Taxonomy of metals

Metal Alloys

Ferrous

Nonferrous

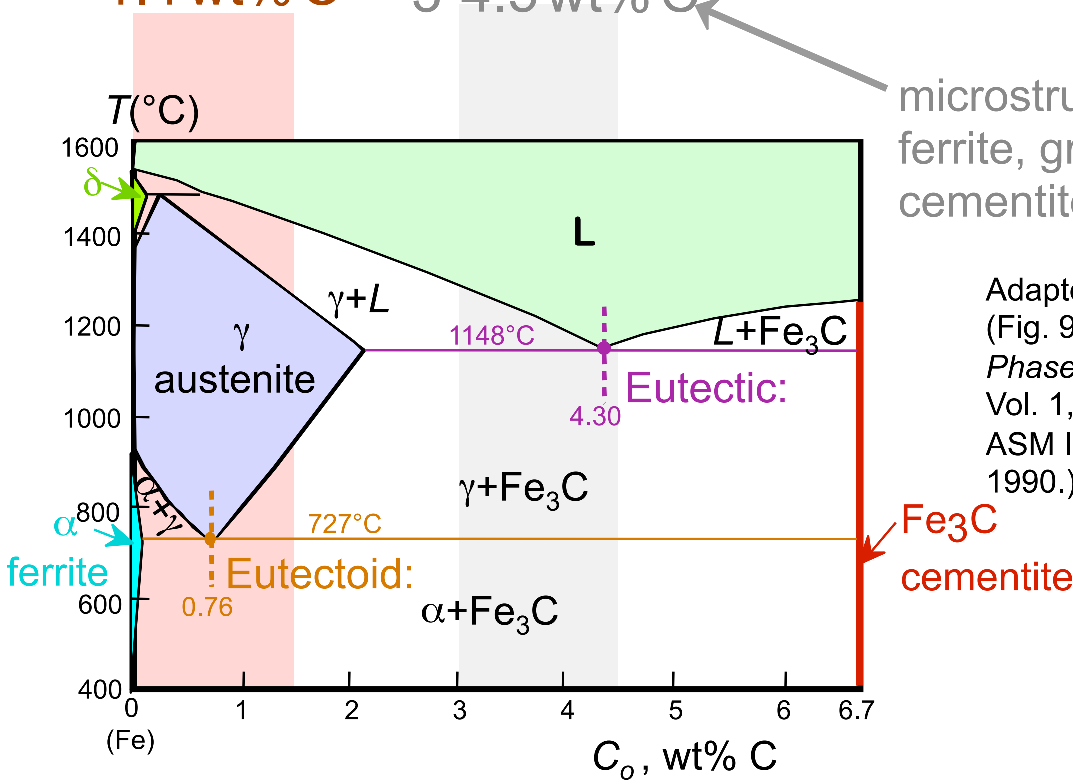
Adapted from Fig. 11.1, *Callister 7e*.

Steels
<1.4 wt% C

Cast Irons
3-4.5 wt% C

Cu Al Mg Ti

microstructure: ferrite, graphite cementite



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 | High Alloy

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

	low carbon		Med carbon		high carbon		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*.

Nomenclature for steel

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

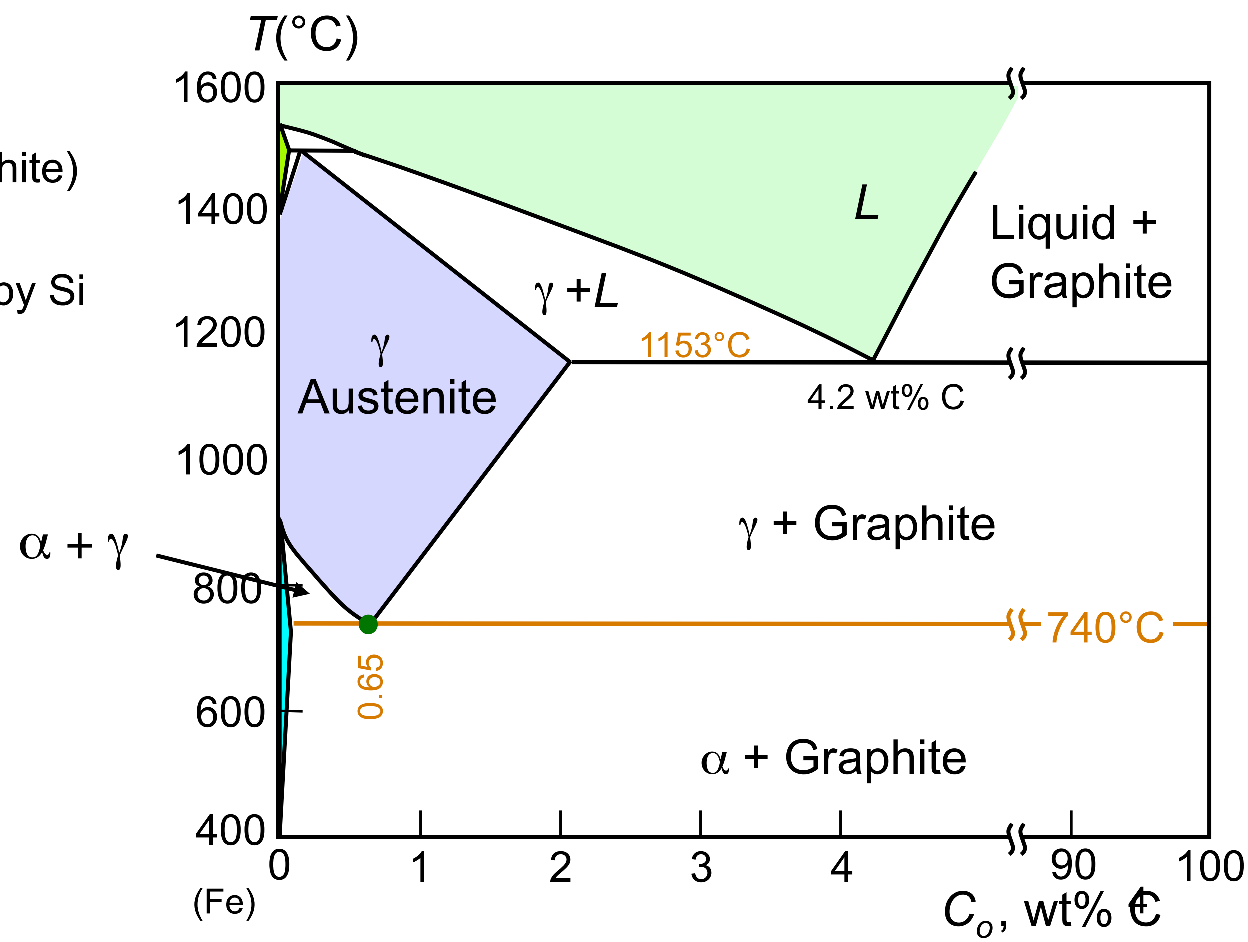
Stainless Steel -- >11% Cr

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

- Decomposition promoted by Si



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

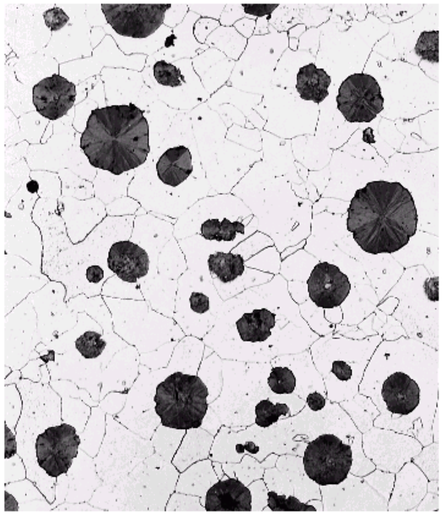
Gray iron

- 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

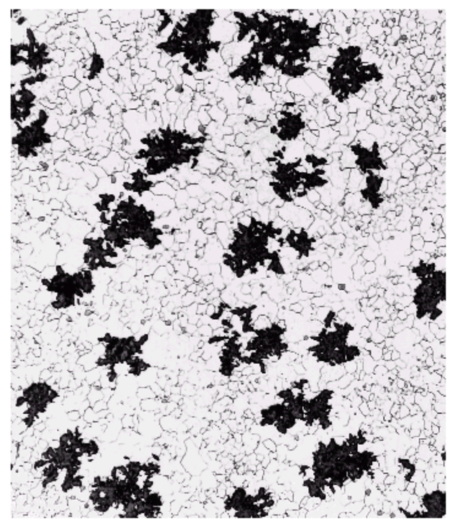
Adapted from Fig. 11.3(c) & (d), *Callister 7e*.

Malleable iron

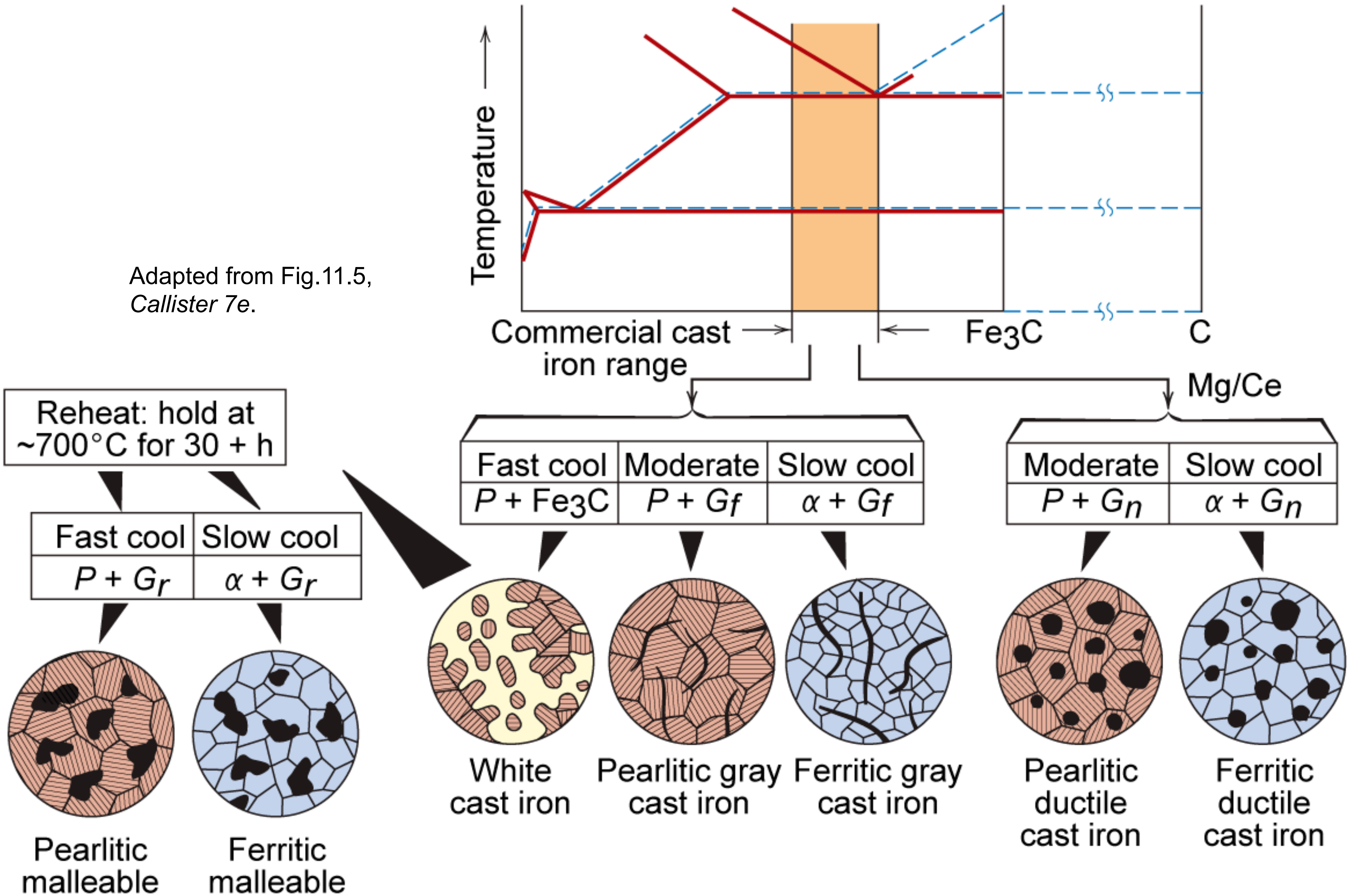
•heat treat at 800-900ºC

•graphite in rosettes

•more ductile



Production of cast iron



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

Other 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**

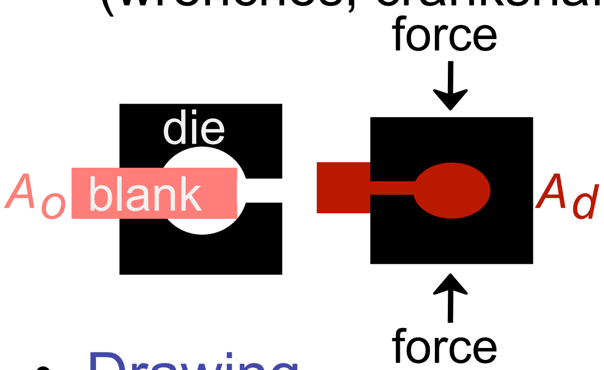
-high melting *T*
-Nb, Mo, W, Ta

Based on discussion and data provided in Section 11.3, *Callister 7e*.

Metal fabrication methods 1

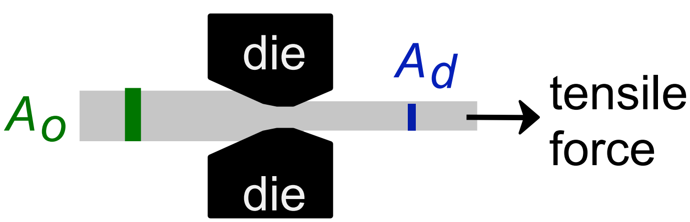
FORMING | CASTING | JOINING

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



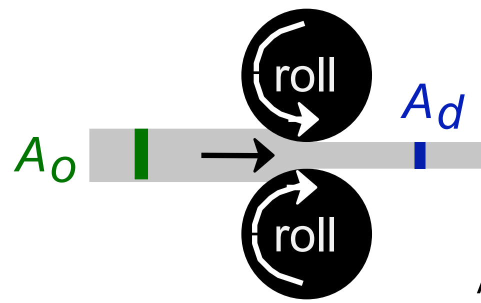
often at elev. T

- Drawing
  (rods, wire, tubing)



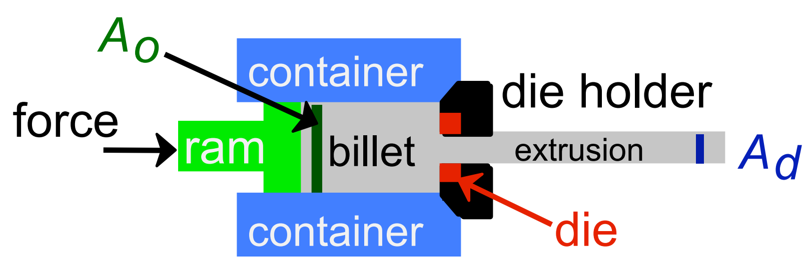
die must be well lubricated & clean

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



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

- Extrusion
  (rods, tubing)

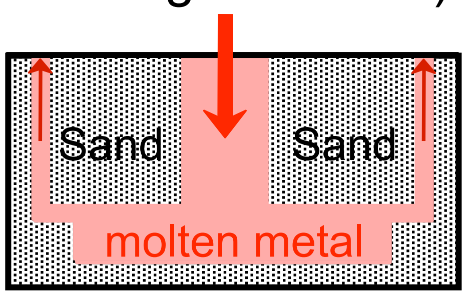


ductile metals, e.g. Cu, Al (hot)

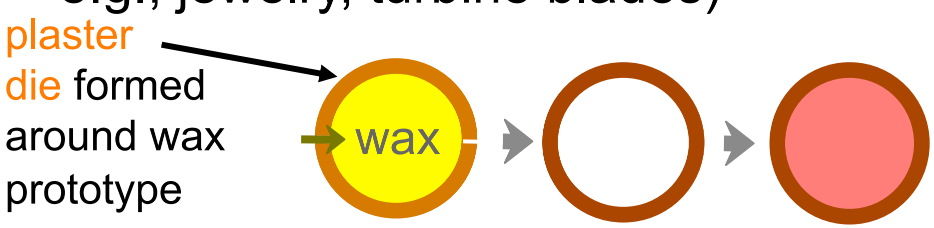
Metal fabrication methods 2

FORMING | **CASTING** | JOINING

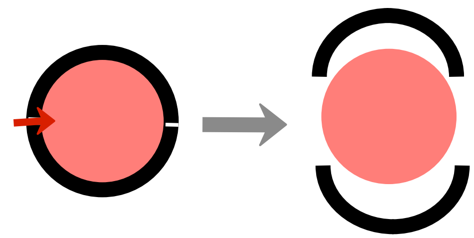
- Sand Casting
  (large parts, e.g.,
  auto engine blocks)



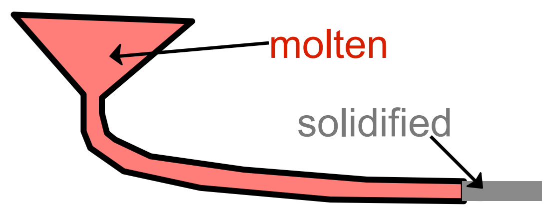
- Investment Casting
  (low volume, complex shapes
  e.g., jewelry, turbine blades)



- Die Casting
  (high volume, low T alloys)



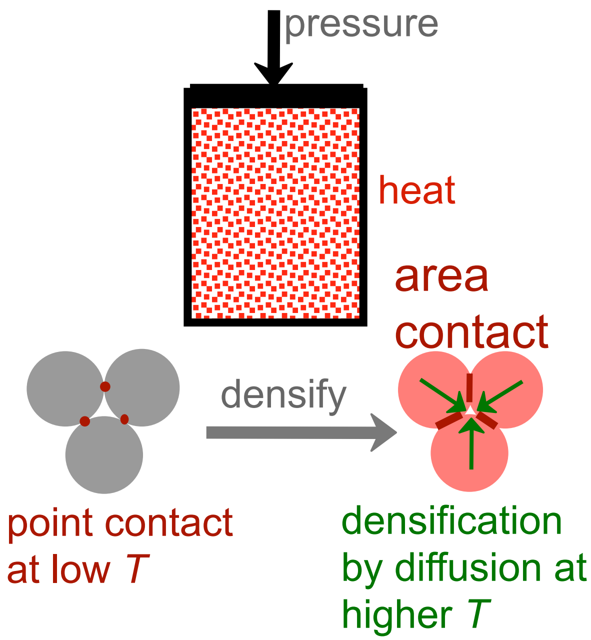
- Continuous Casting
  (simple slab shapes)



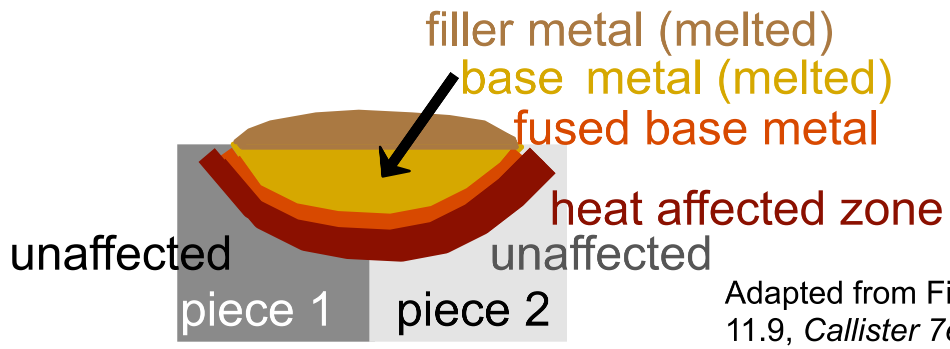
Metal fabrication methods 3

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 large grains, then normalize to make grains small.

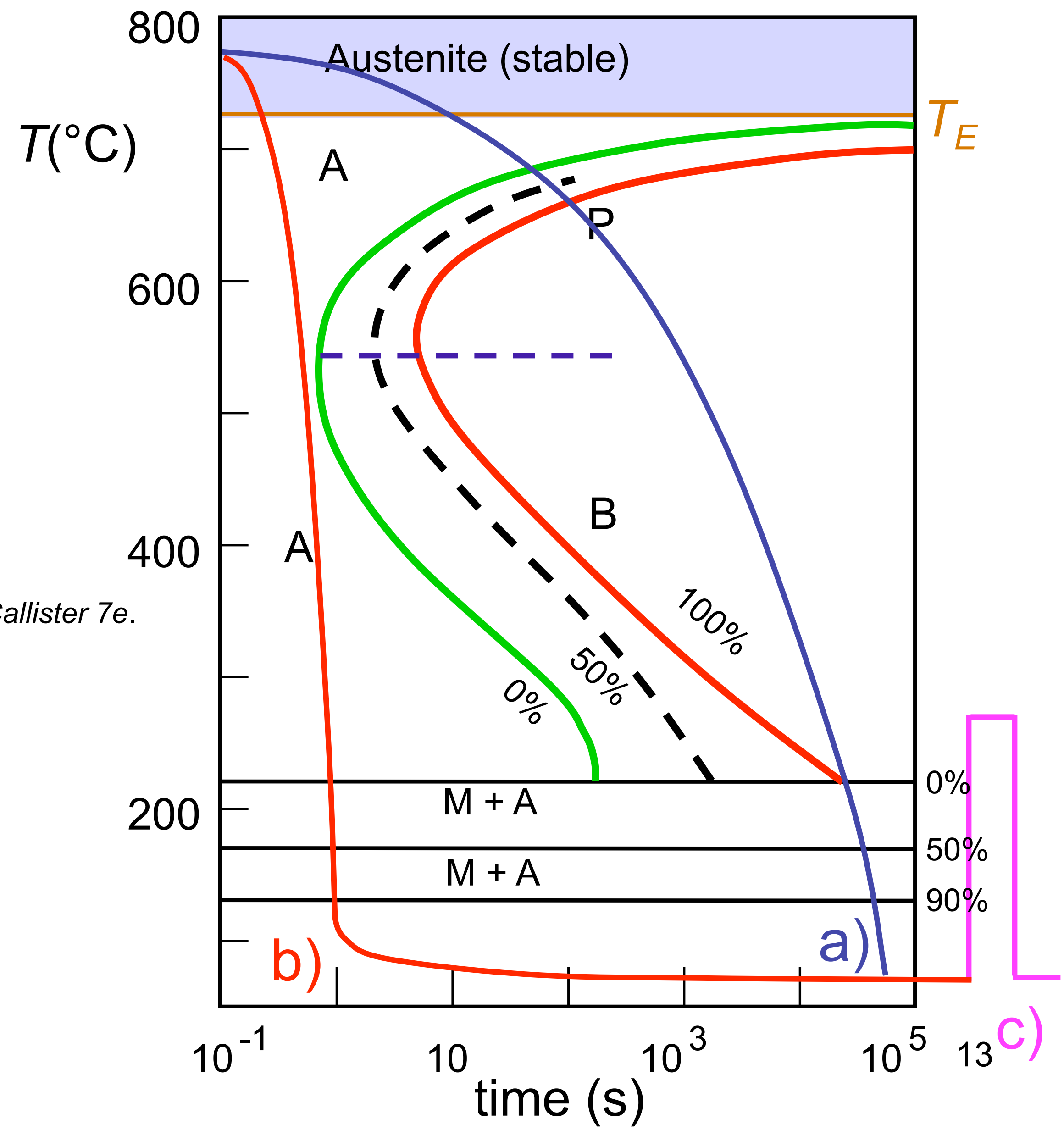
Based on discussion in Section 11.7, *Callister 7e*.

Heat treatments

a) Annealing

b) Quenching

c) Tempered Martensite



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

Precipitation hardening

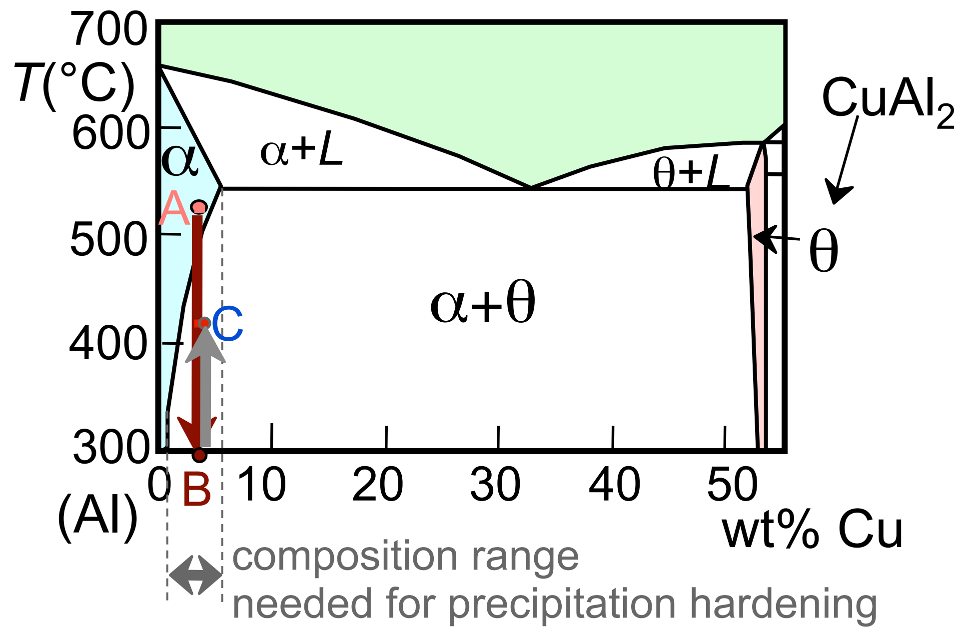
- Particles impede dislocations.
- Ex: Al-Cu system
- Procedure:

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

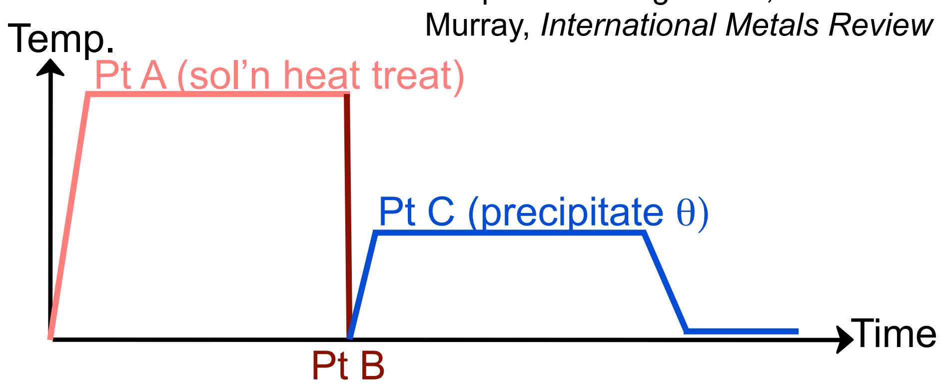
  --Pt B: quench to room temp.

  --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.)

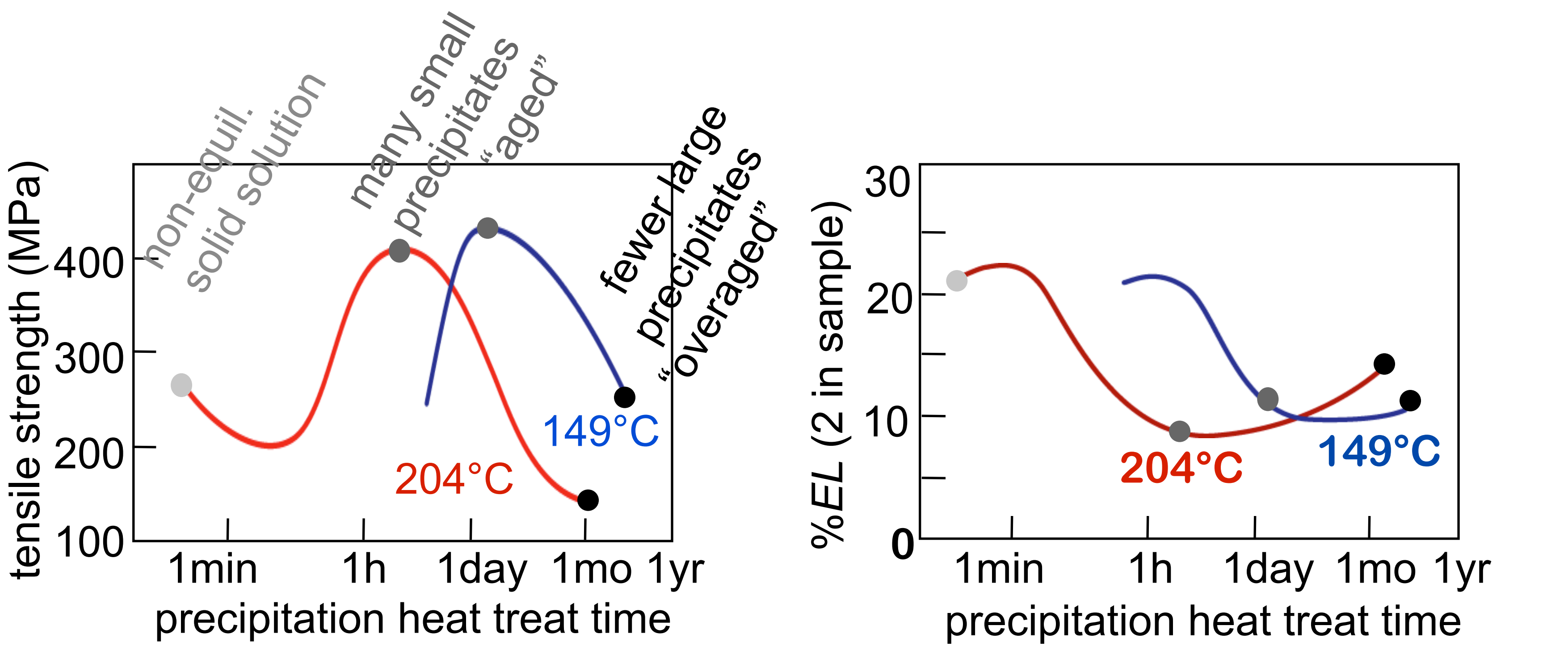


Adapted from Fig. 11.22, *Callister 7e*.

Precipitation hardening

- 2014 Al Alloy:
- *TS* peaks with precipitation time.
- Increasing *T* accelerates process.

- %*EL* reaches minimum with precipitation time.

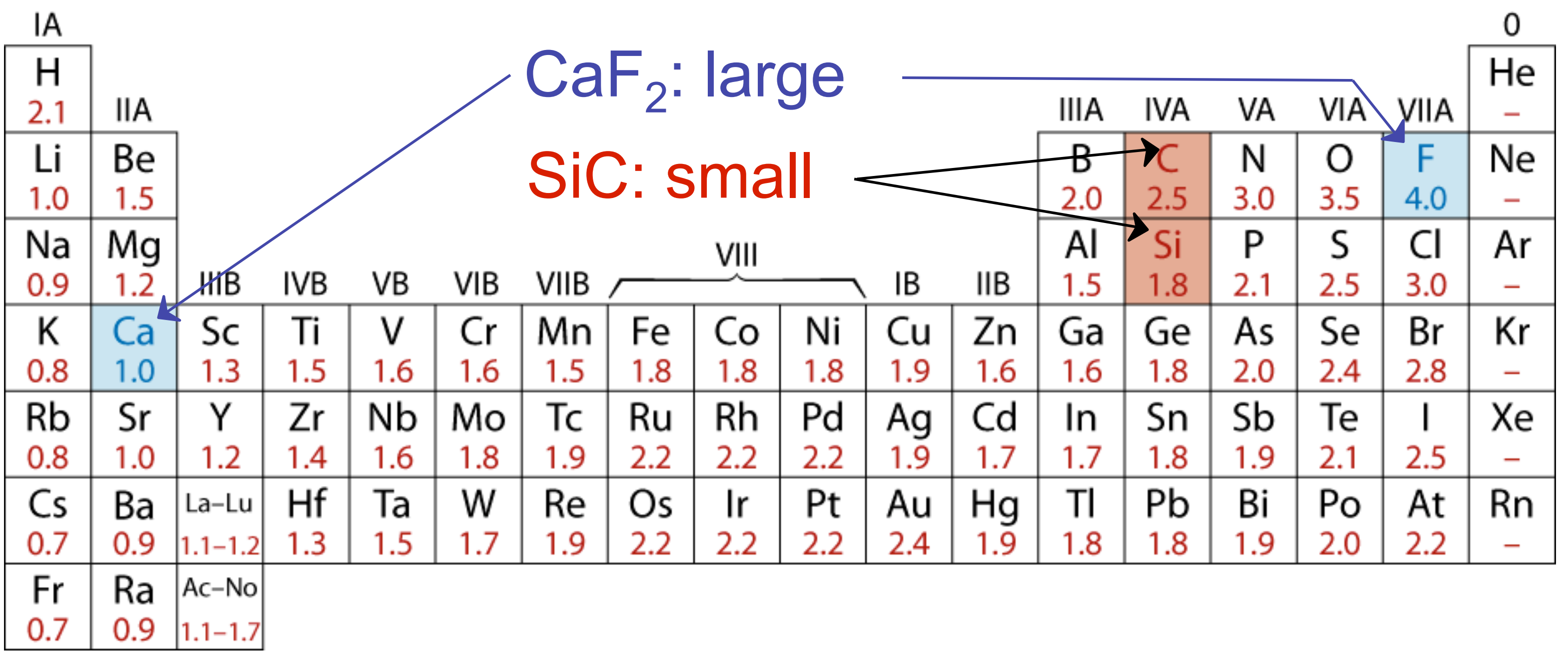


Adapted from Fig. 11.27 (a) and (b), *Callister 7e*. (Fig. 11.27 adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker (Managing Ed.), American Society for Metals, 1979. p. 41.)

Ceramics

- Bonding:
  -- Mostly ionic, some covalent.
  -- % ionic character increases with difference in electronegativity.

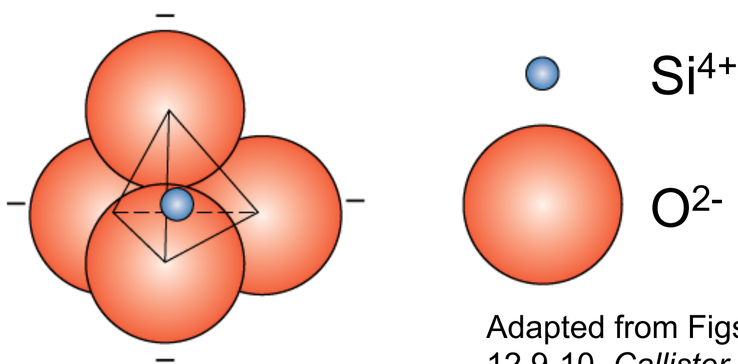
- Large vs small ionic bond character:



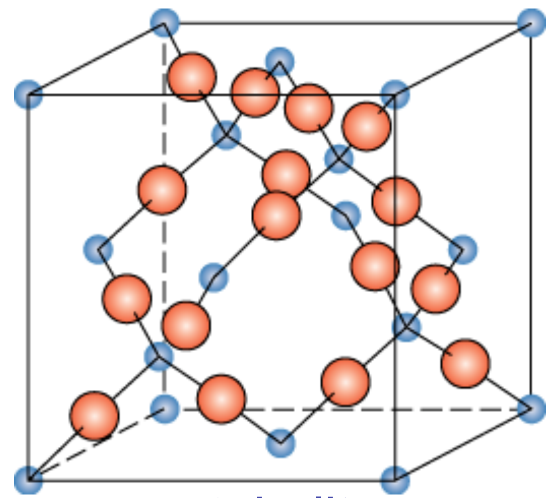
Adapted from Fig. 2.7, *Callister 7e.* (Fig. 2.7 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

Silicate Ceramics

- Most common elements on earth are Si & O



Adapted from Figs. 12.9-10, *Callister 7e.*

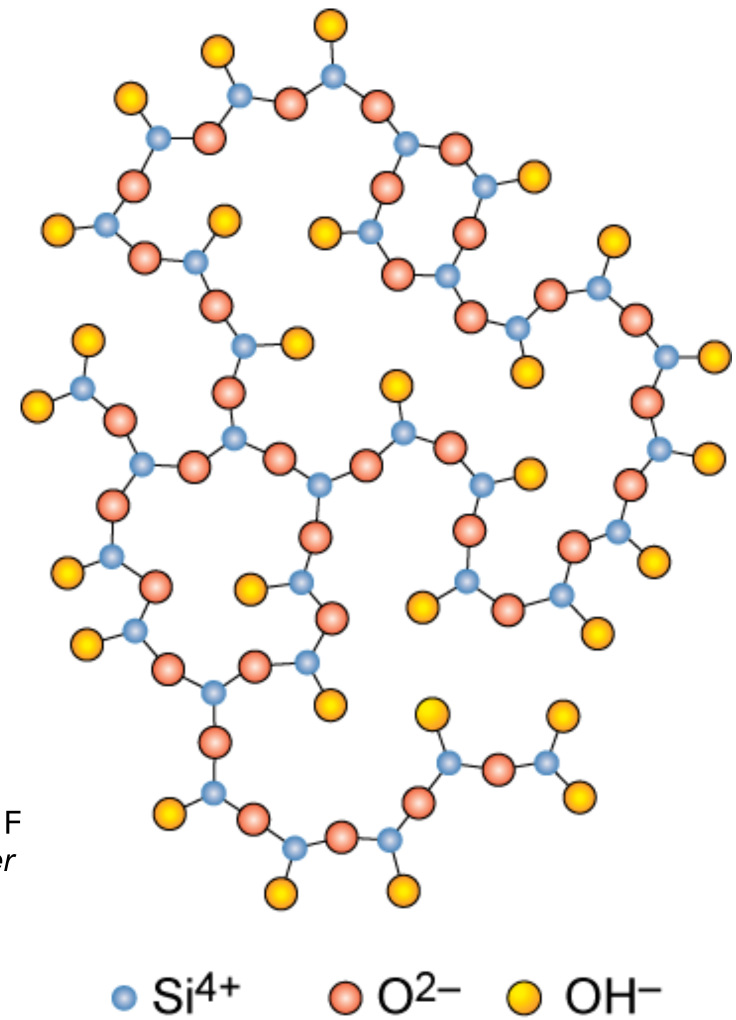


crystobalite

- SiO_2 (silica) structures are quartz, crystobalite, & tridymite
- The strong Si-O bond leads to a strong, high melting material (1710ºC)

Amorphous silica

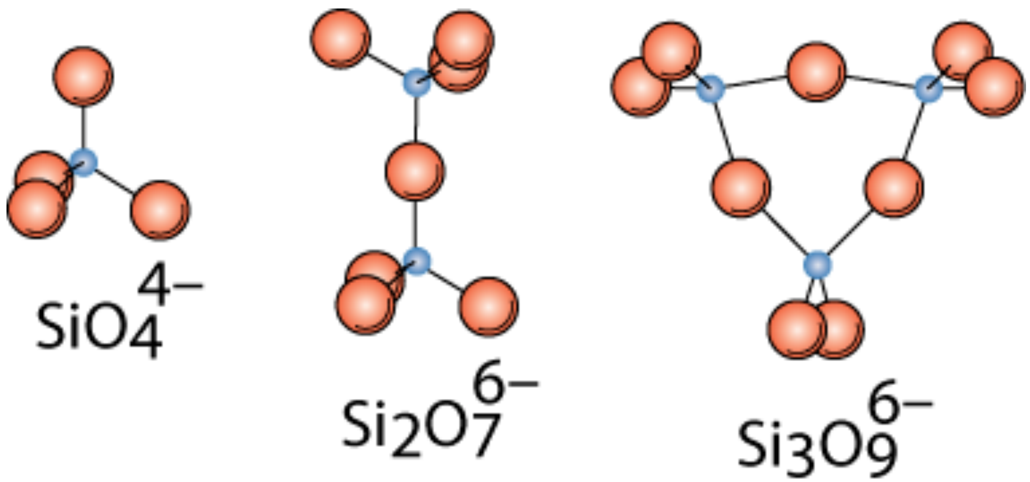
- Silica gels - amorphous SiO_2
  - Si^{4+} and O^{2-} not in well-ordered lattice
  - Charge balanced by H^+ (to form OH^-) at "dangling" bonds
    - very high surface area > 200 m^2/g
  - SiO_2 is quite stable, therefore unreactive
    - makes good catalyst support



Adapted from F 12.11, *Callister*

Silicates

- Combine SiO_4^{4-} tetrahedra by having them share corners, edges, or faces



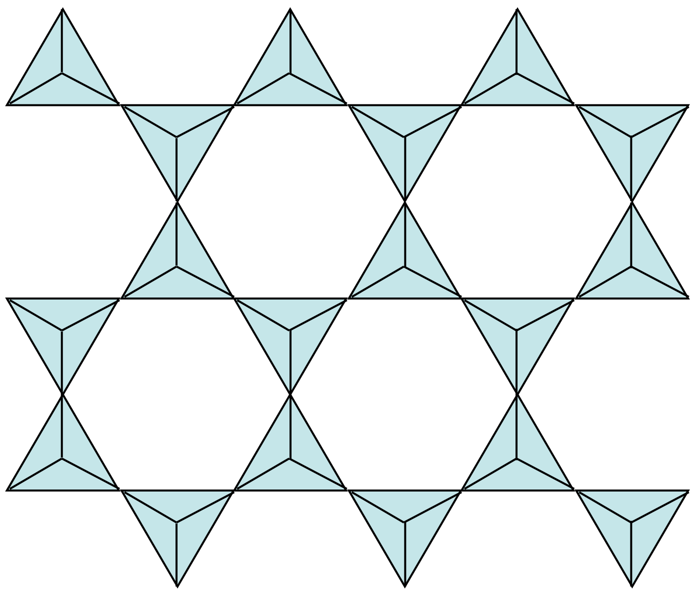
Adapted from Fig. 12.12, *Callister 7e.*

Mg_2SiO_4 $Ca_2MgSi_2O_7$

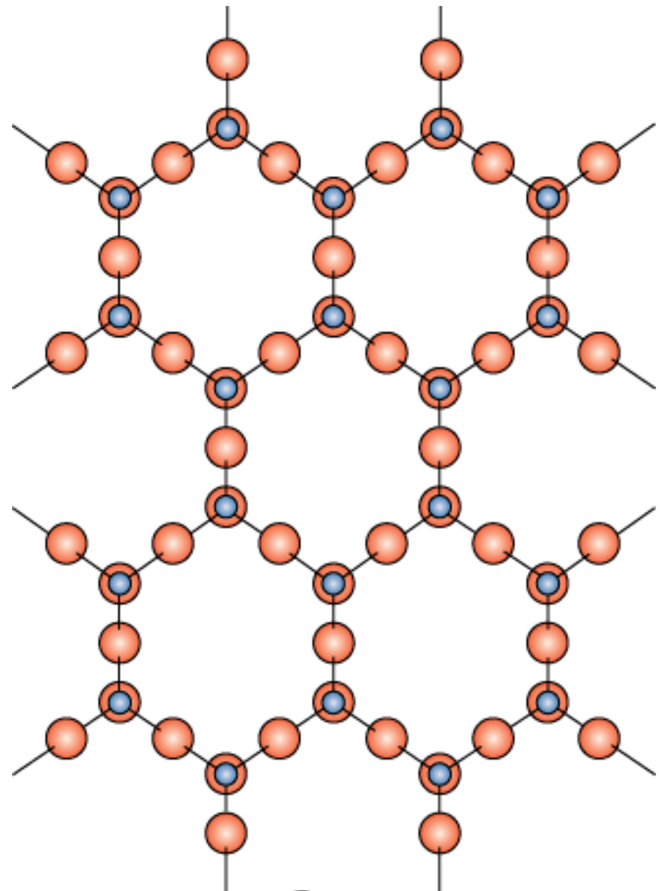
- Cations such as Ca^{2+}, Mg^{2+}, & Al^{3+} act to neutralize & provide ionic bonding

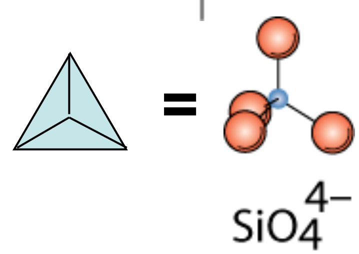
Layered silicates

- Layered silicates (clay silicates)
  - SiO_4 tetrahedra connected together to form 2-D plane



$(Si_2O_5)^{2-}$



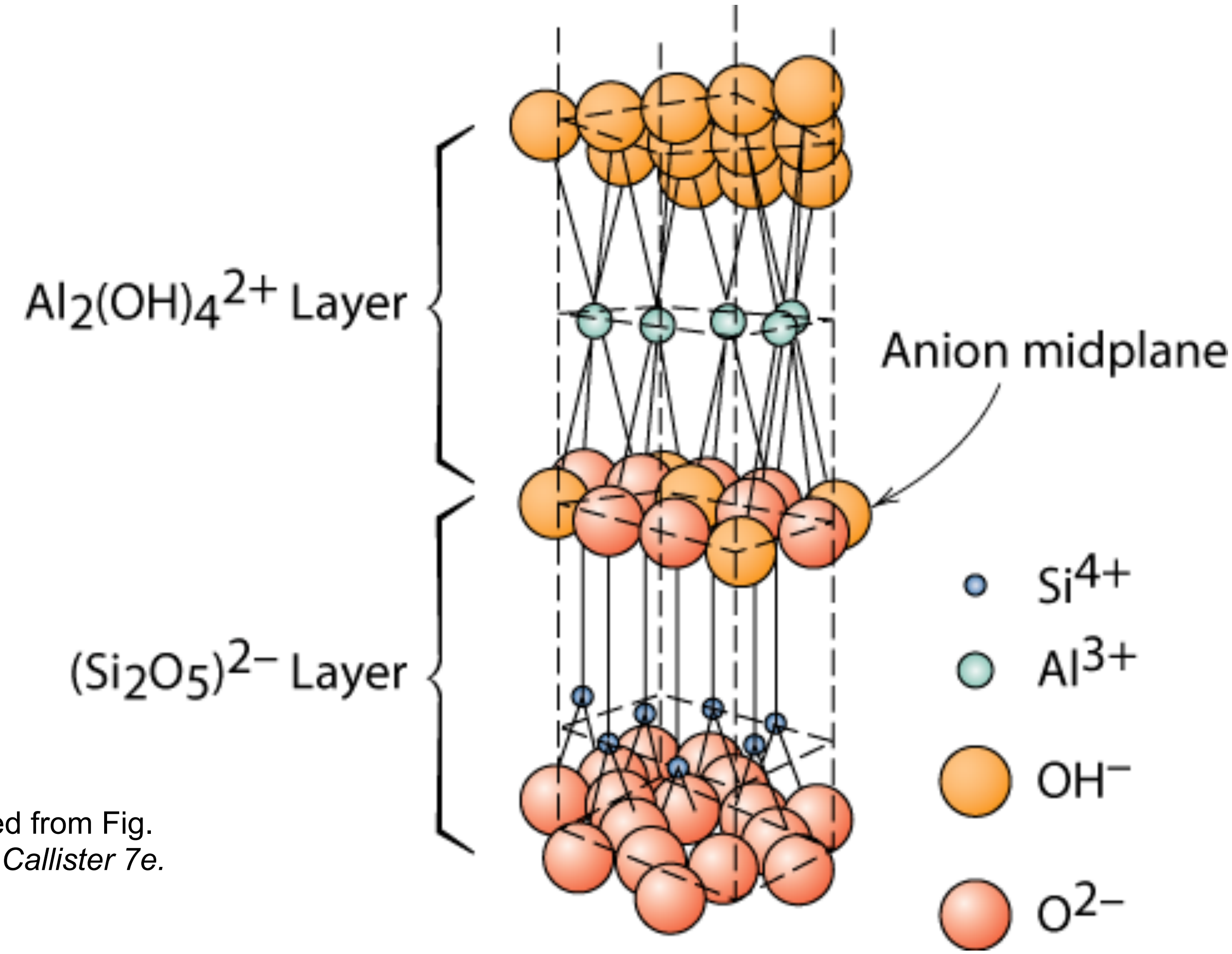


Adapted from Fig. 12.13, *Callister 7e.*

- Therefore, cations are required to balance charge

Layered silicates

Kaolinite clay alternates $(Si_2O_5)^{2-}$ layer with $Al_2(OH)_4^{2+}$ layer

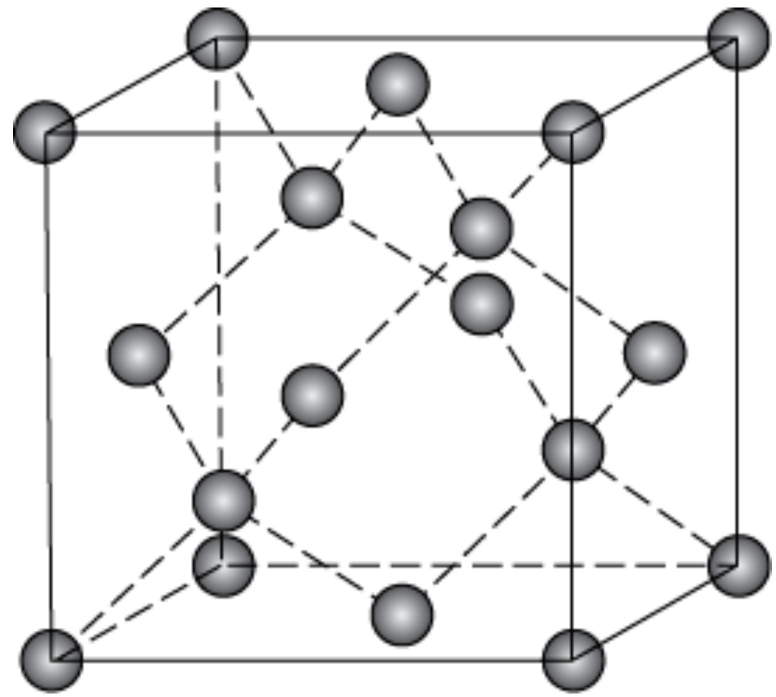


Adapted from Fig. 12.14, *Callister 7e.*

Note: these sheets loosely bound by van der Waal's forces

Carbon forms

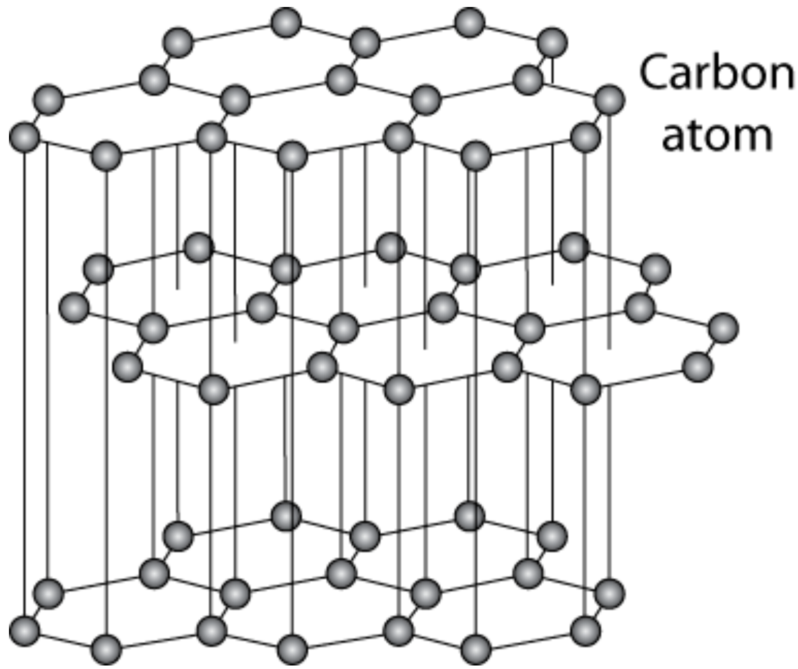
- Carbon black – amorphous – surface area ca. 1000 m^2/g
- Diamond
  - tetrahedral carbon
    - hard – no good slip planes
    - brittle – can cut it
  - large diamonds – jewelry
  - small diamonds
    - often man made - used for cutting tools and polishing
  - diamond films
    - hard surface coat – tools, medical devices, etc.



Adapted from Fig. 12.15, *Callister 7e.*

Carbon forms

- layer structure – aromatic layers



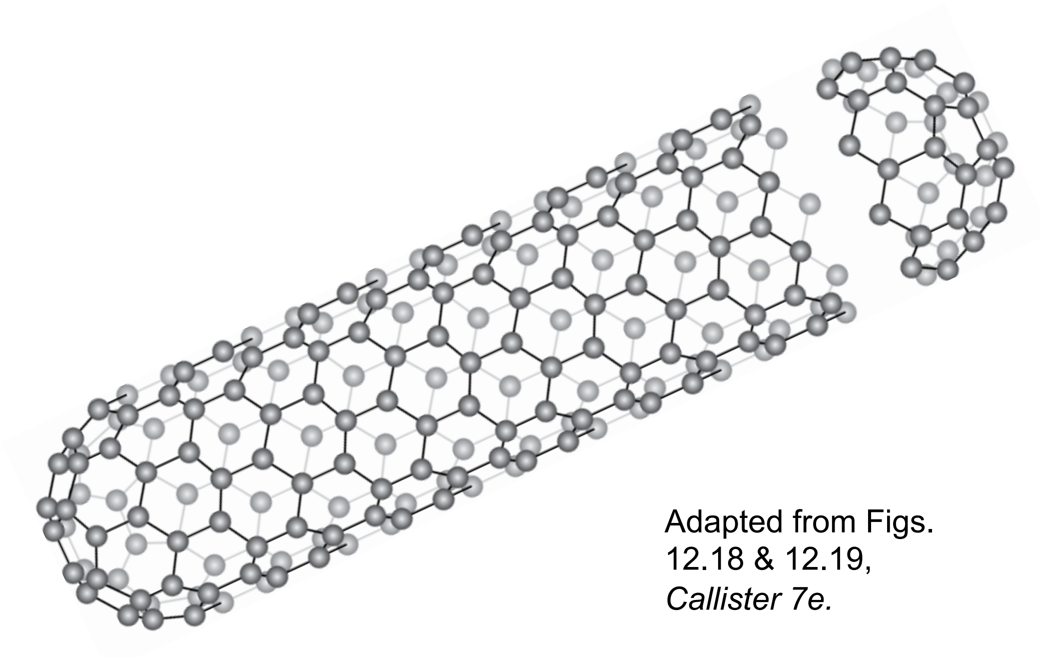
Adapted from Fig. 12.17, *Callister 7e.*

- weak van der Waal's forces between layers
- planes slide easily, good lubricant

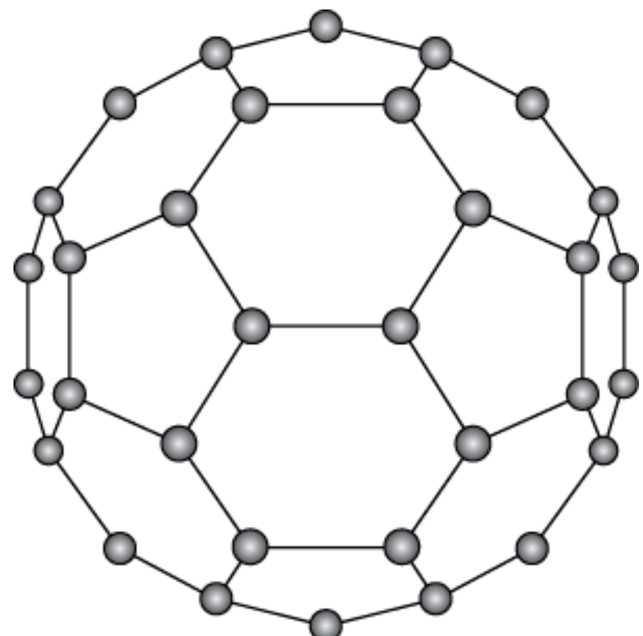
Carbon forms

Fullerenes or carbon nanotubes

- wrap the graphite sheet by curving into ball or tube
- Buckminister fullerenes
  - Like a soccer ball C_{60} - also C_{70} + others



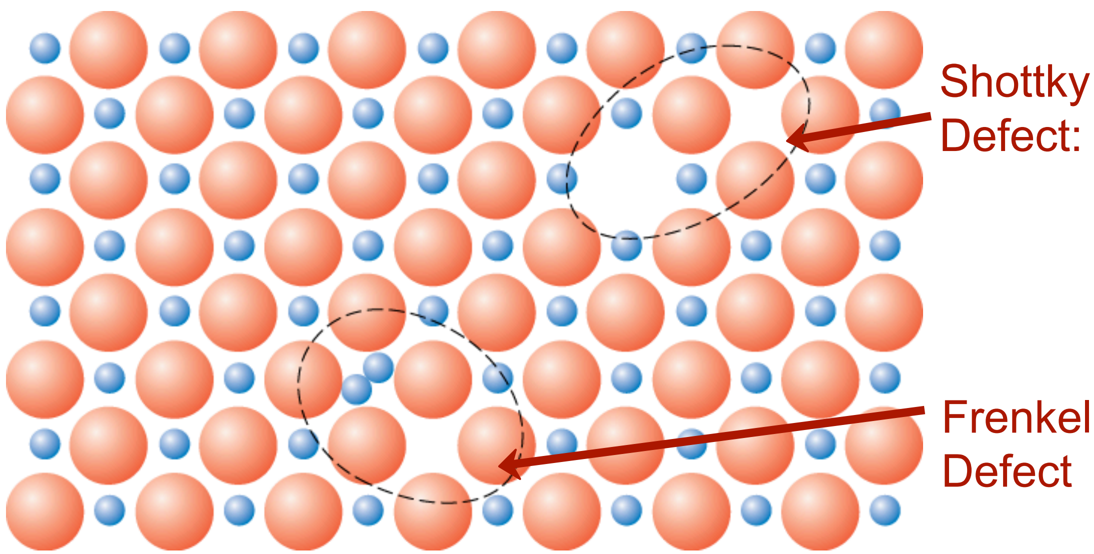
Adapted from Figs. 12.18 & 12.19, *Callister 7e.*



Defects

- Frenkel Defect
  --a cation is out of place.

- Shottky Defect
  --a paired set of cation and anion vacancies.



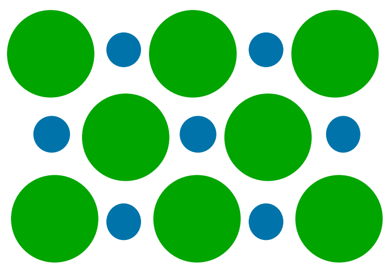
Adapted from Fig. 12.21, *Callister 7e.* (Fig. 12.21 is from W.G. Moffatt, G.W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. 1, *Structure*, John Wiley and Sons, Inc., p. 78.)

- Equilibrium concentration of defects $\sim e^{-Q_D / kT}$

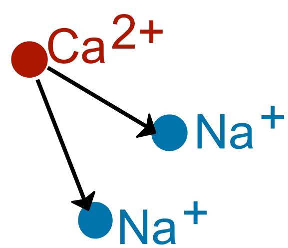
Impurities

- Impurities must also satisfy charge balance = Electroneutrality
- Ex: NaCl

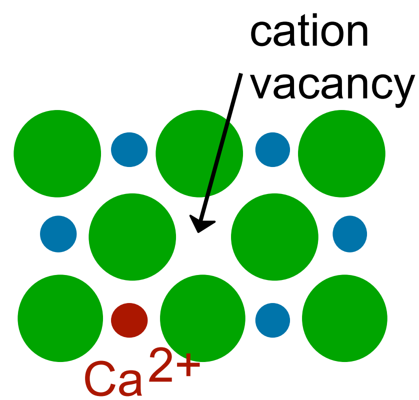
- Substitutional cation impurity



initial geometry

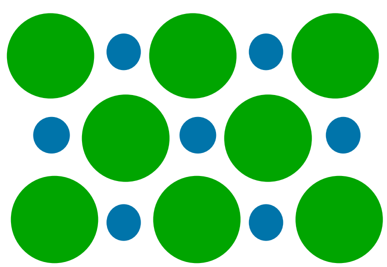


Ca^{2+} impurity

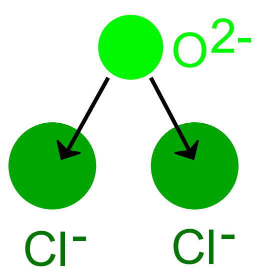


resulting geometry

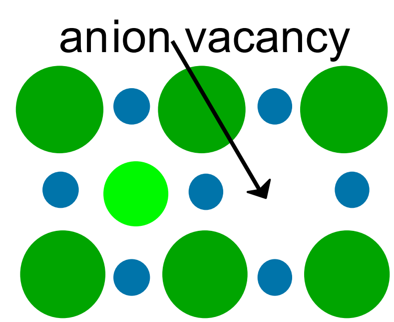
- Substitutional anion impurity



initial geometry



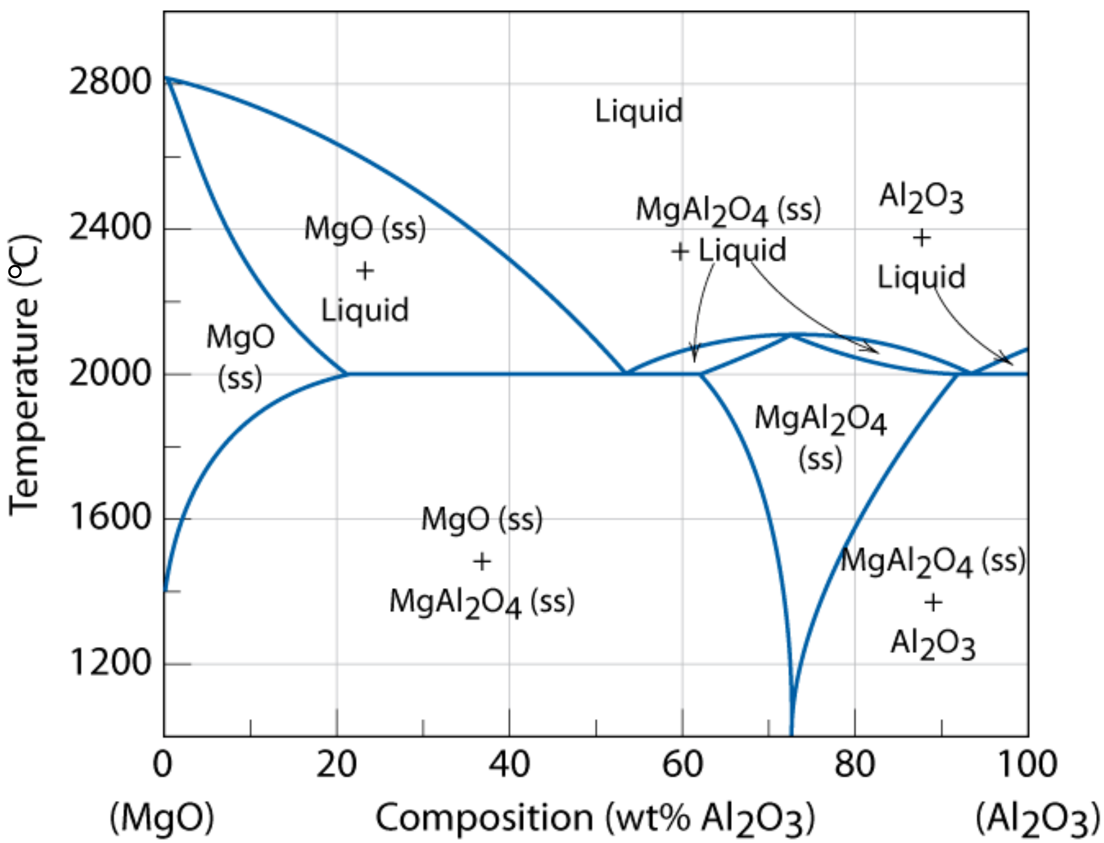
O^{2-} impurity



resulting geometry

Ceramic phase diagrams

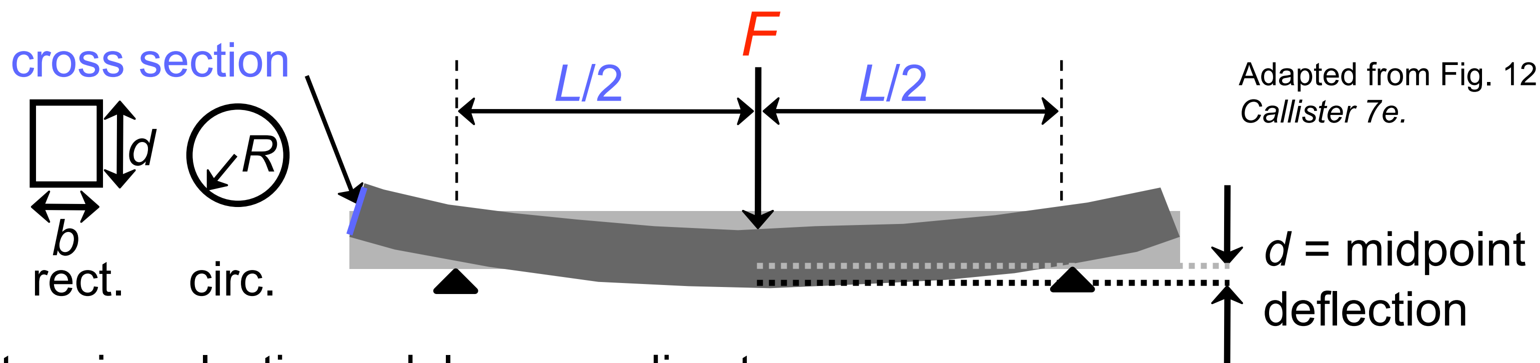
MgO-Al_2O_3 diagram:



Adapted from Fig. 12.25, *Callister 7e.*

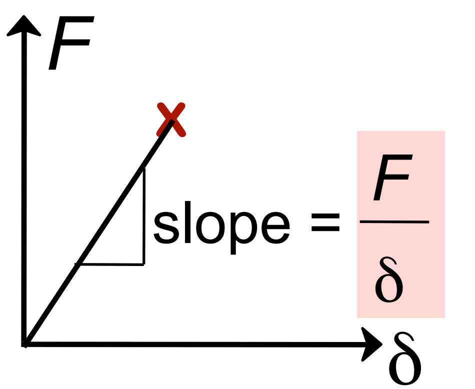
Measuring the elastic modulus

- Room *T* behavior is usually elastic, with brittle failure.
- 3-Point Bend Testing often used.
  --tensile tests are difficult for brittle materials.



Adapted from Fig. 12.32, *Callister 7e.*

- Determine elastic modulus according to:



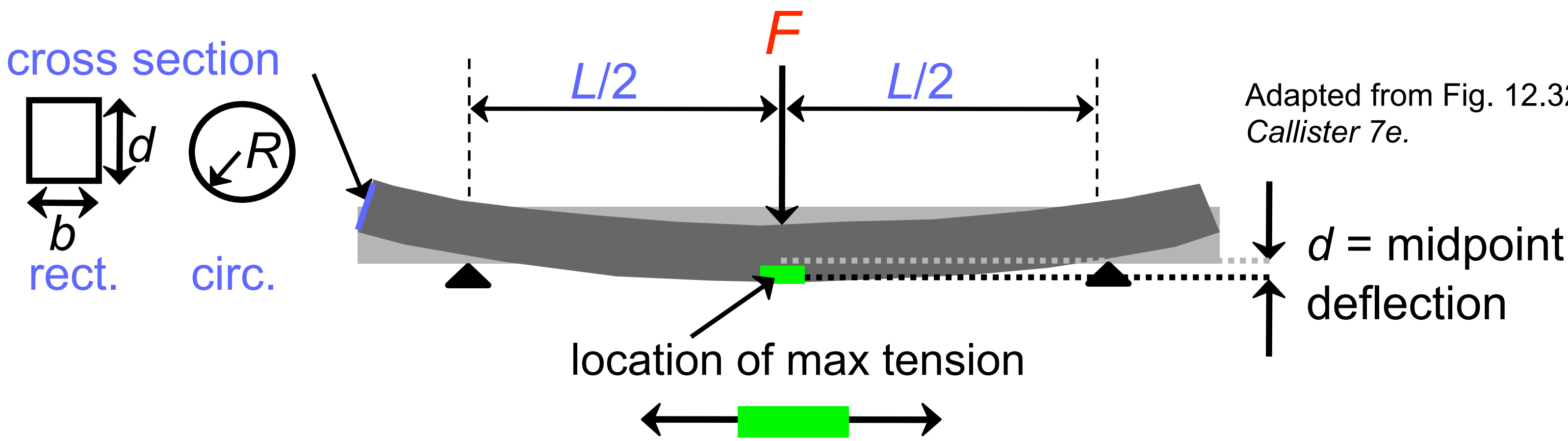
linear-elastic behavior

$$E = \frac{F}{\delta}\frac{L^3}{4bd^3} = \frac{F}{\delta}\frac{L^3}{12\pi R^4}$$

rect. cross section | circ. cross section

Measuring strengths

- 3-point bend test to measure room *T* strength.

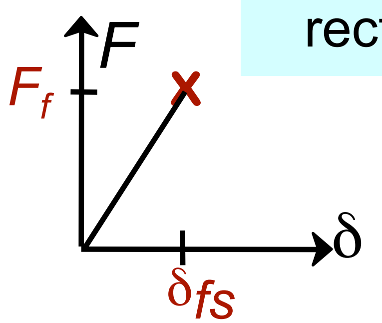


Adapted from Fig. 12.32, *Callister 7e.*

- Flexural strength:

$$\sigma_{fs} = \frac{1.5 F_f L}{bd^2} = \frac{F_f L}{\pi R^3}$$

(rect.)



- Typ. values:

Material	σ_{fs} (MPa)	*E*(GPa)
Si nitride	250-1000	304
Si carbide	100-820	345
Al oxide	275-700	393
glass (soda)	69	69

Data from Table 12.5, *Callister 7e.*