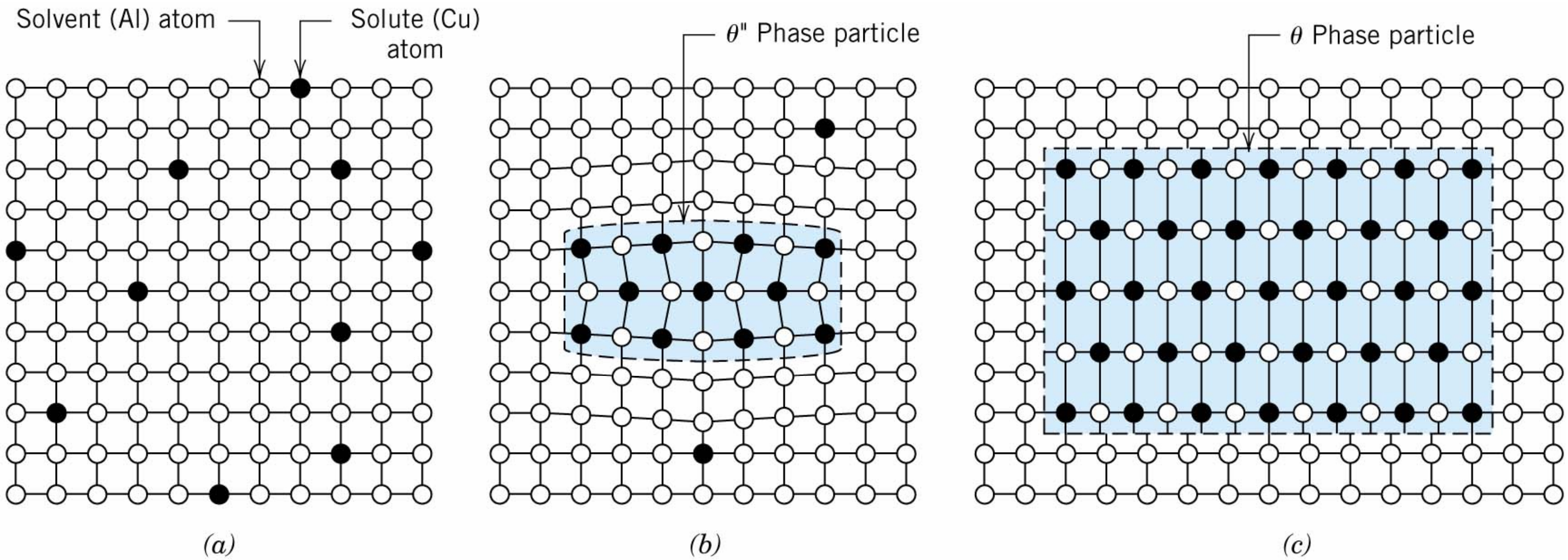


Figure 11.23 Schematic depiction of several stages in the formation of the equilibrium precipitate (θ) phase. (*a*) A supersaturated α solid solution. (*b*) A transition, θ'', precipitate phase. (*c*) The equilibrium θ phase, within the α-matrix phase. Actual phase particle sizes are much larger than shown here.

Cu-Be Phase diagram

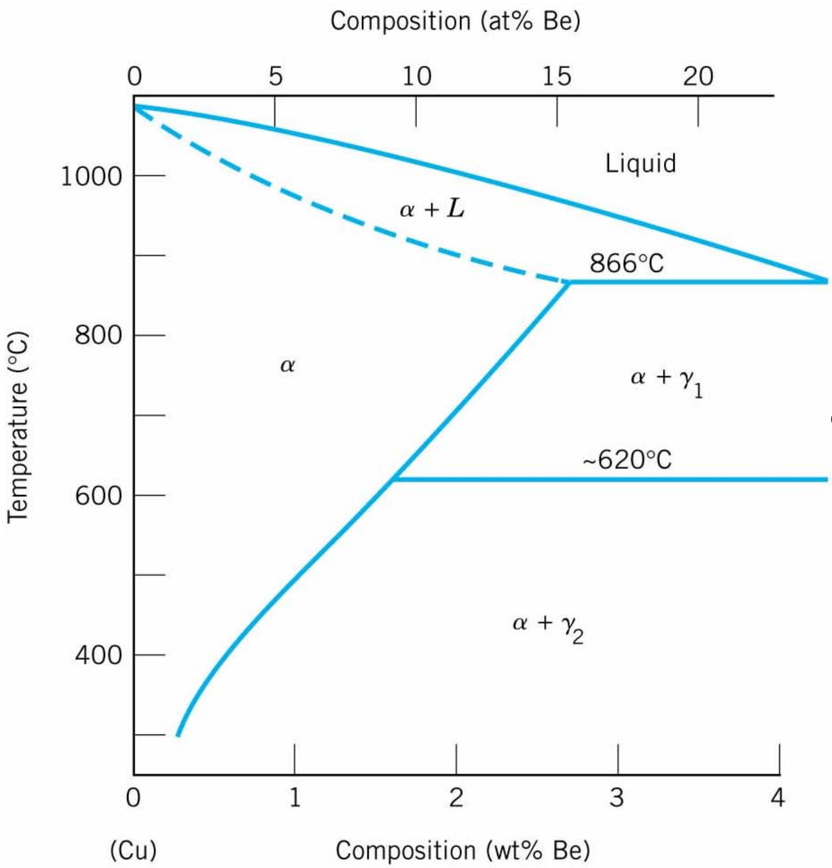


FIGURE 11.26 The copper-rich side of the copper–beryllium phase diagram. [Adapted from *Binary Alloy Phase Diagrams,* 2nd edition, Vol. 2, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

- Requirements for precipitation hardening
  - Expanded solubility with increasing temperature, restricted at low T
  - Matrix relatively soft and ductile
  - Alloy is quenchable
  - A coherent precipitate must form

Comparison – Steel vs Aged hardened alloys

- Precipitation hardened
  - Quenched from single phase field – with no resulting phase change
  - A supersaturated solid solution is obtained
  - Reheated to moderately high temperature within 2-phase field
  - **Result:** homogeneous distribution of fine and coherent equilibrium precipitates

- Tempered steels
  - Quenched from single phase - austenite - phase field with resulting phase change
  - Martensite, a hard and brittle phase is obtained
  - Reheated to moderately high temperature within 2-phase field
  - **Result:** homogeneous distribution of fine equilibrium precipitates