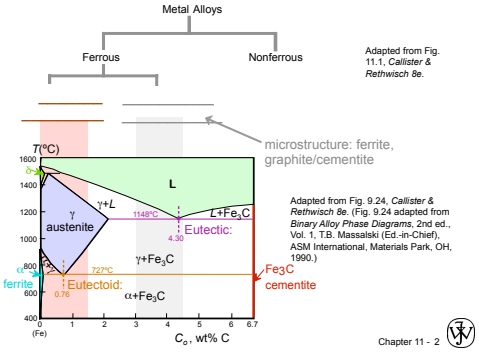
Chapter 11: Applications and Processing of Metal Alloys

ISSUES TO ADDRESS...

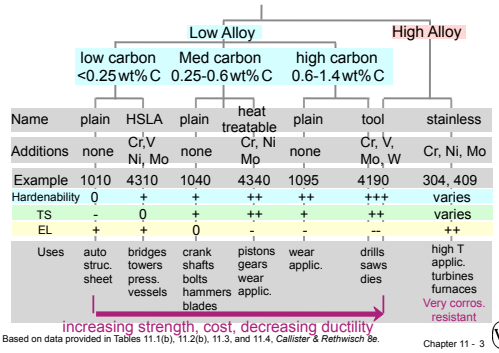
- How are metal alloys _____ and what are their common applications ?
- What are some of the common _____ techniques for _____?
- What heat treatment procedures are used to improve the mechanical properties of both _____ alloys?

Classification of Metal Alloys



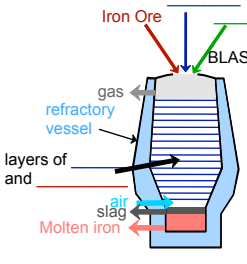
Adapted from Fig. 9.24, *Callister & Rethwisch 8e.* (Fig. 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

Steels



Based on data provided in Tables 11.1(b), 11.2(b), 11.3, and 11.4, *Callister & Rethwisch 8e.*

Refinement of Steel from Ore



heat generation

$C + O_2 \rightarrow CO_2$

reduction of iron ore to metal

$CO_2 + C \rightarrow 2CO$

$\rightarrow$ _____

purification

$CaCO_3 \rightarrow CaO + CO_2$

$CaO + SiO_2 + Al_2O_3 \rightarrow$ slag

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Ferrous Alloys

Iron-based alloys

- Steels
- Cast Irons

Nomenclature for steels (AISI/SAE)

10xx _____

11xx Plain Carbon Steels (resulfurized for machinability)

15xx Mn (1.00 - 1.65%)

40xx Mo (0.20 ~ 0.30%)

43xx Ni (1.65 - 2.00%), Cr (0.40 - 0.90%), Mo (0.20 - 0.30%)

44xx Mo (0.5%)

where xx is wt% C x 100

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

_____ >11% Cr

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Cast Irons

- Ferrous alloys with > _____
  - more _____
- Low melting – relatively easy to cast
- Generally brittle

- Cementite decomposes to _____ + _____

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

  - generally a slow process

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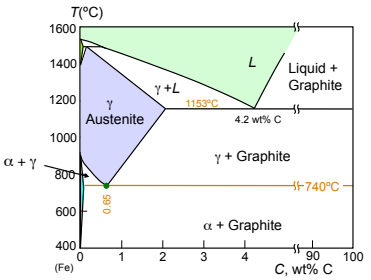
Fe-C True Equilibrium Diagram

Graphite formation promoted by

- _____
- _____



Adapted from Fig. 11.2, *Callister & Rethwisch 8e.* [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

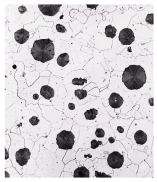
_____ iron

- _____
- weak & brittle in tension
- stronger in compression
- excellent _____ dampening
- wear resistant

Adapted from Fig. 11.3(a) & (b), *Callister & Rethwisch 8e.*

_____ iron

- add Mg and/or Ce
- graphite as _____ not flakes
- matrix often pearlite – stronger but less ductile



Types of Cast Iron (cont.)

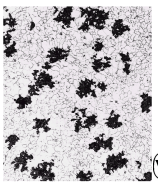
White iron

- < 1 wt% Si
- pearlite + _____
- very hard and _____

Adapted from Fig. 11.3(c) & (d), *Callister & Rethwisch 8e.*

_____ iron

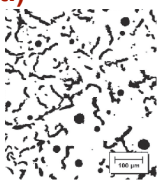
- heat treat white iron at 800-900°C
- graphite in _____
- reasonably strong and ductile



Types of Cast Iron (cont.)

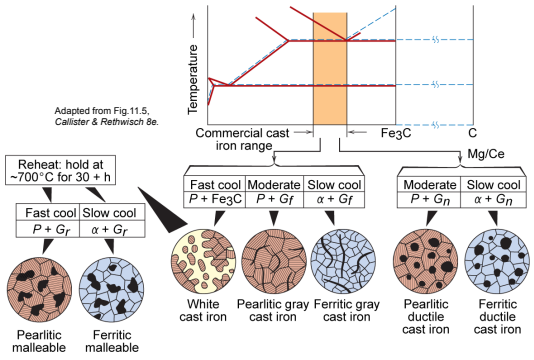
Compacted _____ iron

- relatively high _____
- good resistance to thermal shock
- lower oxidation at elevated temperatures



Adapted from Fig. 11.3(e), *Callister & Rethwisch 8e.*

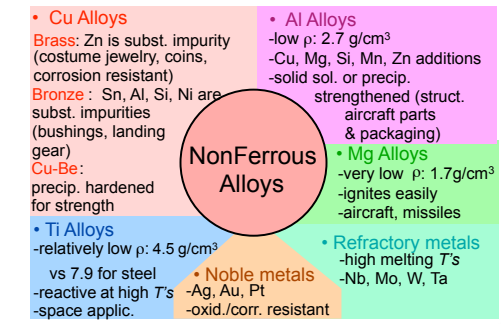
Production of Cast Irons



Limitations of Ferrous Alloys

1) Relatively high densities
2) Relatively low electrical conductivities
3) Generally poor corrosion resistance

Nonferrous Alloys



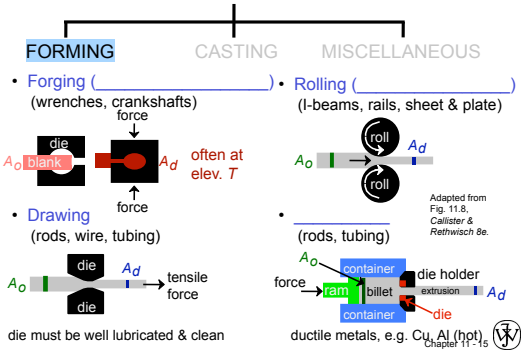
Based on discussion and data provided in Section 11.3, *Callister & Rethwisch 3e.*

Metal Fabrication

- How do we fabricate metals?
  - _____ - hammer (forged)
  - Cast molten metal into mold
- _____
  - Rough stock formed to final shape

Hot working	vs.	Cold working
• Deformation _____ high enough for _____		• Deformation below _____ temperature
• Large _____		• Strain hardening occurs • Small _____

Metal Fabrication Methods (i)



Metal Fabrication Methods (ii)

FORMING | CASTING | MISCELLANEOUS

- Casting- mold is filled with molten metal
  - _____, perhaps alloying elements added, then _____ in a mold
  - _____
  - gives good production of shapes
  - weaker products, internal defects
  - _____

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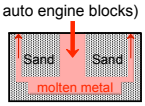
Metal Fabrication Methods (iii)

FORMING | CASTING | MISCELLANEOUS

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



- What material will withstand T >1600ºC and is _____ and easy to mold?
- Answer: _____!!!
- To create mold, pack _____ around form (pattern) of desired shape

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Metal Fabrication Methods (iv)

FORMING | CASTING | MISCELLANEOUS

- _____
  (low volume, complex shapes e.g., jewelry, turbine blades)
- Stage I — _____ formed by pouring _____ around wax pattern. Plaster allowed to harden.
- Stage II — Wax is melted and then poured from mold—hollow mold cavity remains.
- Stage III — _____ into mold and allowed to solidify.

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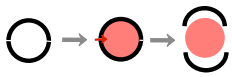
Metal Fabrication Methods (v)

FORMING | CASTING | MISCELLANEOUS

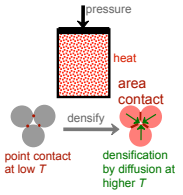
- Die Casting
  - -- high _____
  - -- for alloys having ____ melting temperatures
- Continuous Casting
  - -- _____ shapes (e.g., rectangular slabs, cylinders)



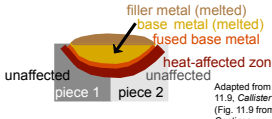
Metal Fabrication Methods (vi)

FORMING | CASTING | MISCELLANEOUS

- _____ (metals w/low ductilities)



- _____ (when fabrication of 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 _____ (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 stresses resulting from:
  - plastic deformation
  - _____ cooling
  - phase transform.
- _____ (steels): Make very soft steels for good machining. Heat just below $T_{eutectoid}$ & hold for 15-25 h.
- Full Anneal (steels): Make soft steels for good forming. Heat to get γ, then furnace-cool to obtain coarse pearlite.
- _____: Negate effects of cold working by (recovery/ recrystallization)
- _____(steels): Deform steel with large grains. Then heat treat to allow _____ and formation of smaller grains.

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

Heat Treatment Temperature-Time Paths

a) _____

b) _____

c) Tempering (Tempered Martensite)

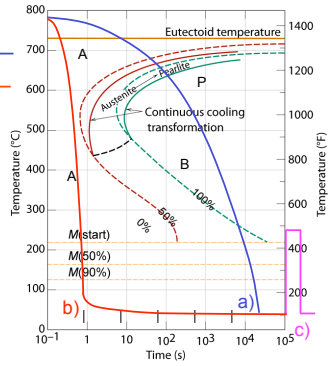
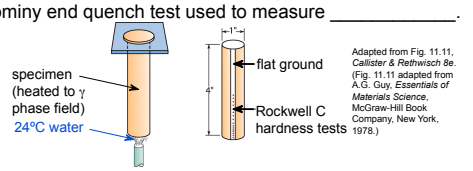


Fig. 10.25, *Callister & Rethwisch 8e.*

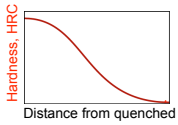
Hardenability -- Steels

- _____ – measure of the ability to form martensite
- Jominy end quench test used to measure _____.



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.)

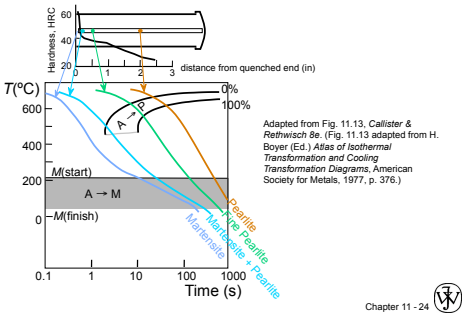
- Plot _____ versus distance from the quenched end.



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

Reason Why Hardness Changes with Distance

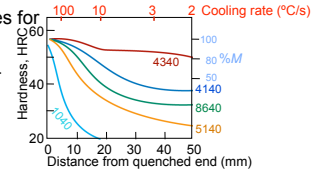
- The cooling rate _____ with distance from quenched end.



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.)

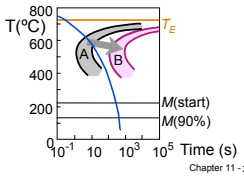
Hardenability vs Alloy Composition

- _____ curves for five alloys each with, C = _____



Adapted from Fig. 11.14, *Callister & Rethwisch 8e.* (Fig. 11.14 adapted from figure furnished courtesy Republic Steel Corporation.)

- "Alloy Steels" (4140, 4340, 5140, 8640)
  - -- contain Ni, Cr, Mo (0.2 to 2 wt%)
  - -- these _____ shift the "nose" to longer times (from A to B)
  - -- martensite is easier to form

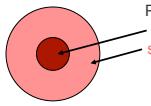


Influences of Quenching Medium & Specimen Geometry

- Effect of quenching medium:

Medium	Severity of Quench	Hardness
air	_____	_____
oil	_____	_____
water	_____	_____

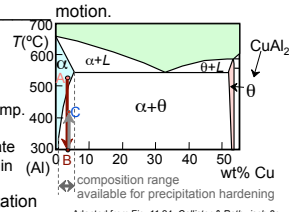
- Effect of specimen geometry:
  When surface area-to-volume ratio increases:
  - -- cooling rate throughout interior increases
  - -- hardness throughout interior increases



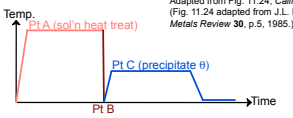
Position	Cooling rate	Hardness
center	low	low
surface	high	high

Precipitation Hardening

- Particles impede _____ motion.
- Ex: Al-Cu system
- Procedure:
  - --Pt A: _____ (get α solid solution)
  - --Pt B: _____ to room temp. (retain α solid solution)
  - --Pt C: _____ to nucleate small θ _____ within α phase.
- Other alloys that precipitation harden:
  - Cu-Be
  - Cu-Sn
  - Mg-Al



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



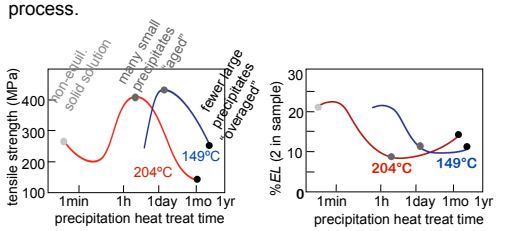
Adapted from Fig. 11.22, *Callister & Rethwisch 8e.*

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

• 2014 Al Alloy:

• _____ on *TS* curves.
• _____ *T* accelerates process.

• _____ on %*EL* curves.



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.
  -- increases with alloy content.
- Precipitation hardening
  --hardening, strengthening due to formation of precipitate particles.
  --Al, Mg alloys precipitation hardenable.