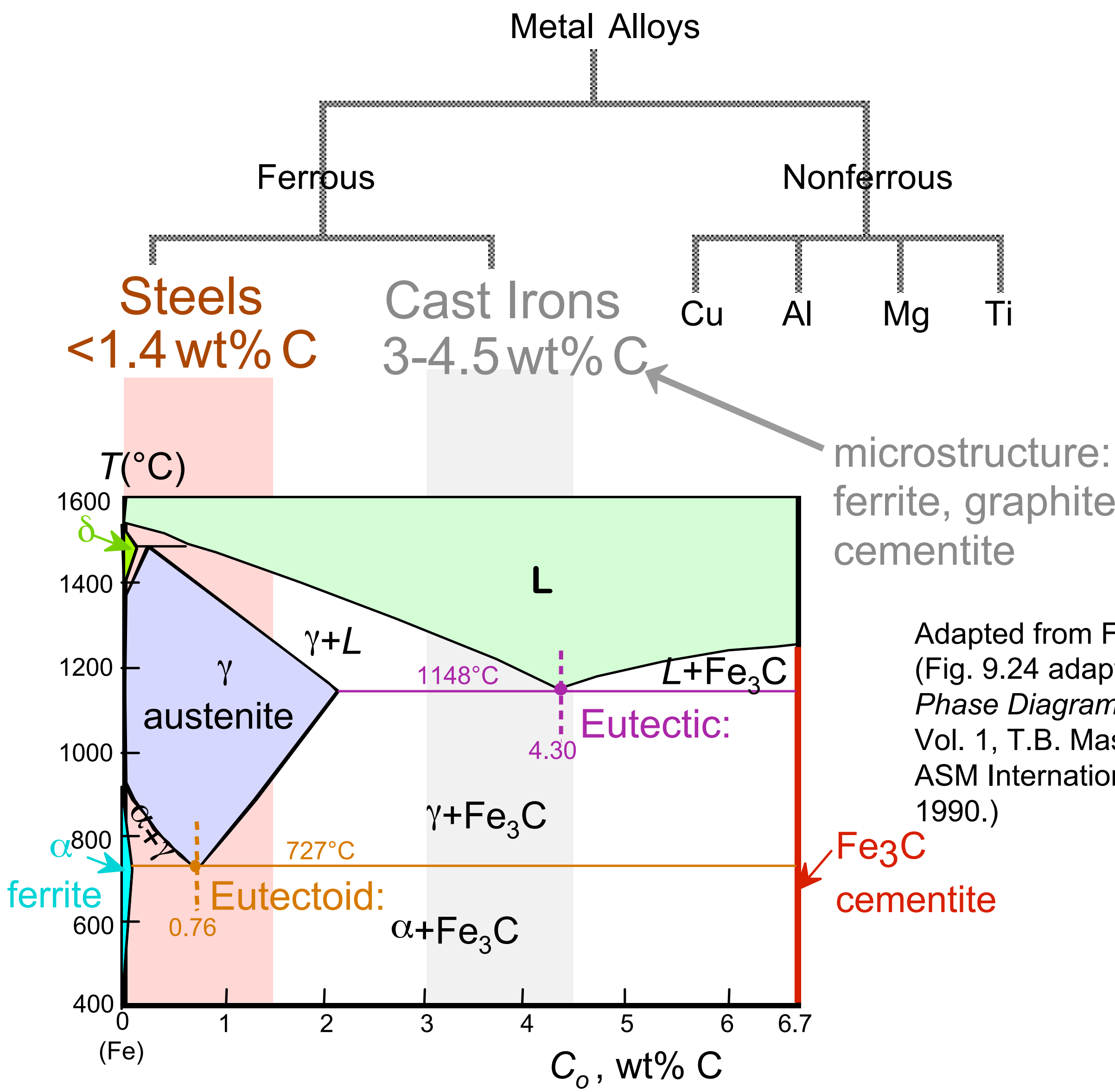
Taxonomy of metals



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

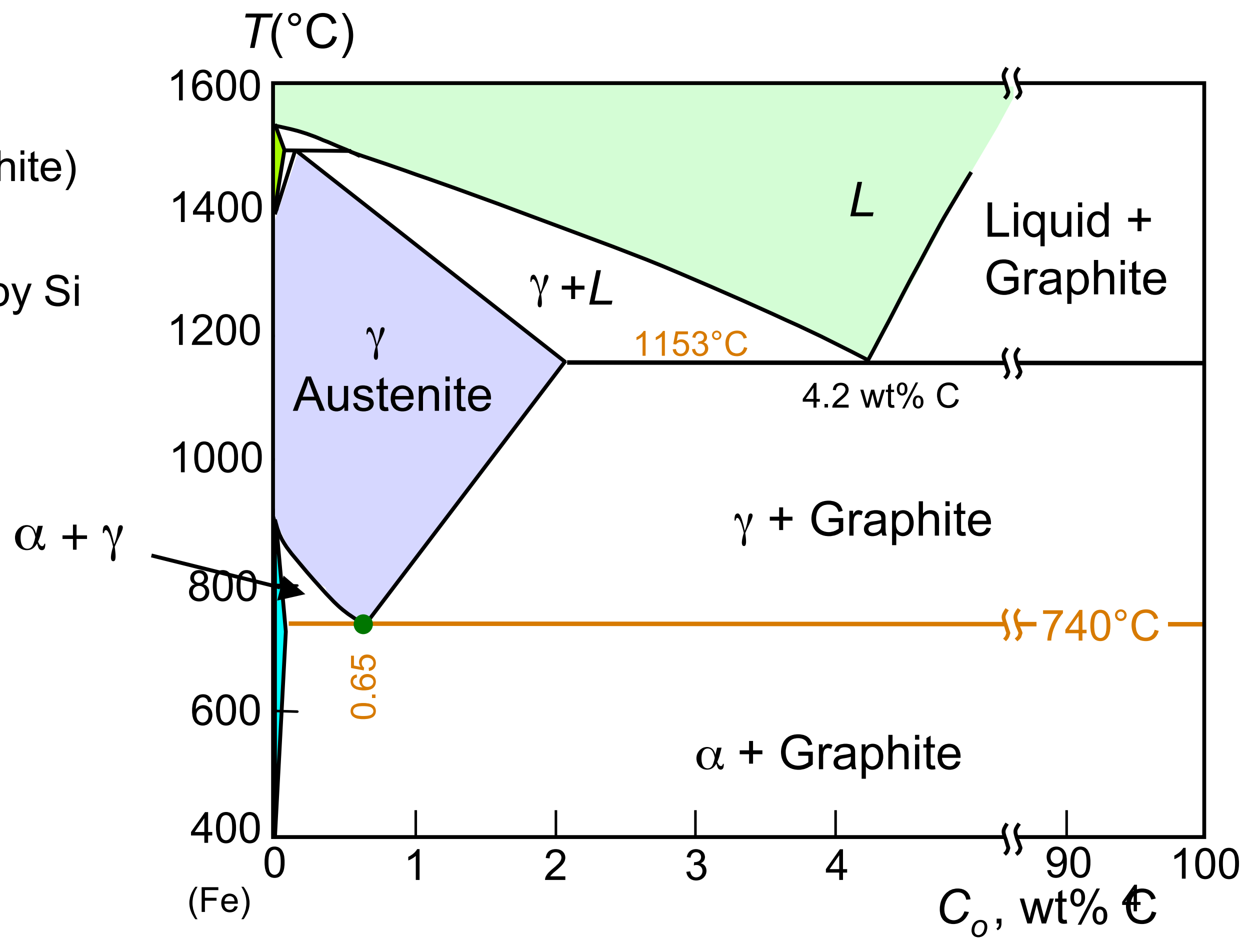
Stainless Steel -- >11% Cr

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

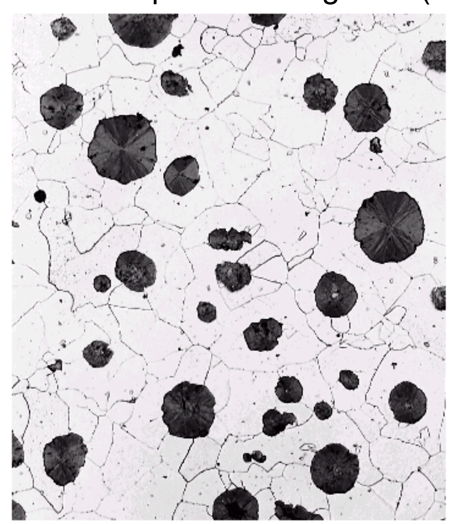
Gray iron

- 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

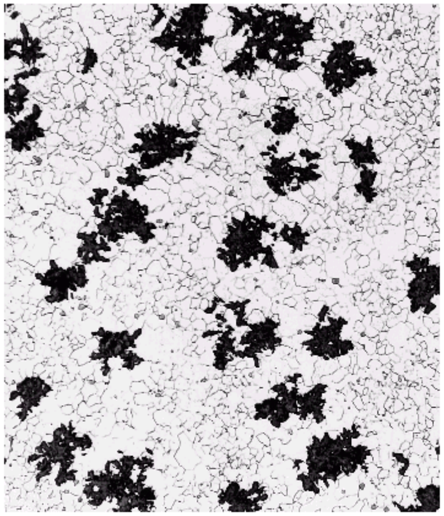
Adapted from Fig. 11.3(c) & (d), *Callister 7e*.

Malleable iron

•heat treat at 800-900ºC

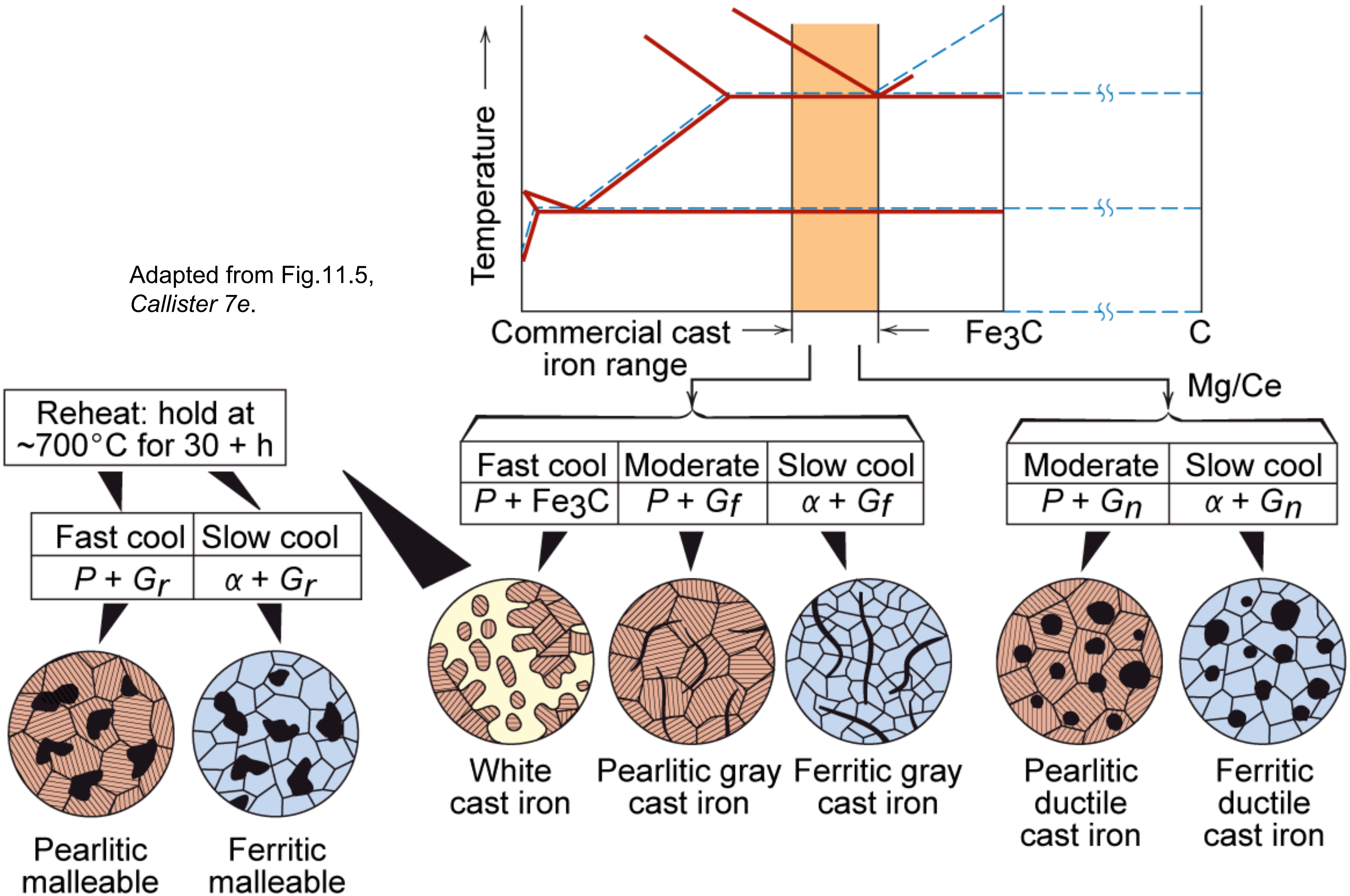
•graphite in rosettes

•more ductile



Production of cast iron

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



Other alloys

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, 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*

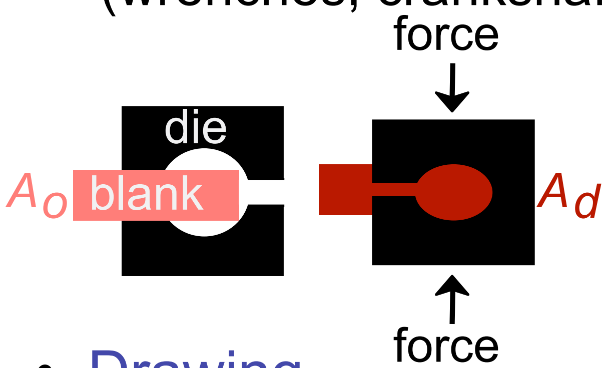
-Nb, Mo, W, Ta

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

Metal fabrication methods 1

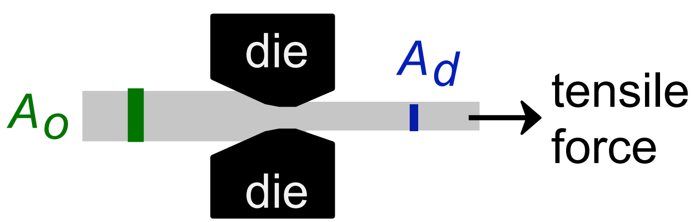
FORMING | CASTING | JOINING

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



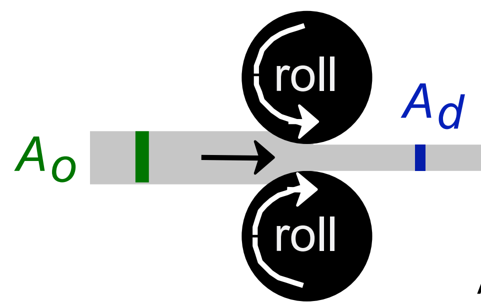
often at elev. T

- Drawing
  (rods, wire, tubing)



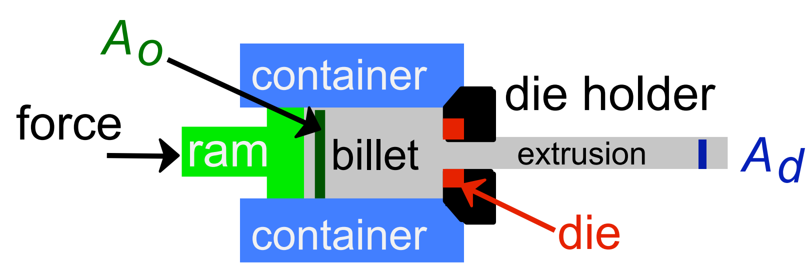
die must be well lubricated & clean

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



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

- Extrusion
  (rods, tubing)



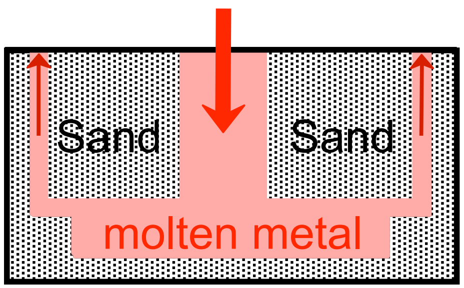
ductile metals, e.g. Cu, Al (hot)

Metal fabrication methods 2

FORMING | **CASTING** | JOINING

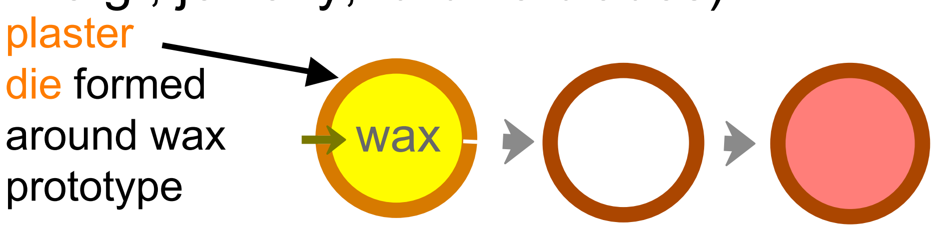
- Sand Casting

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



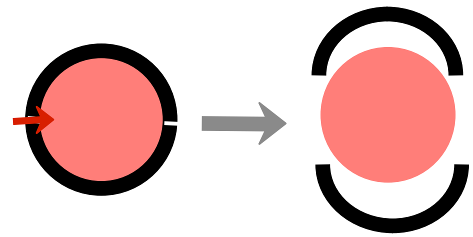
- Investment Casting

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



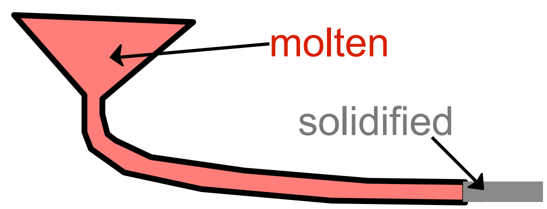
- Die Casting

  (high volume, low T alloys)



- Continuous Casting

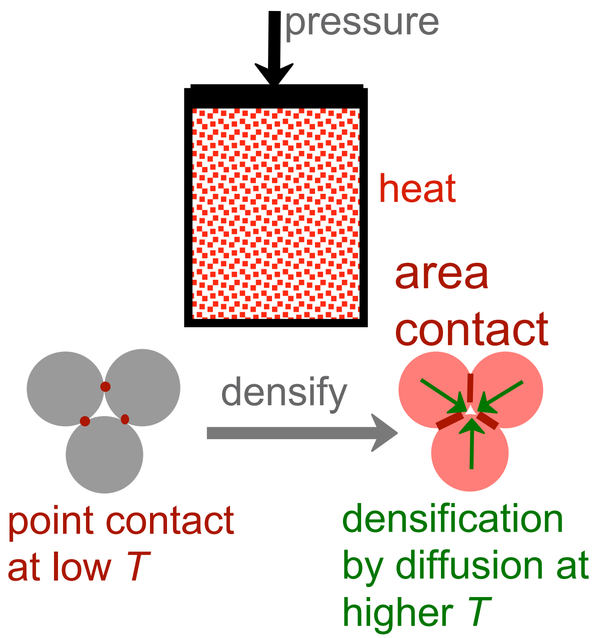
  (simple slab shapes)



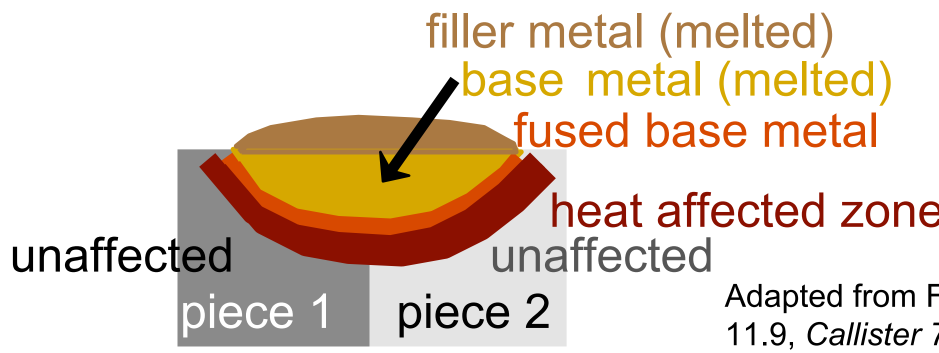
Metal fabrication methods 3

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.

- **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.

Types of Annealing

- **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.

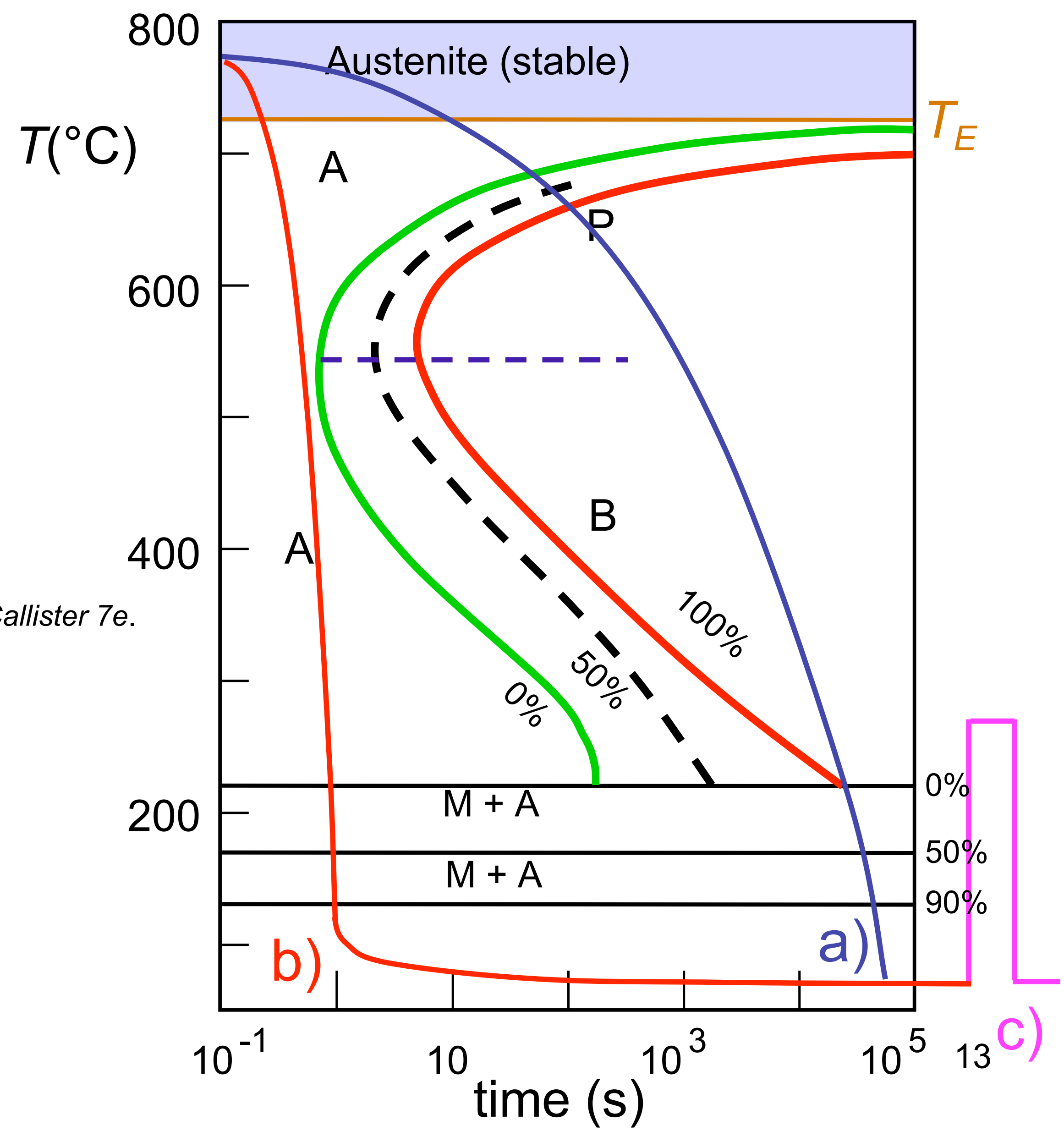
Based on discussion in Section 11.7, *Callister 7e*.

Heat treatments

a) Annealing

b) Quenching

c) Tempered Martensite



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

Precipitation hardening

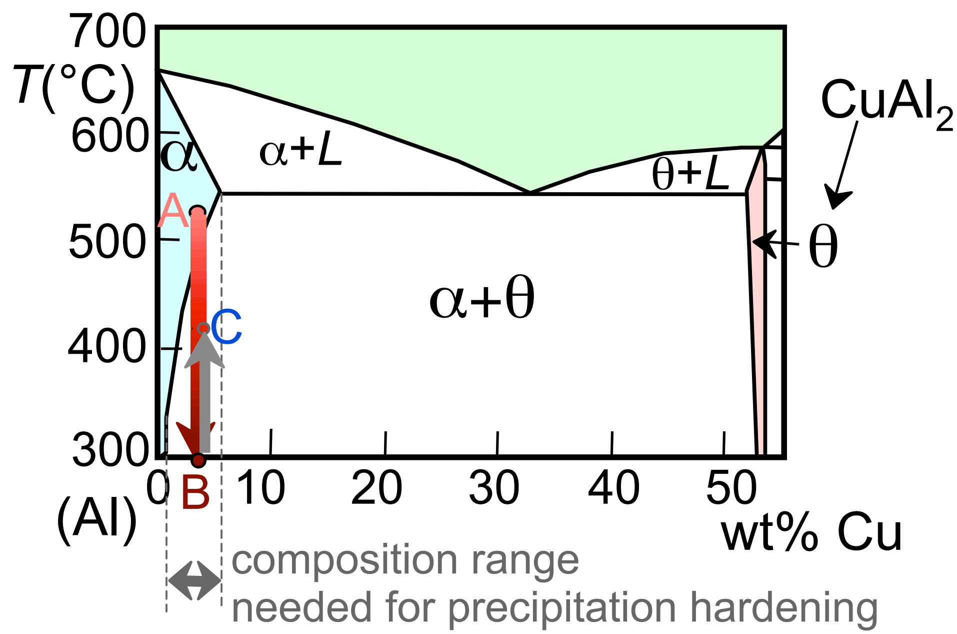
- Particles impede dislocations.
- Ex: Al-Cu system
- Procedure:

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

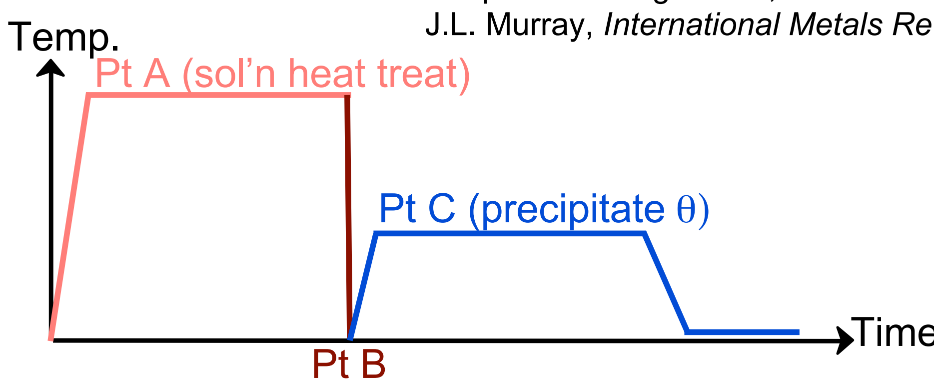
  --Pt B: quench to room temp.

  --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.)

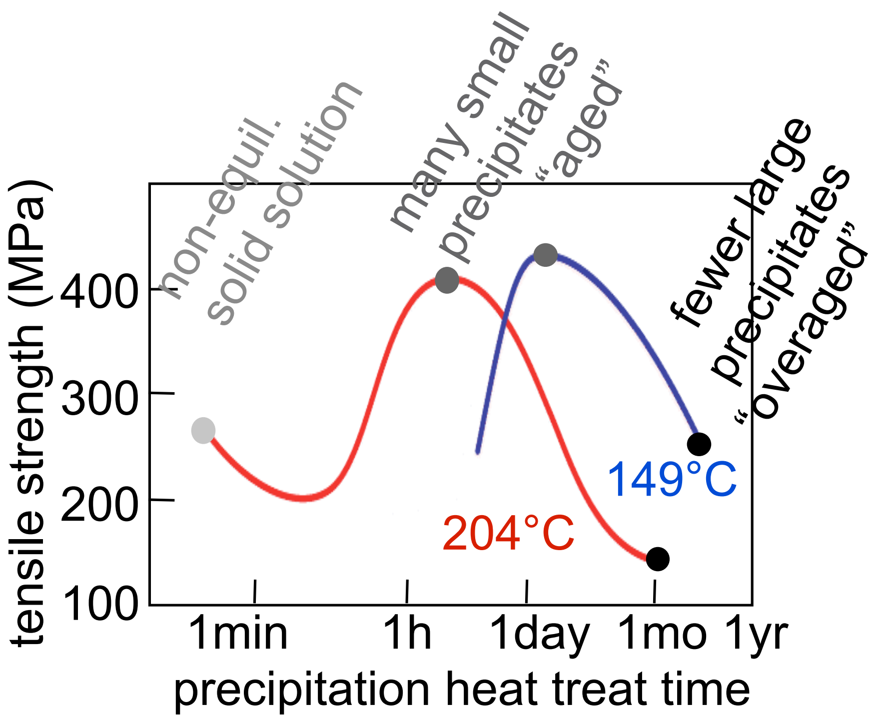


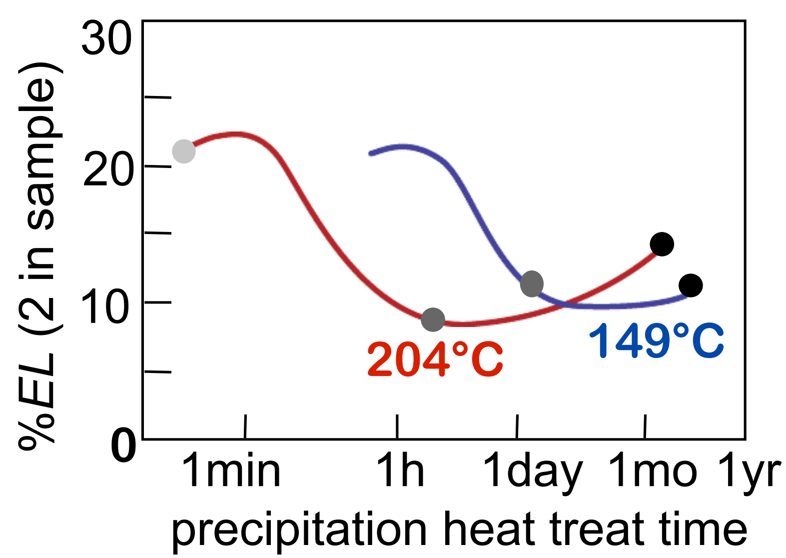
Adapted from Fig. 11.22, *Callister 7e*.

Precipitation hardening

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

- %*EL* reaches minimum with precipitation time.



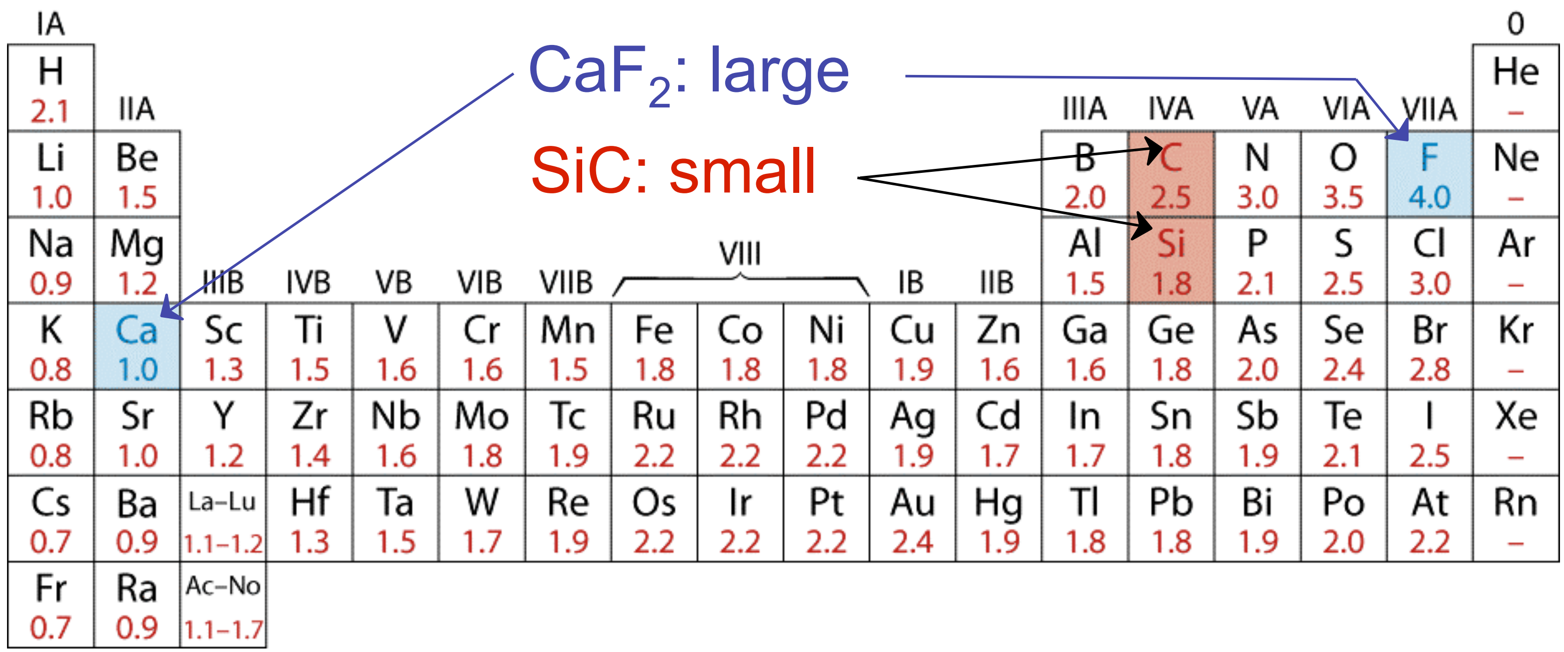


Adapted from Fig. 11.27 (a) and (b), *Callister 7e*. (Fig. 11.27 adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker (Managing Ed.), American Society for Metals, 1979. p. 41.)

Ceramics

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

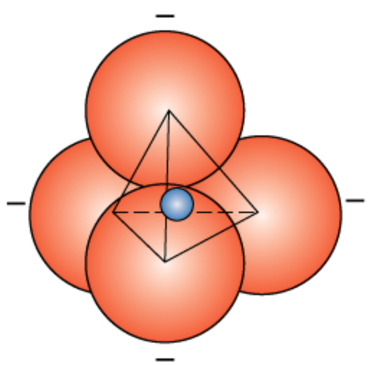
- Large vs small ionic bond character:

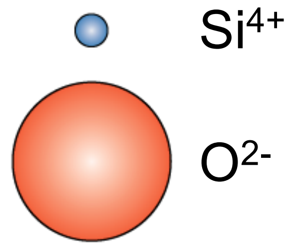


Adapted from Fig. 2.7, *Callister 7e.* (Fig. 2.7 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

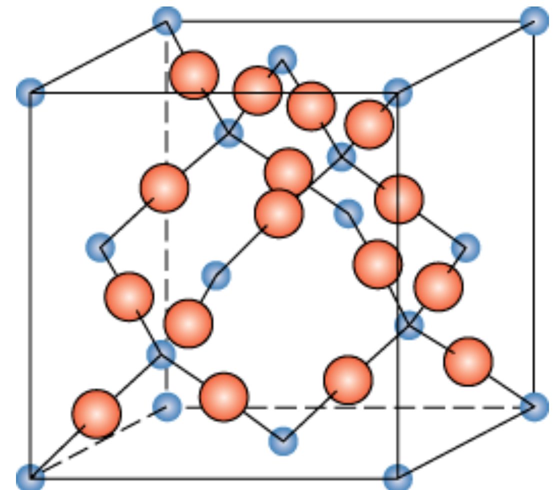
Silicate Ceramics

- Most common elements on earth are Si & O





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

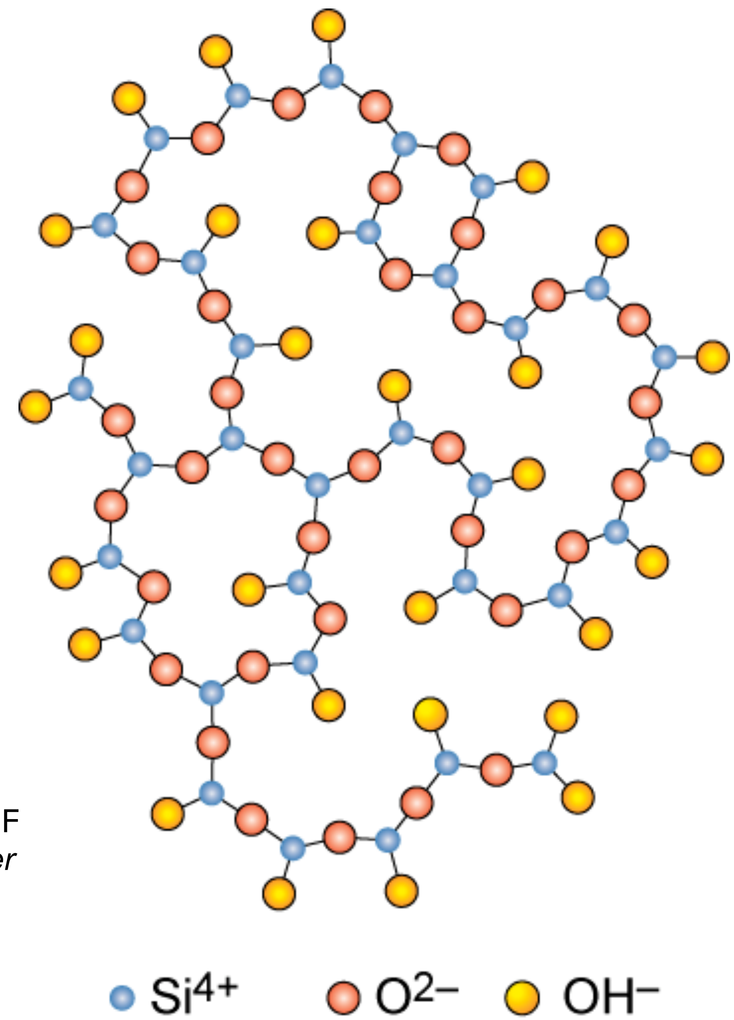


crystobalite

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

Amorphous silica

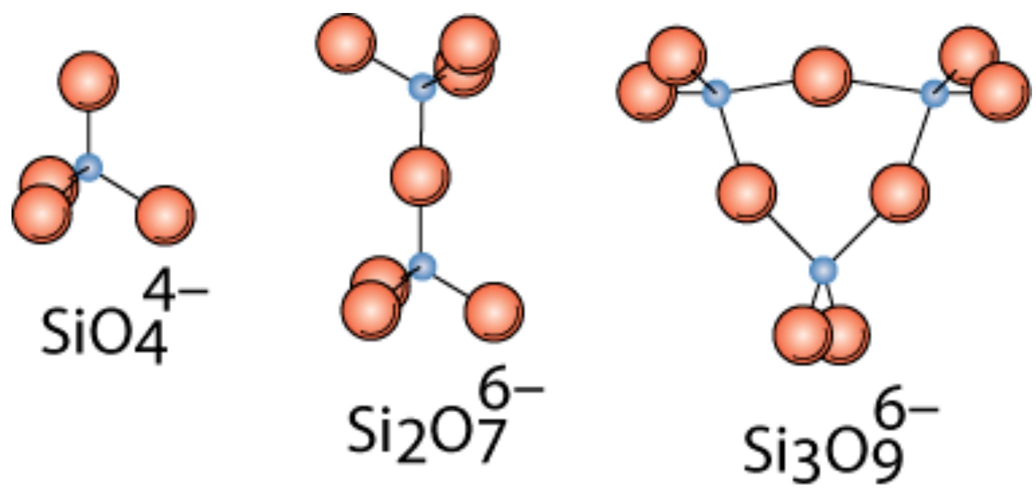
- Silica gels - amorphous SiO_2
  - Si^{4+} and O^{2-} not in well-ordered lattice
  - Charge balanced by H^+ (to form OH^-) at “dangling” bonds
    - very high surface area > 200 m^2/g
  - SiO_2 is quite stable, therefore unreactive
    - makes good catalyst support



Adapted from F 12.11, *Callister*

Silicates

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



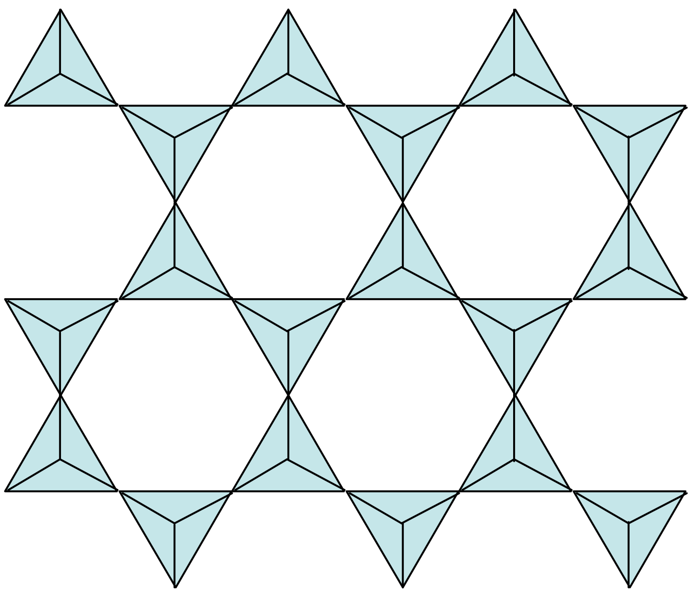
Adapted from Fig. 12.12, *Callister 7e.*

Mg_2SiO_4 $Ca_2MgSi_2O_7$

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

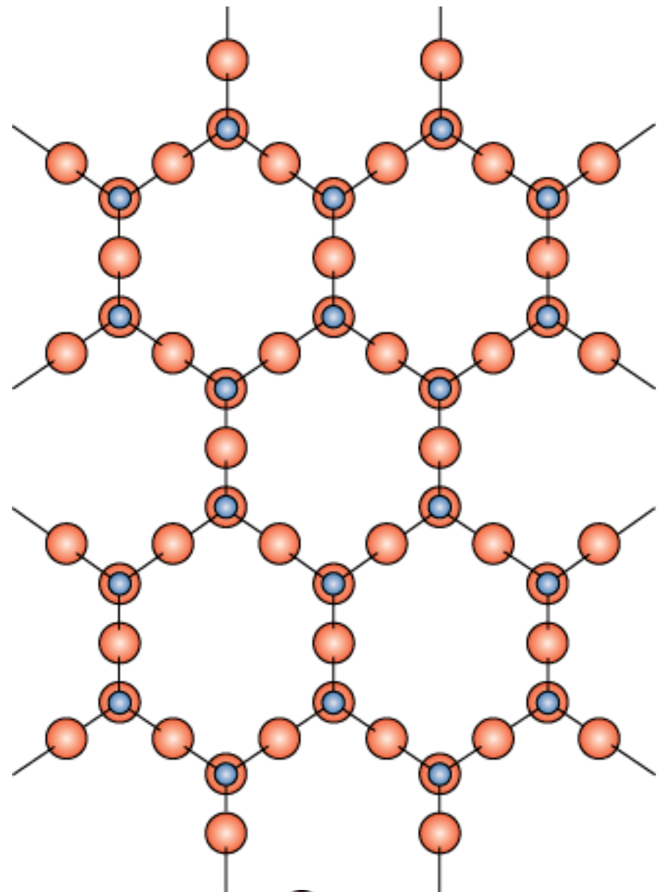
Layered silicates

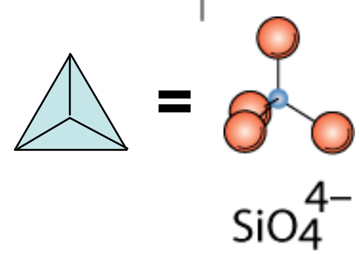
- Layered silicates (clay silicates)
  - SiO_4 tetrahedra connected together to form 2-D plane



$(Si_2O_5)^{2-}$

- Therefore, cations are required to balance charge

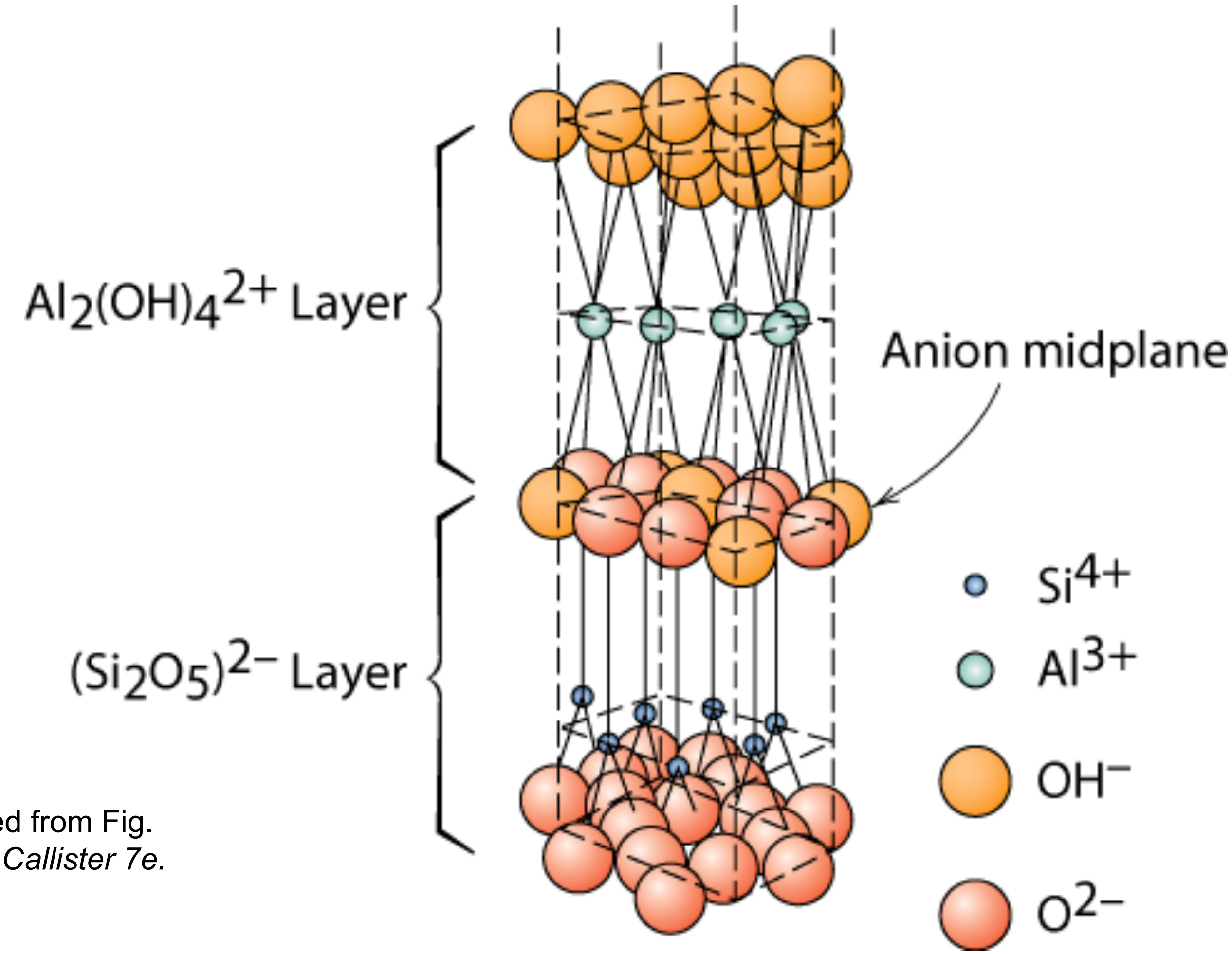




Adapted from Fig. 12.13, *Callister 7e.*

Layered silicates

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

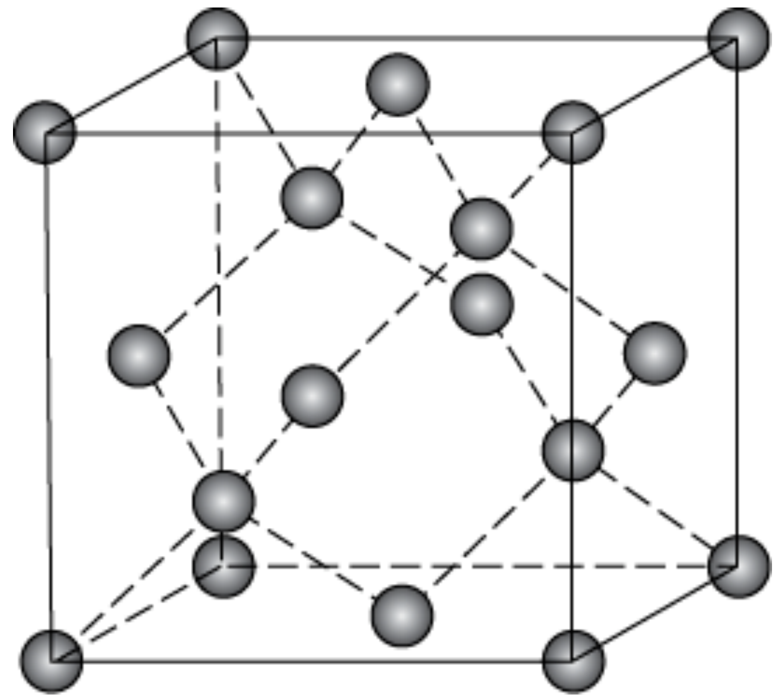


Adapted from Fig. 12.14, *Callister 7e.*

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

Carbon forms

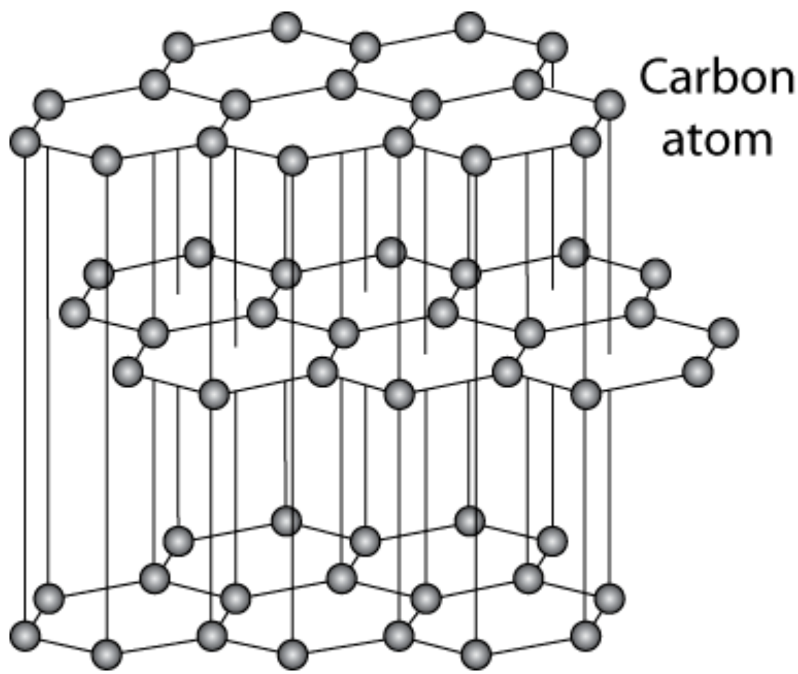
- Carbon black – amorphous – surface area ca. 1000 m^2/g
- Diamond
  - tetrahedral carbon
    - hard – no good slip planes
    - brittle – can cut it
  - large diamonds – jewelry
  - small diamonds
    - often man made - used for cutting tools and polishing
  - diamond films
    - hard surface coat –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



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

Carbon forms

- layer structure – aromatic layers



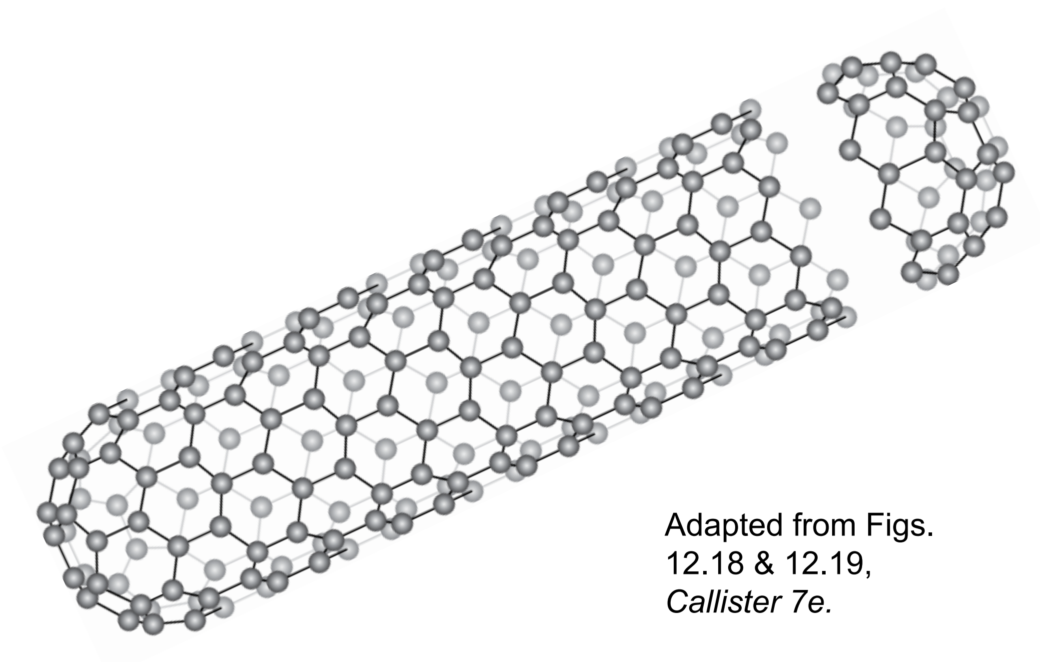
Adapted from Fig. 12.17, *Callister 7e.*

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

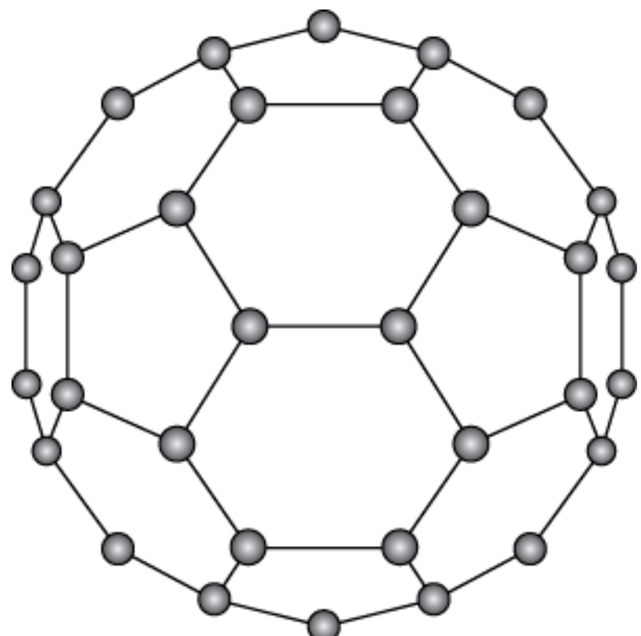
Carbon forms

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

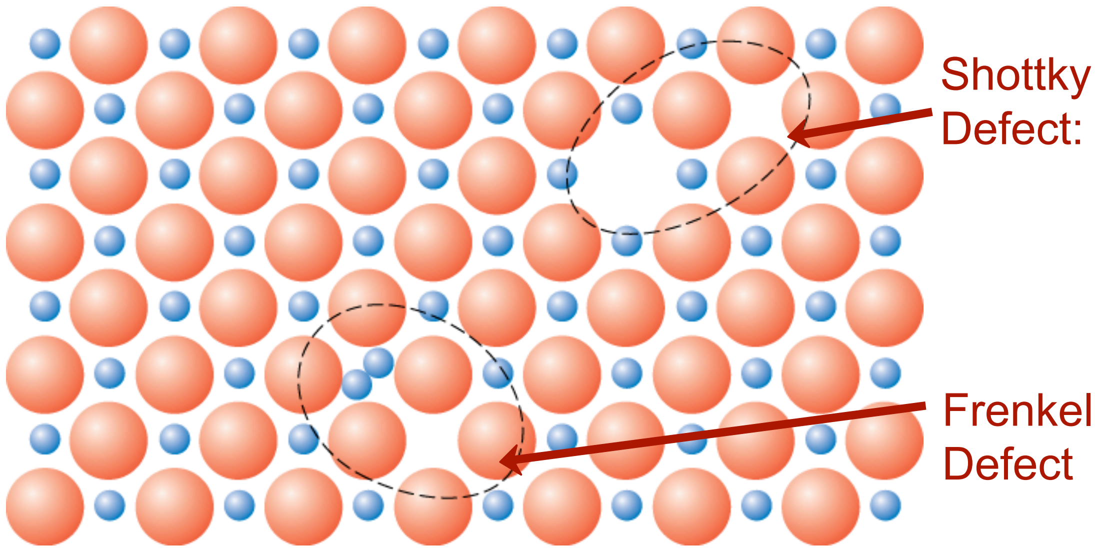


Adapted from Figs. 12.18 & 12.19, *Callister 7e.*



Defects

- Frenkel Defect
  --a cation is out of place.
- Shottky Defect
  --a paired set of cation and anion vacancies.

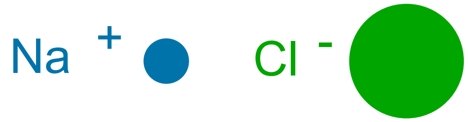


Adapted from Fig. 12.21, *Callister 7e.* (Fig. 12.21 is from W.G. Moffatt, G.W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. 1, *Structure*, John Wiley and Sons, Inc., p. 78.)

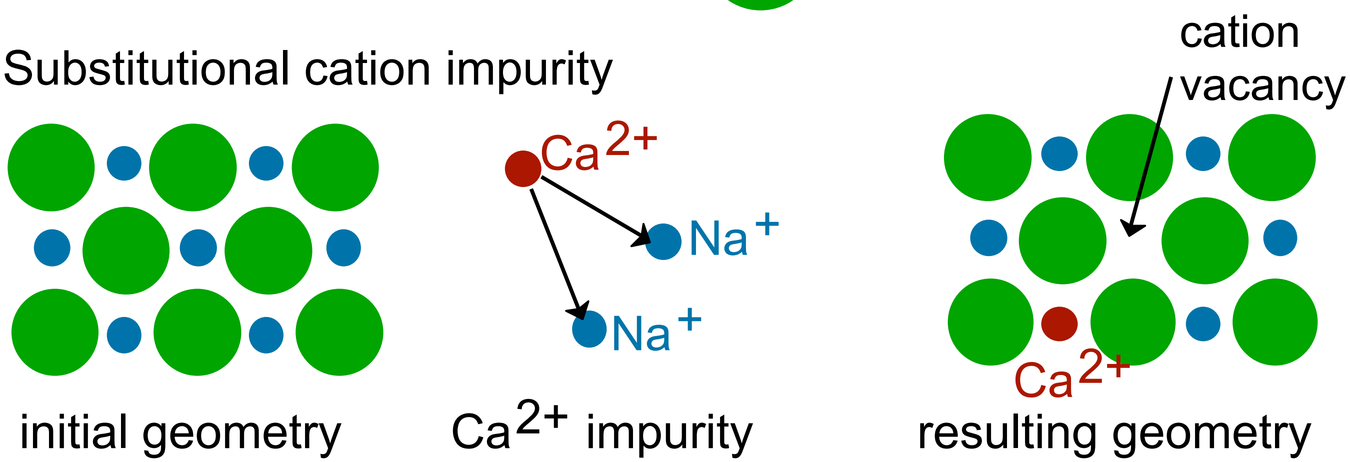
- Equilibrium concentration of defects $\sim e^{-Q_D / kT}$

Impurities

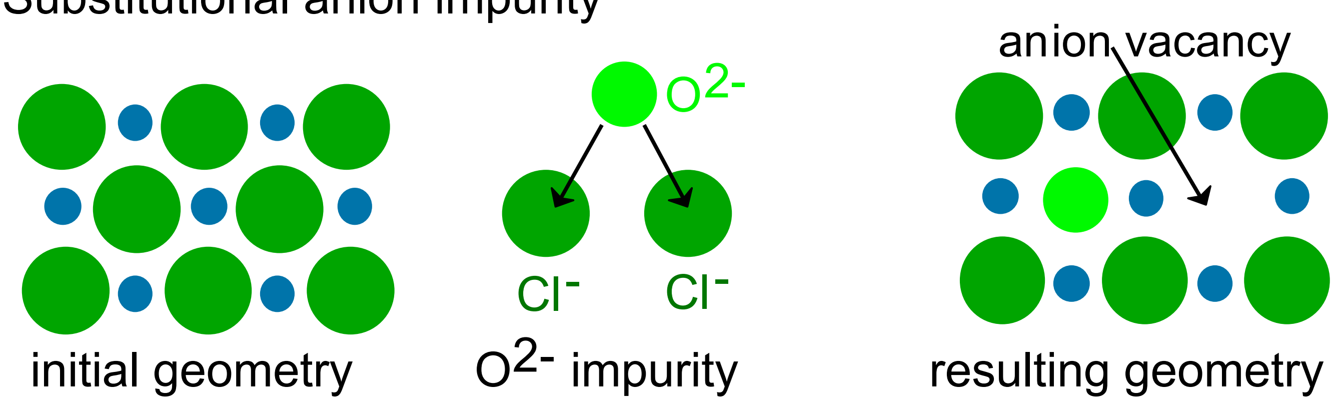
- Impurities must also satisfy charge balance = Electroneutrality
- Ex: NaCl



- Substitutional cation impurity

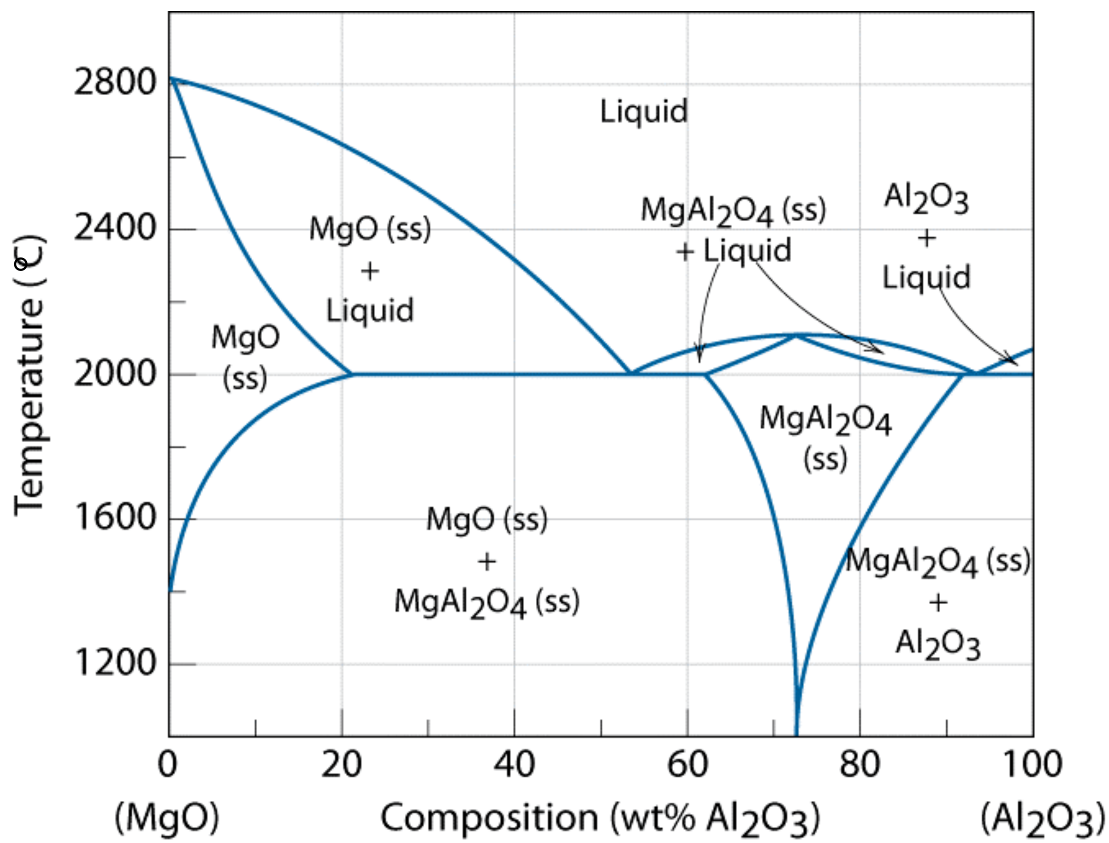


- Substitutional anion impurity



Ceramic phase diagrams

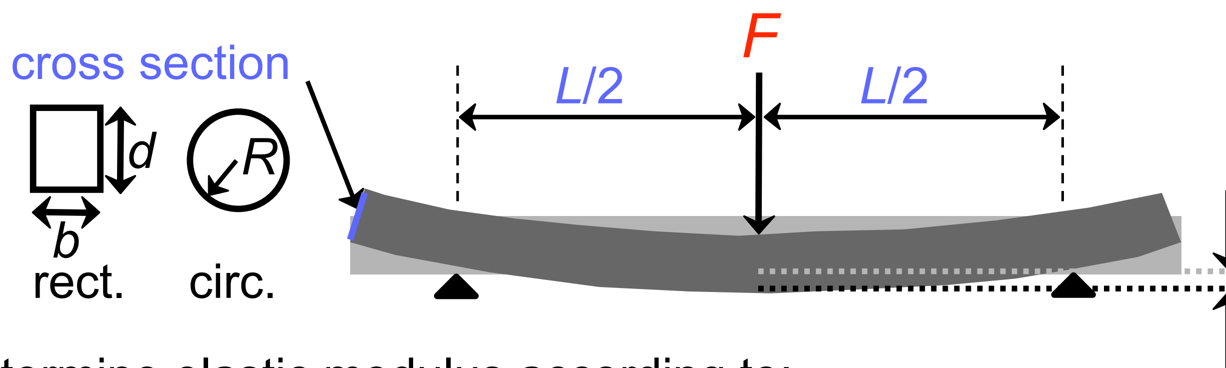
MgO-Al_2O_3 diagram:



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

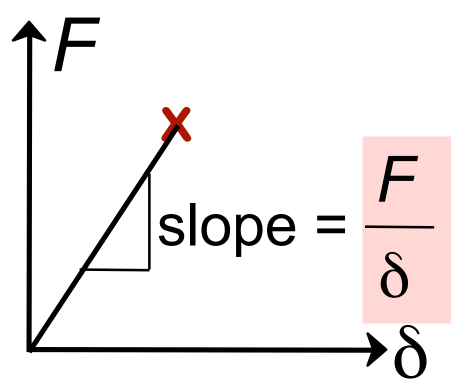
Measuring the elastic modulus

- 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:



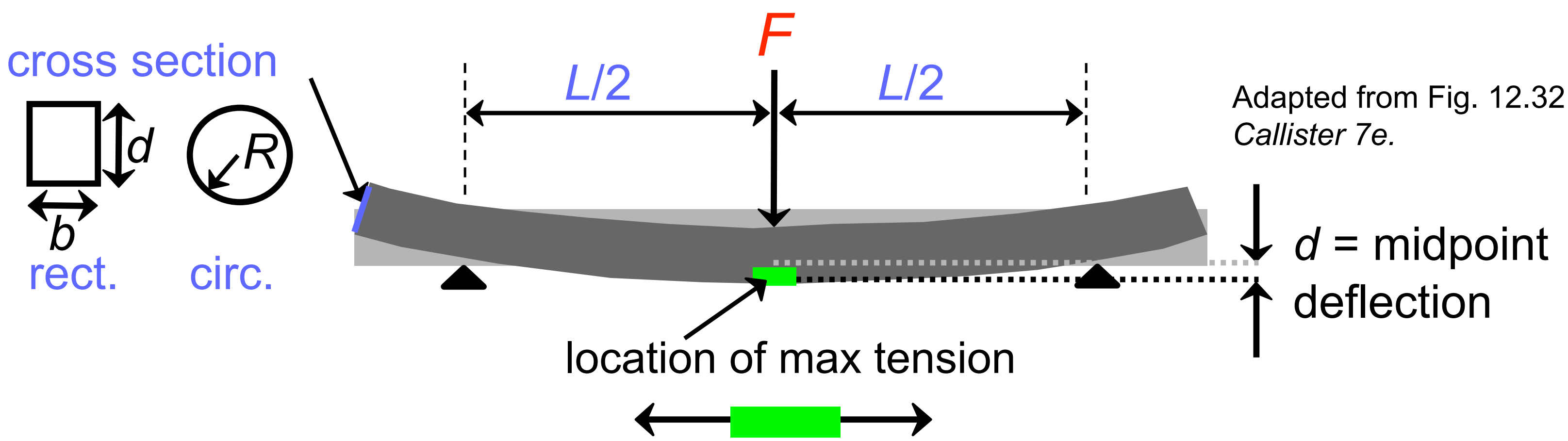
linear-elastic behavior

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

rect. cross section — circ. cross section

Measuring strengths

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

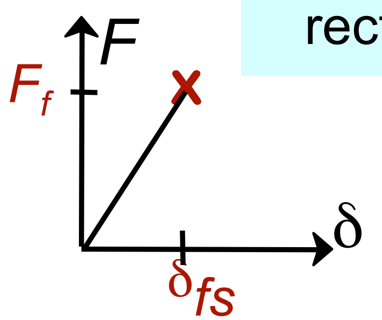


Adapted from Fig. 12.32, *Callister 7e.*

- Flexural strength:

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

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.*