Chapter 11: Applications and Processing of Metal Alloys

ISSUES TO ADDRESS...

- What are some of the common fabrication techniques for metals?
- What heat treatment procedures are used to improve the mechanical properties of both ferrous and nonferrous alloys?

Metal Fabrication

How do we fabricate metals?

1. Refining (Extraction)
2. Forming

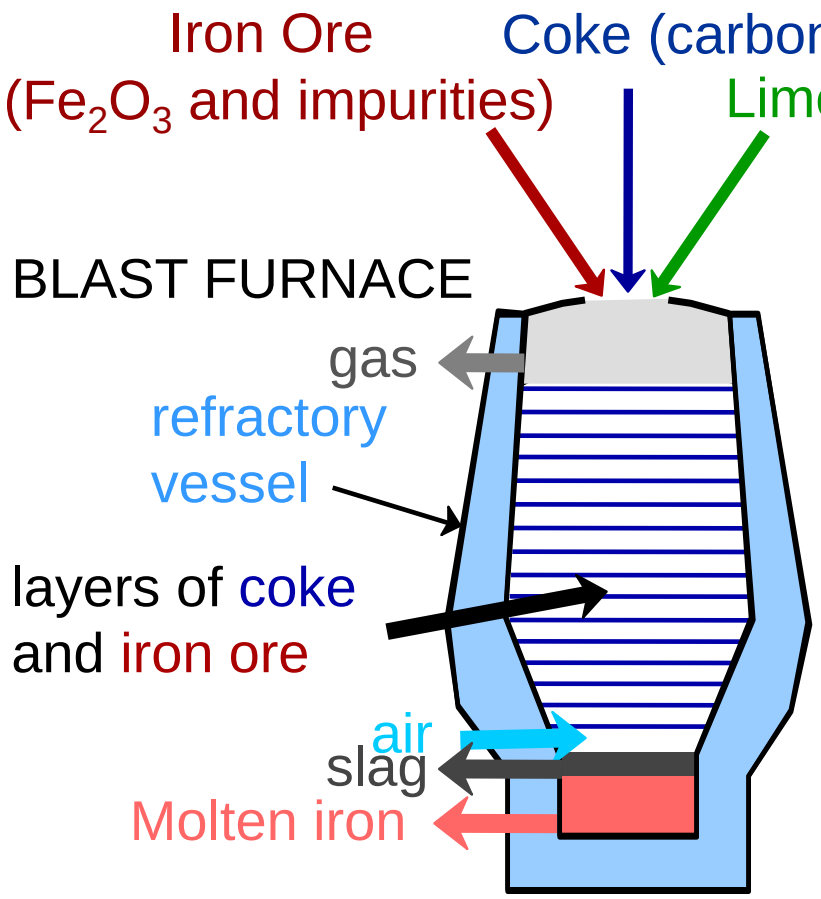
Refining

Forming

– Rough stock formed to final shape

Hot working vs. Cold working

Production of Iron 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

$$CaCO_3 \rightarrow CaO + CO_2$$

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

World annual production: ~10^9 ton

Production of Copper

1. Mining copper sulfides ($CuFeS_2$, Cu_2S)
2. Remove Fe (through oxides)
3. Oxidize copper sulfides into copper oxides and decompose Cu_2O to obtain copper

   $2Cu_2S + 3O_2 = 2Cu_2O + 2SO_2$

   $2Cu_2O = 4Cu + O_2$
4. Further refining with help of (sulfuric) acid digestion and electro-deposition or further melting

   $Cu^{2+} + 2e^- = Cu$

Annual world production: ~20×10^6 ton

~80% of all copper recycled

Production of Aluminum

Al bonds to oxygen strongly, difficult to reduce by carbon (as compared with Fe or Cu) or by thermal decomposition (as for Cu)

Electrolytic production in molten salt of Na_3AlF_6-CaF_2:

$$2Al_2O_3 = 4Al + 3O_2$$

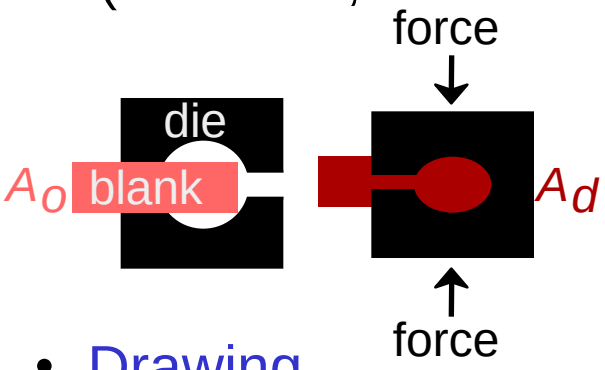
World annual production: 40×10^6 ton

Metal Fabrication Methods (i)

FORMING | CASTING | MISCELLANEOUS

- Forging (Hammering; Stamping)

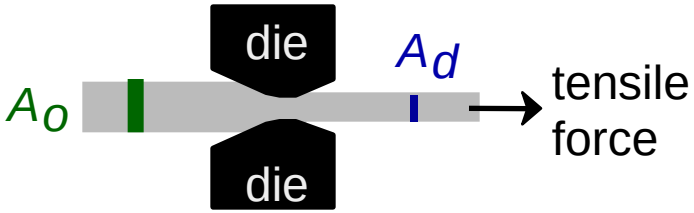
  (wrenches, crankshafts)



often at elev. *T*

- Drawing

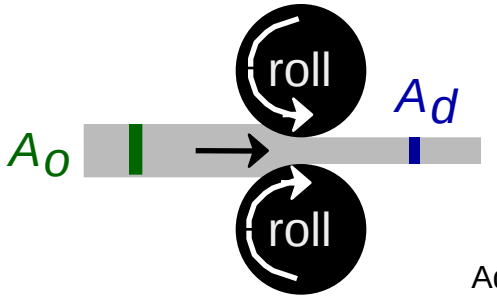
  (rods, wire, tubing)



die must be well lubricated & clean

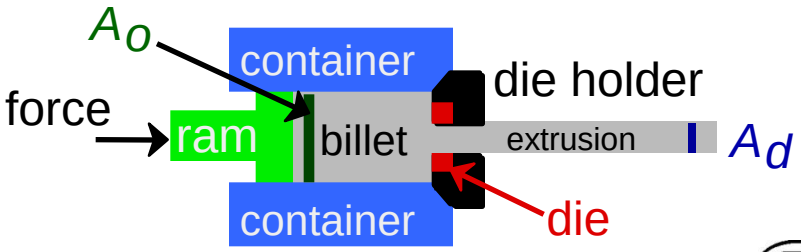
- Rolling (Hot or Cold Rolling)

  (I-beams, rails, sheet & plate)



- Extrusion

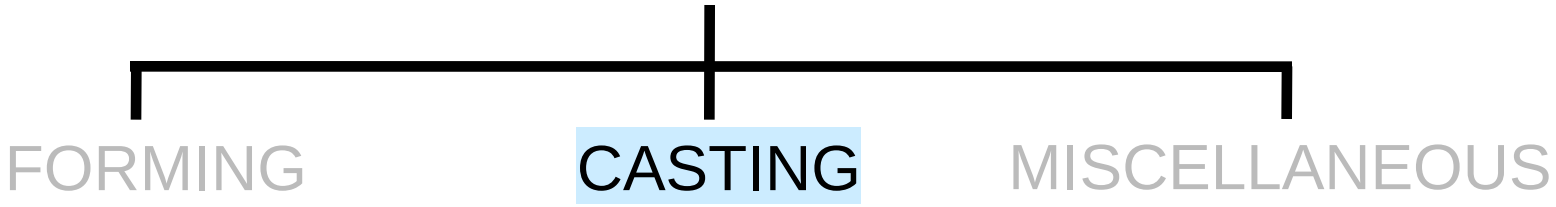
  (rods, tubing)



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

Adapted from Fig. 11.8, *Callister & Rethwisch 8e.*

Metal Fabrication Methods (ii)



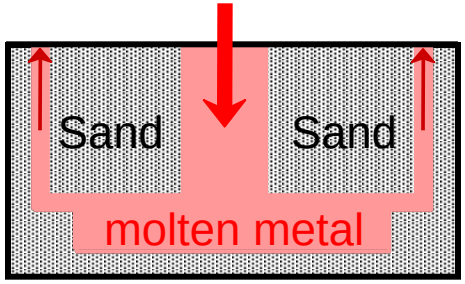
- Casting- mold is filled with molten metal
  - metal melted in furnace, perhaps alloying elements added, then cast in a mold
  - common and inexpensive
  - gives good production of shapes
  - weaker products, internal defects
  - good option for brittle materials and/or complex shape

Metal Fabrication Methods (iii)

FORMING | CASTING | MISCELLANEOUS

- Sand Casting

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

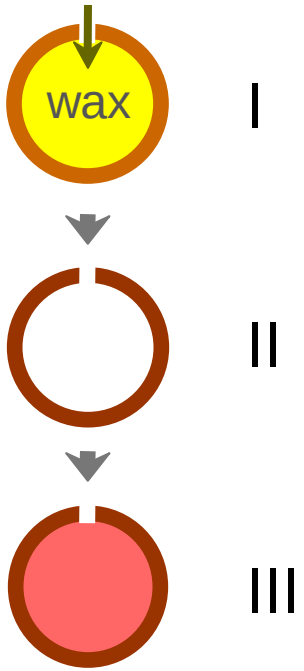


- Model material need to withstand *T* >~1500ºC and is inexpensive and easy to mold, e.g., sand
- To create mold, pack sand around form (pattern) of desired shape

Metal Fabrication Methods (iv)

FORMING | CASTING | MISCELLANEOUS

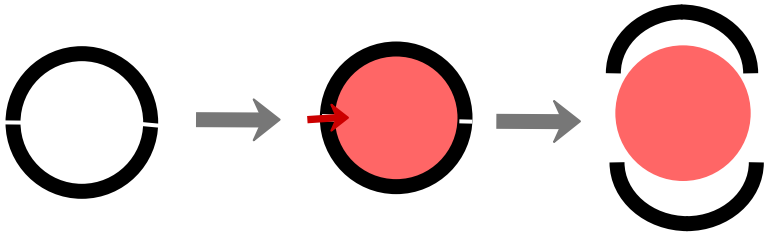
- Investment Casting
  (low volume, complex shapes
  e.g., jewelry, turbine blades)
- Stage I — Mold formed by pouring plaster of paris ($CaSO_4 \cdot 2H_2O$) around wax pattern. Plaster allowed to harden.
- Stage II — Wax is melted and then poured from mold—hollow mold cavity remains
- Stage III — Molten metal is poured into mold and allowed to solidify.



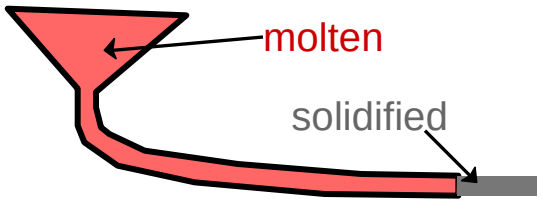
Metal Fabrication Methods (v)

FORMING | CASTING | MISCELLANEOUS

- Die Casting
  - -- high volume
  - -- for alloys having low melting temperatures



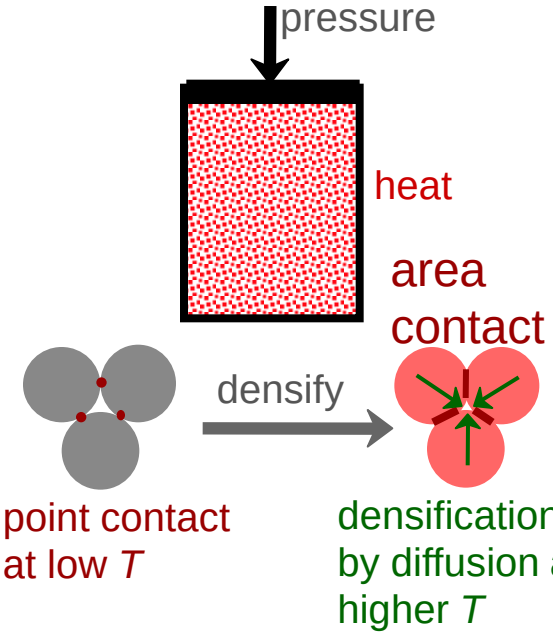
- Continuous Casting
  - -- simple shapes (e.g., rectangular slabs, cylinders)



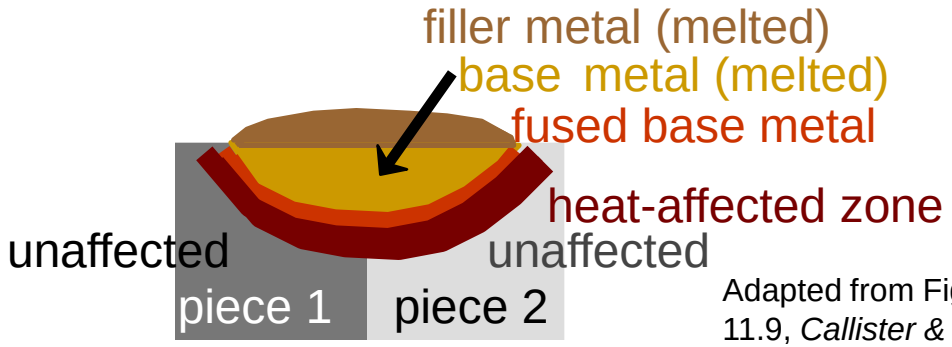
Metal Fabrication Methods (vi)

FORMING | CASTING | MISCELLANEOUS

- Powder Metallurgy
  (metals w/low ductility or very high melting points)



- Welding
  (when fabrication of one large part is impractical)

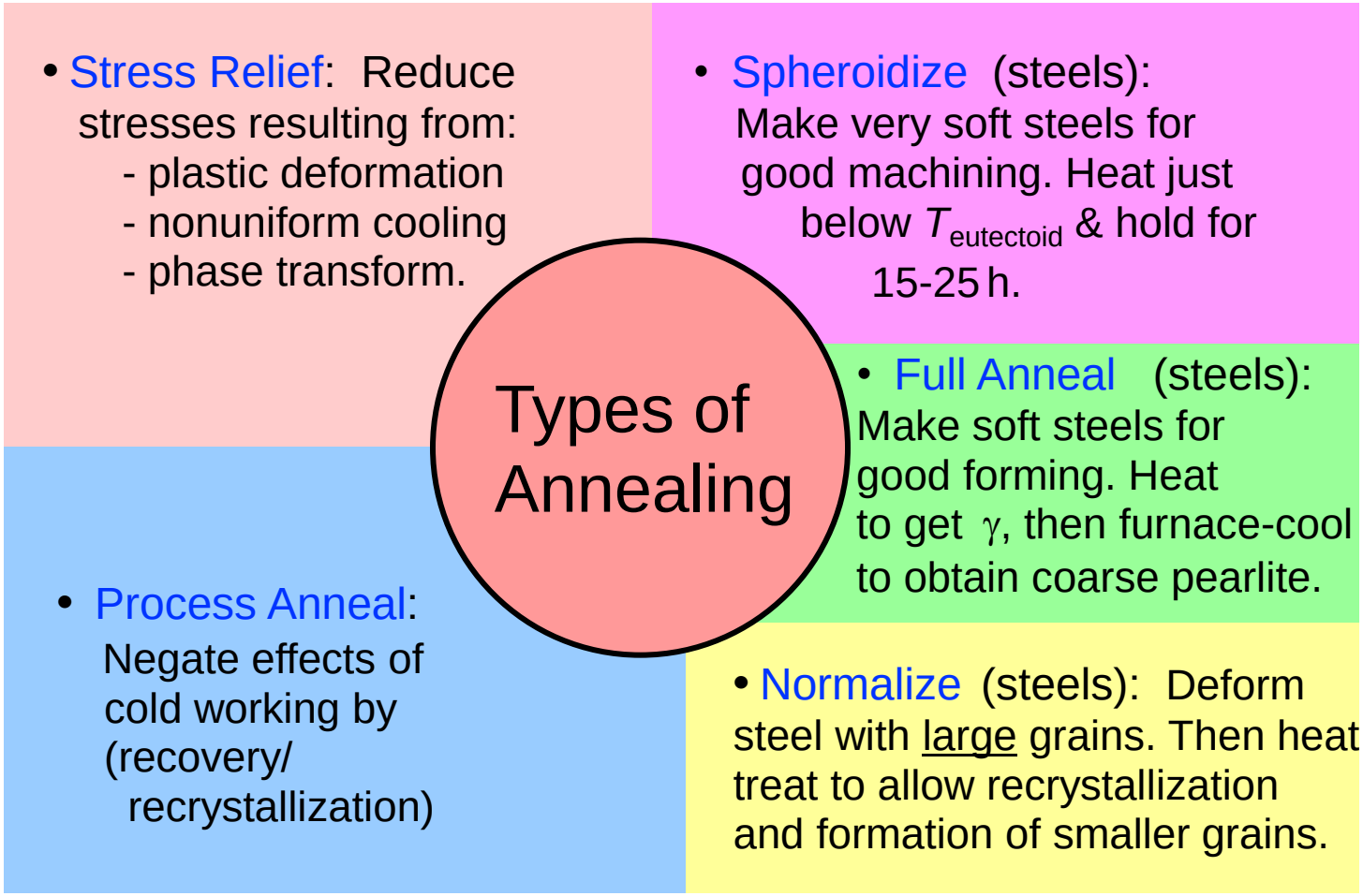


- (Electro) plating or other electrodeposition

Adapted from Fig. 11.9, *Callister & Rethwisch 8e.* (Fig. 11.9 from *Iron Castings Handbook*, C.F. Walton and T.J. Opar (Ed.), 1981.)

Annealing of Metals

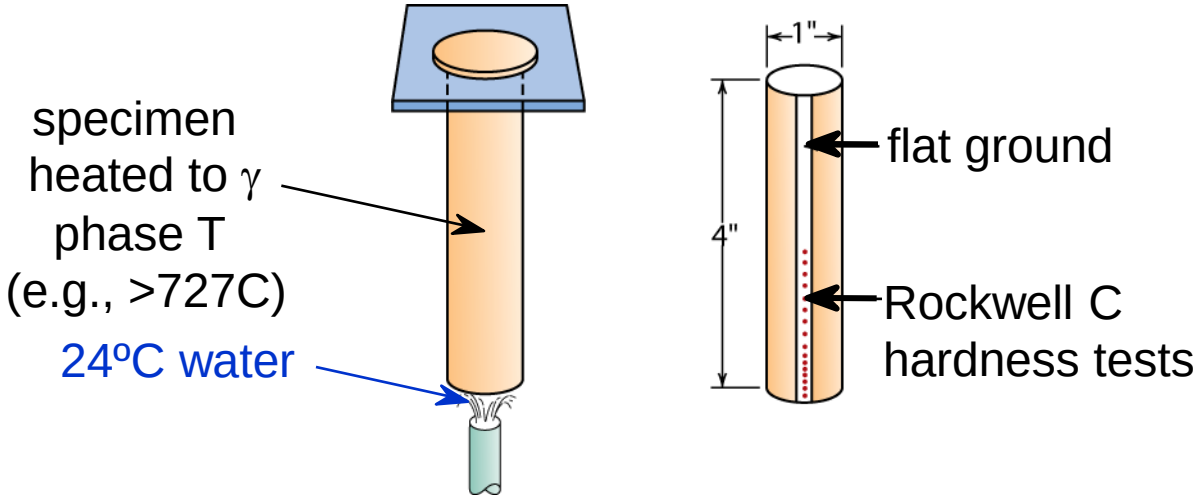
Annealing: Heat to certain temperature T_{anneal}, then cool slowly.



Based on discussion in Section 11.7, *Callister & Rethwisch 8e*.

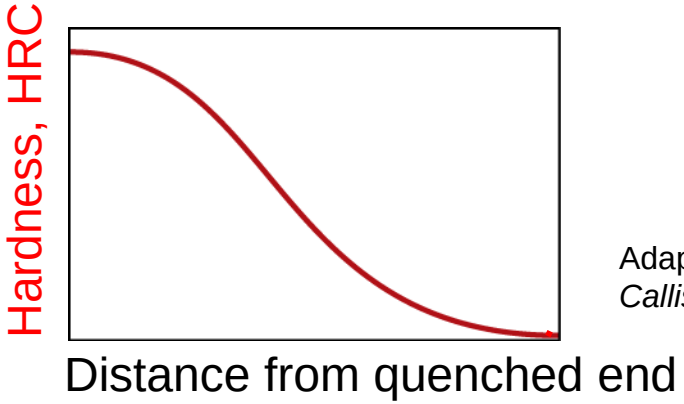
Quenching & Hardenability -- Steels

- Hardenability – measure of the ability for steel to form martensite – a meta-stable phase with very high hardness



Adapted from Fig. 11.11, *Callister & Rethwisch 8e*. (Fig. 11.11 adapted from A.G. Guy, *Essentials of Materials Science*, McGraw-Hill Book Company, New York, 1978.)

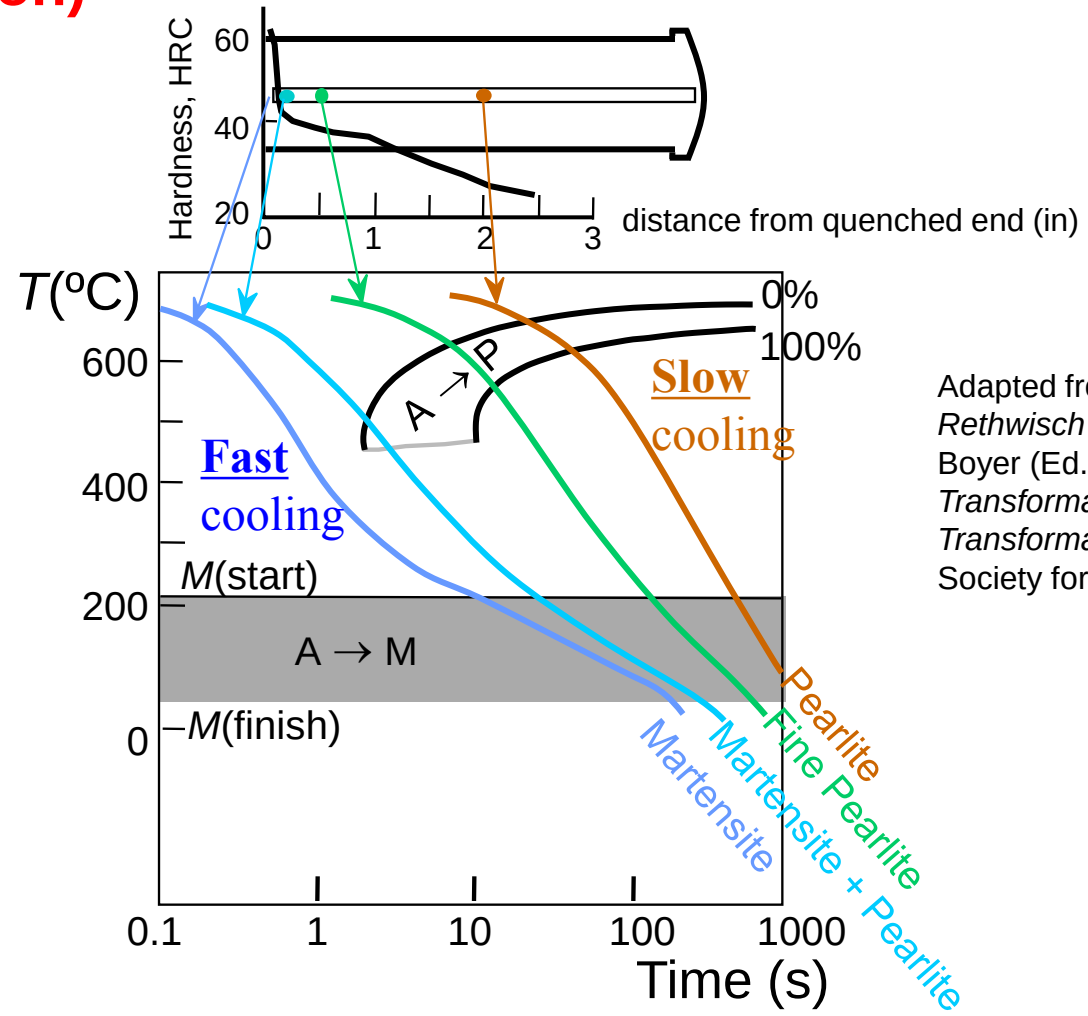
- Plot hardness versus distance from the quenched end.



Adapted from Fig. 11.12, *Callister & Rethwisch 8e*.

Reason Why Hardness Changes with Distance/Cooling Rate

For steel, **faster cooling – harder (certain hard (meta-stable) phase formation); slower cooling – softer (less or no hard phase formation)**



Adapted from Fig. 11.13, *Callister & Rethwisch 8e*. (Fig. 11.13 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1977, p. 376.)

Influences of Quenching Medium & Specimen Geometry

- Effect of quenching medium:

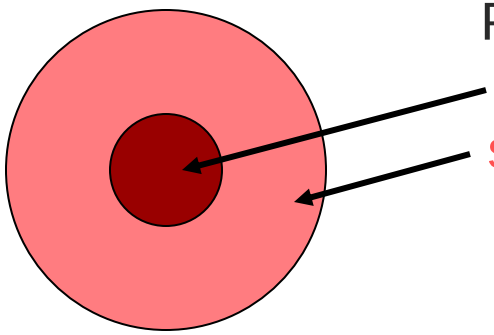
Medium	Rate of cooling	Hardness
air	low	low
oil	moderate	moderate
water	high	high

- Effect of specimen geometry:

  When surface area-to-volume ratio increases:

  -- cooling rate throughout interior increases

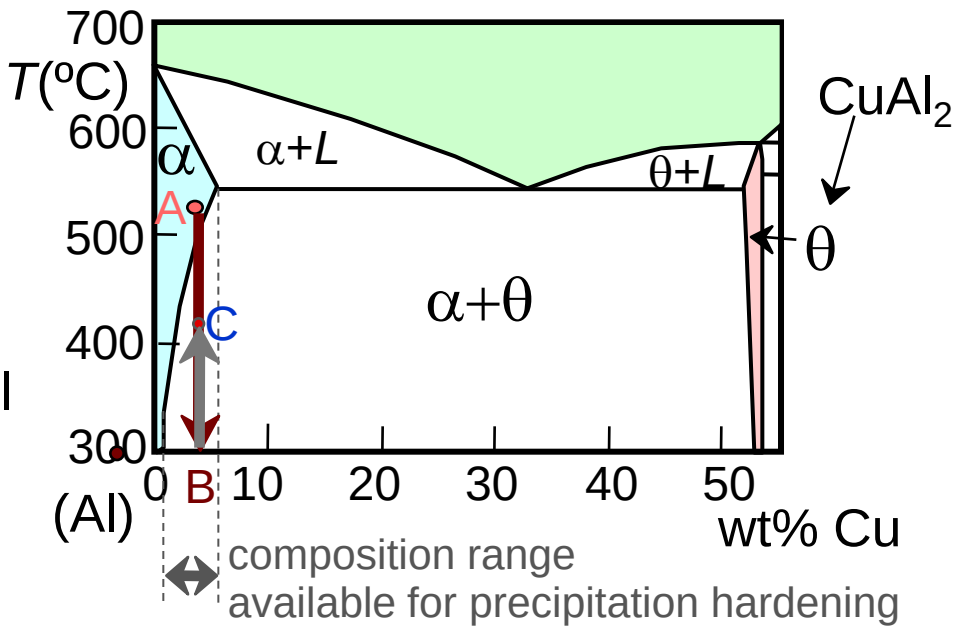
  -- hardness throughout interior increases



Position	Cooling rate	Hardness
center	low	low
surface	high	high

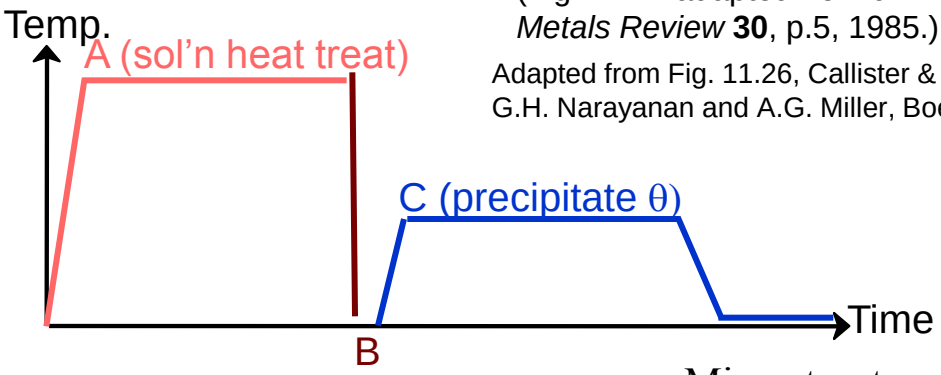
Precipitation Hardening

- Particles impede dislocation motion and make alloys harder & stronger
- Ex: Al-Cu system
- Procedure:
  - -- A: solution heat treatment (get uniform α solid solution)
  - -- B: quench to room temp. (uniform α solid solution)
  - -- C: reheat/**aging** to nucleate small precipitates (θ within α phase)



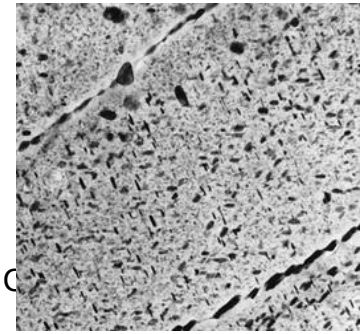
Adapted from Fig. 11.24, *Callister & Rethwisch 8e*. (Fig. 11.24 adapted from J.L. Murray, *International Metals Review* **30**, p.5, 1985.)

- Other alloys that display precipitation hardening:
  - Cu-Be
  - Cu-Sn
  - Mg-Al



Adapted from Fig. 11.22, *Callister & Rethwisch 8e*.

Adapted from Fig. 11.26, Callister & Rethwisch 8e. (Fig. 11.26 is courtesy of G.H. Narayanan and A.G. Miller, Boeing Commercial Airplane Company.)

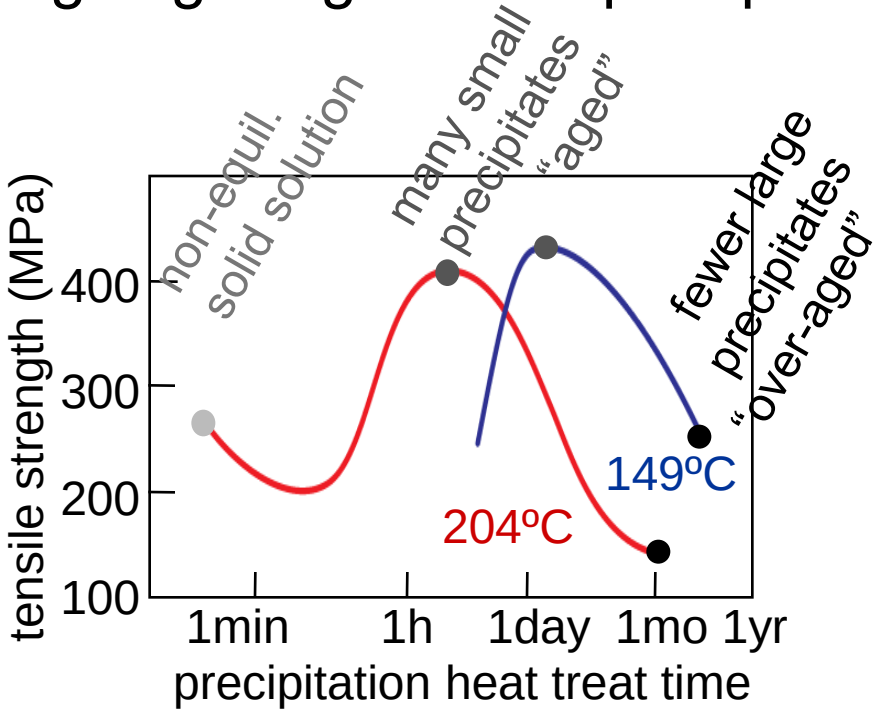


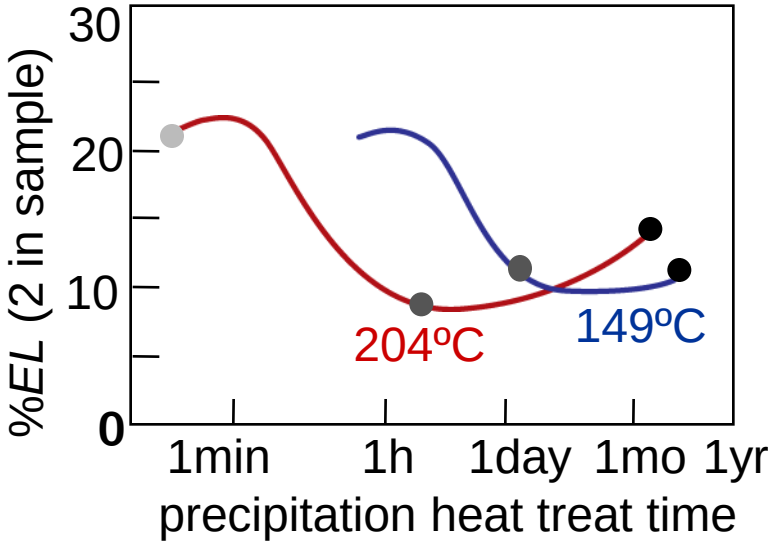
Microstructure of Al with fine precipitates

Influence of Precipitation Heat Treatment on *TS* & *%EL*

Example of Al Alloys:

- Maxima on *TS* curves w/ aging time yet min on EL% curve
- Increasing *T* accelerates precipitation hardening process
- Too long aging decreases strength again due to "over-ageing" or growth of precipitates





Adapted from Fig. 11.27, *Callister & Rethwisch 8e*. (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.)

Summary

- Ferrous alloys: steels and cast irons
- Non-ferrous alloys:
  -- Cu, Al, Ti, and Mg alloys; refractory alloys; and noble metals.
- Metal fabrication techniques:
  -- forming, casting, miscellaneous.
- Hardenability of metals
  -- measure of ability of a steel to be heat treated.
- Precipitation hardening
  --hardening & strengthening due to formation of
  precipitate particles.
  --Al, Mg alloys precipitation hardenable.