Chapter 11: Metal Alloys Applications and Processing

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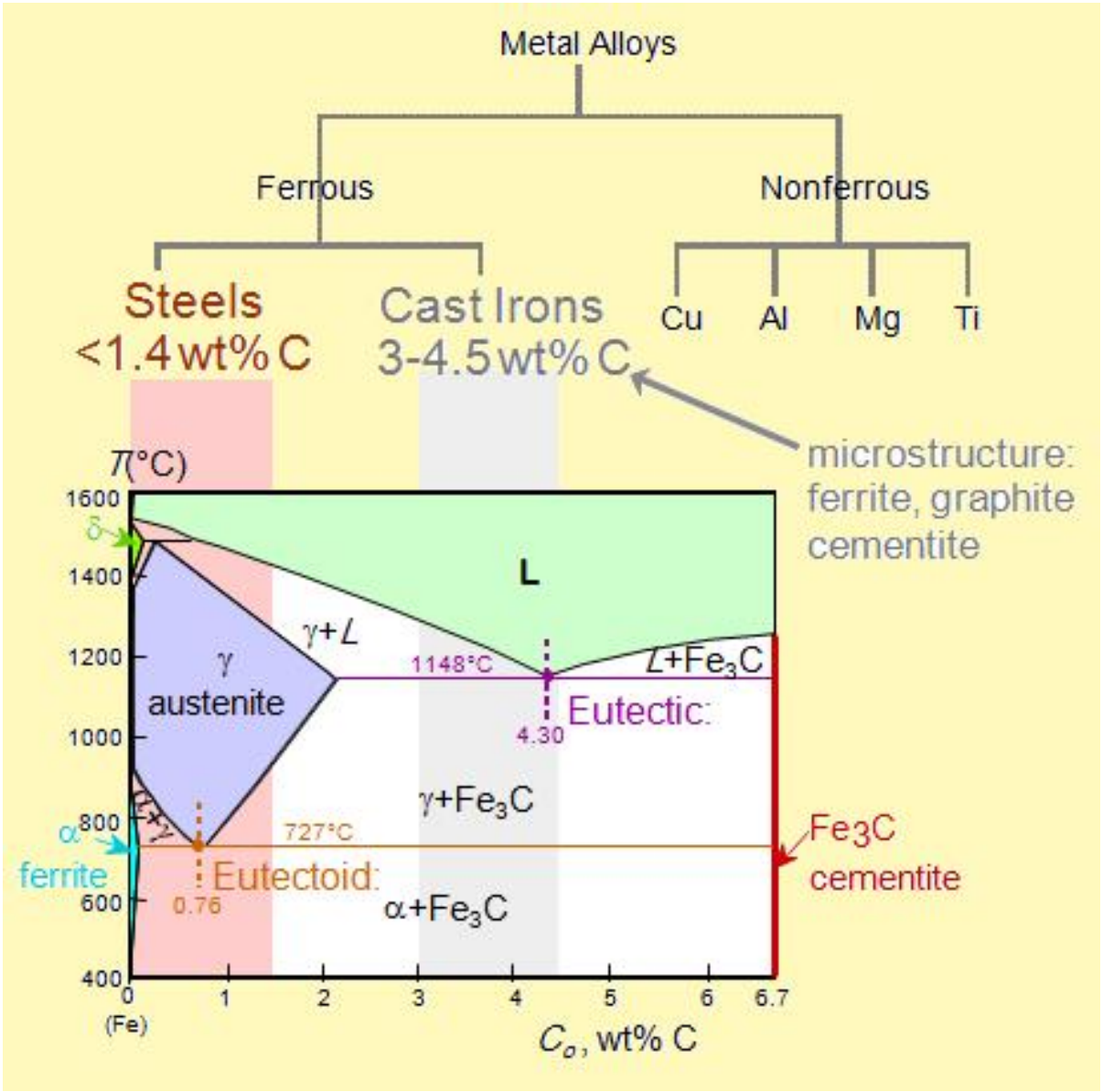
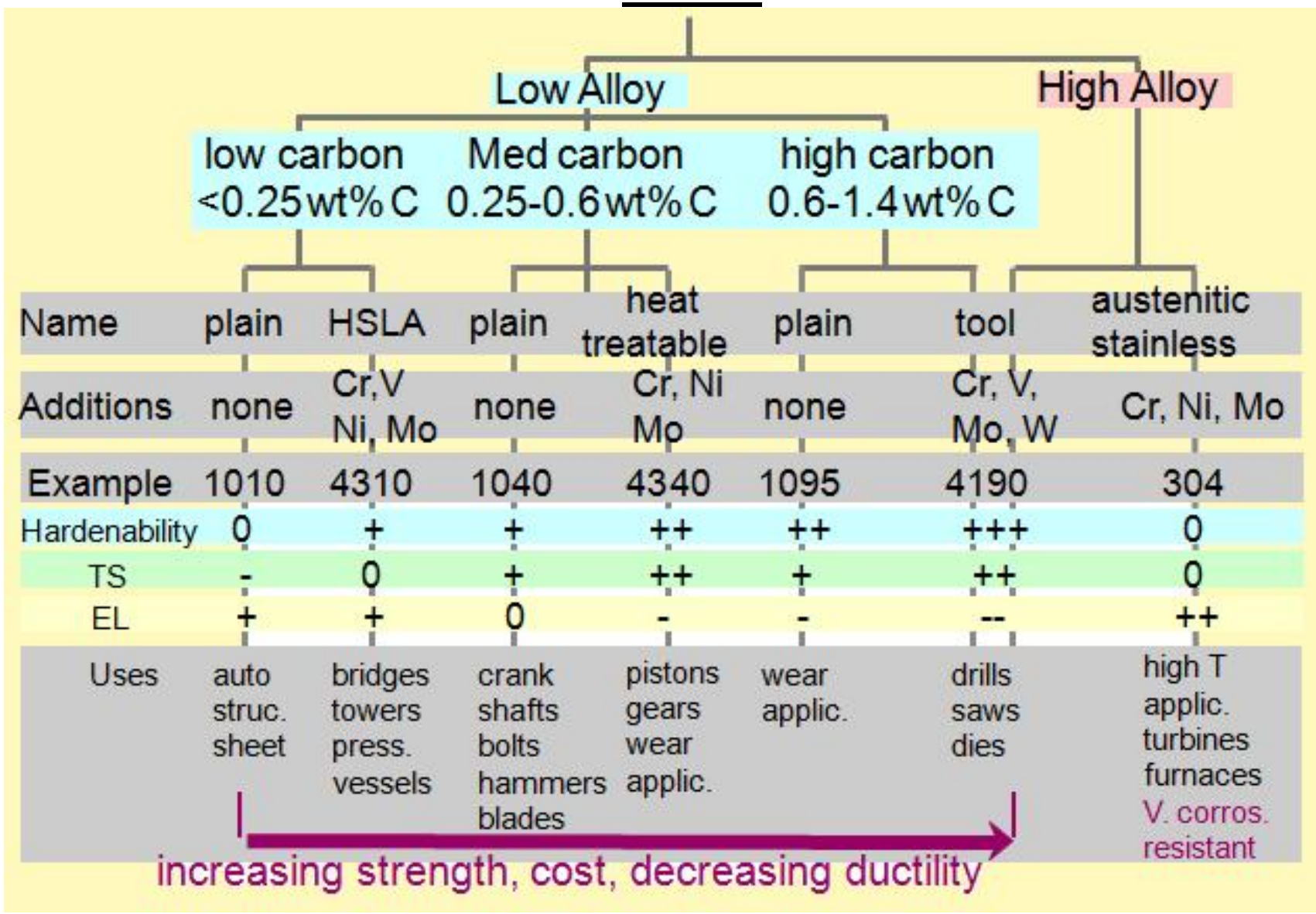
ISSUES TO ADDRESS...

- 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?

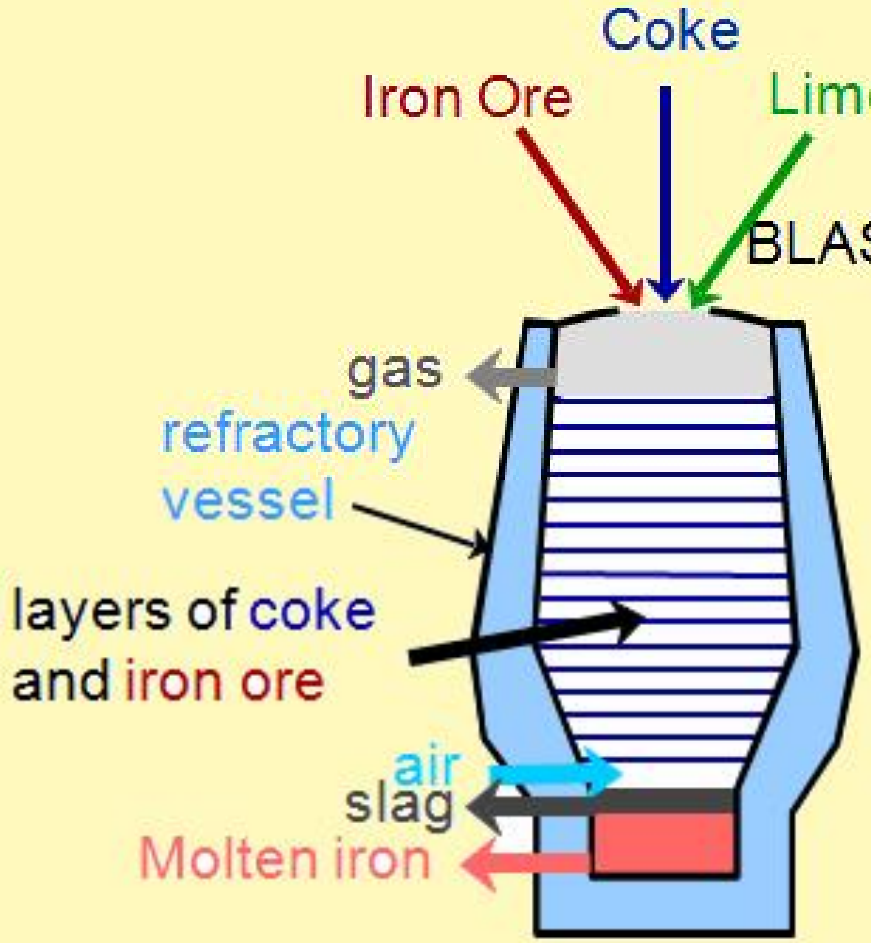
Definitions: Components and Phases



Steel


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

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

$$CaCO_3 \rightarrow CaO + CO_2$$

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

Ferrous Alloys

Iron containing – Steels - cast irons

Nomenclature AISI (American Iron and Steel Institute) & SAE (Society of Auotomotive Engineers)

- **10xx** Plain Carbon Steels
- **11xx** Plain Carbon Steels (resulfurized for machinability)
- **15xx** Mn (1.0 ~ 1.65%)
- **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

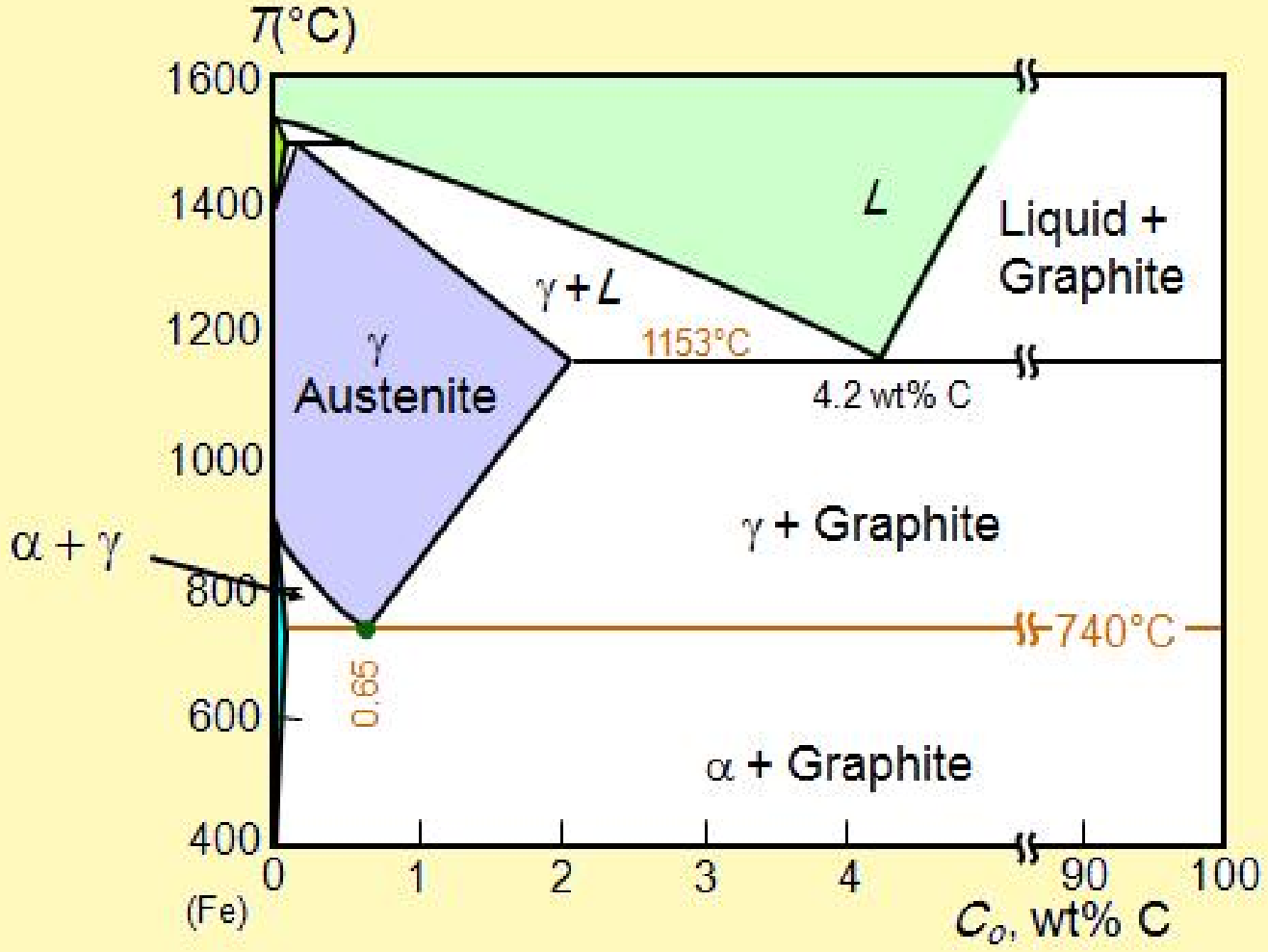
  $Fe_3C \rightarrow 3\ Fe\ (\alpha) + C\ (graphite)$

  - generally a slow process

Fe-C True Equilibrium Diagram

Graphite formation promoted by

- Si > 1 wt%
- slow cooling



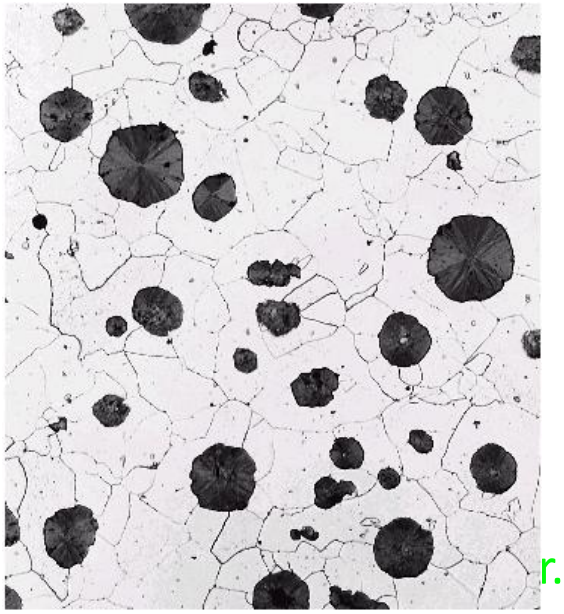
Types of Cast Iron

Gray iron (C, Si, Fe)

- graphite flakes.
- weak & brittle under tension
- stronger under compression
- excellent vibrational dampening
- wear resistant

Ductile iron

- add Mg or Ce (Cerium)
- graphite in nodules not flakes
- matrix often pearlite - better ductility



Types of Cast Iron

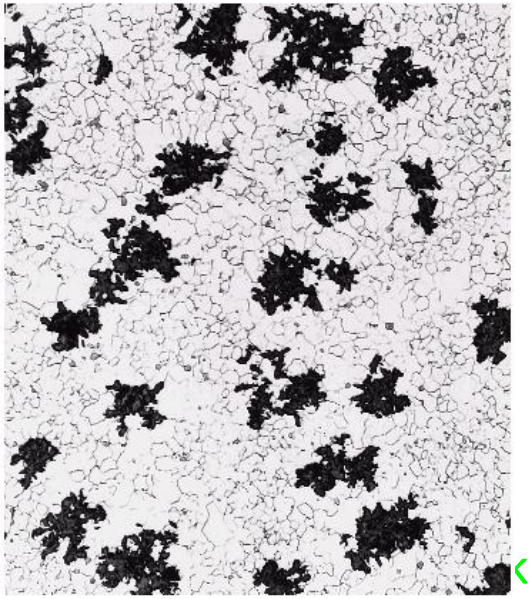
White iron

- <1 wt % Si so harder but brittle

more cementite

Malleable iron

- Starts as a white iron casting then heat treated at 800-900^{o}C
- graphite separates out slowly
- more ductile

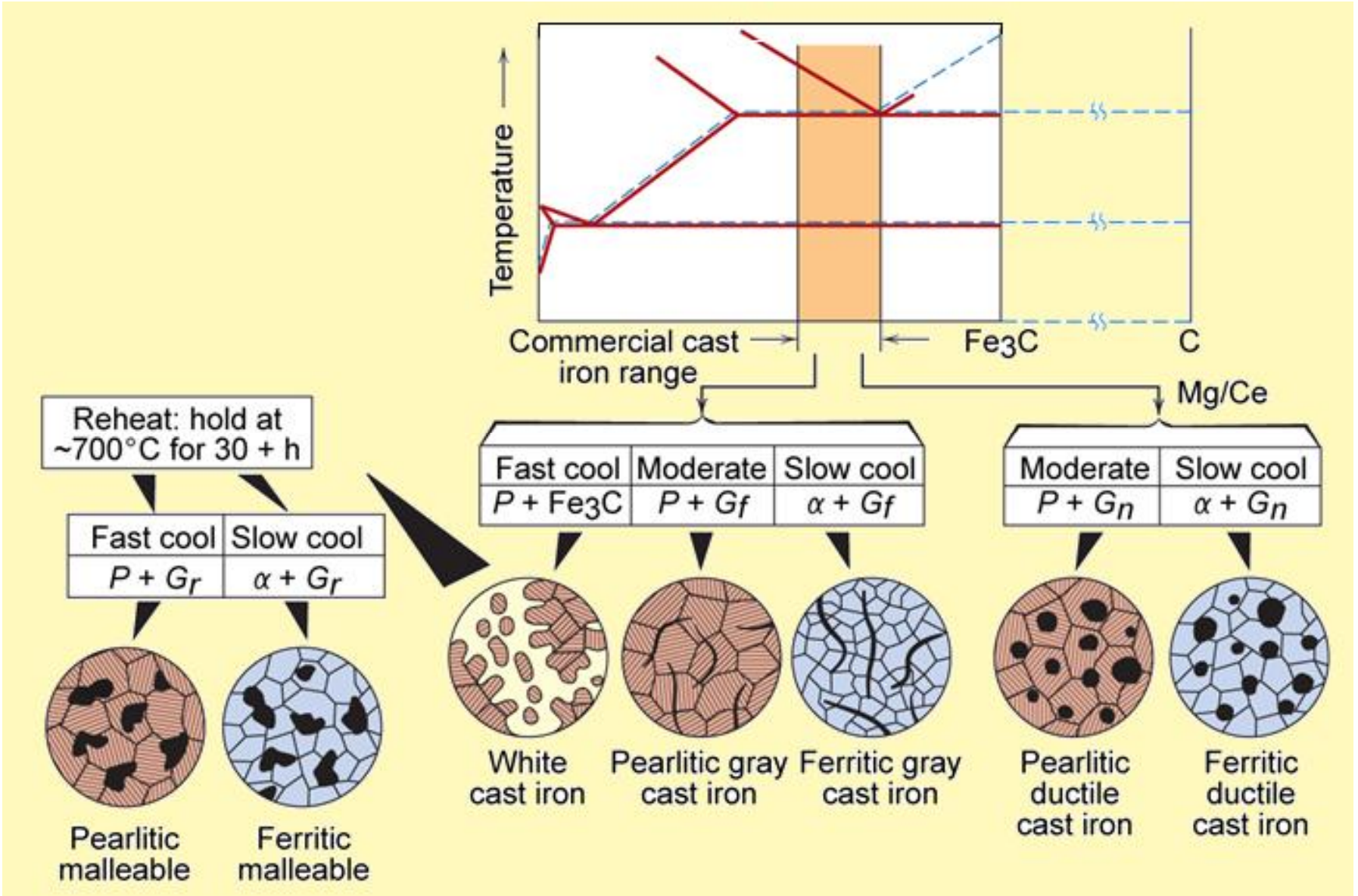


Production of Cast Iron

Comparative qualities of cast irons[1]

Name	Nominal composition [% by weight]	Form and condition	Yield strength [ksi (0.2% offset)]	Tensile strength [ksi]	Elongation [% (in 2 inches)]	Hardness [Brinell scale]	Uses
Cast grey iron (ASTM A48)	C 3.4, Si 1.8, Mn 0.5	Cast	—	25	0.5	180	Engine blocks, fly-wheels, gears, machine-tool bases
White	C 3.4, Si 0.7, Mn 0.6	Cast (as cast)	—	25	0	450	Bearing surfaces
Malleable iron (ASTM A47)	C 2.5, Si 1.0, Mn 0.55	Cast (annealed)	33	52	12	130	Axle bearings, track wheels, automotive crankshafts
Ductile or nodular iron	C 3.4, P 0.1, Mn 0.4, Ni 1.0, Mg 0.06	Cast	53	70	18	170	Gears, cams, crankshafts
Ductile or nodular iron (ASTM A339)	—	Cast (quench tempered)	108	135	5	310	—
Ni-hard type 2	C 2.7, Si 0.6, Mn 0.5, Ni 4.5, Cr 2.0	Sand-cast	—	55	–	550	Strength
Ni-resist type 2	C 3.0, Si 2.0, Mn 1.0, Ni 20.0, Cr 2.5	Cast	—	27	2	140	Resistance to heat and corrosion

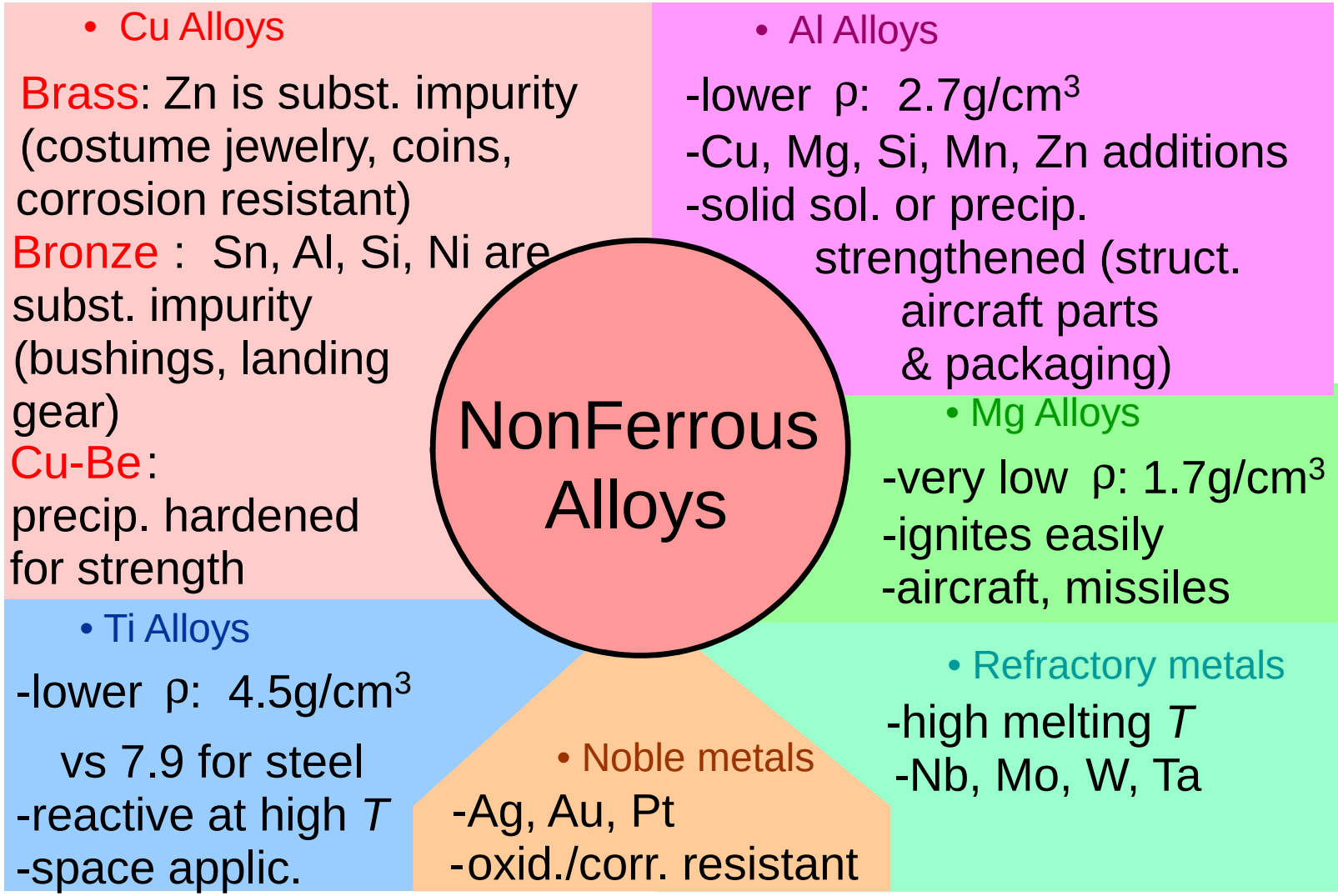
Production of Cast Iron



Limitations of Ferrous Alloys

1) Relatively high density
2) Relatively low conductivity
3) Poor corrosion resistance

Nonferrous Alloys



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

Metal Fabrication

1. Forming
2. Casting
3. Joining

Metal Fabrication

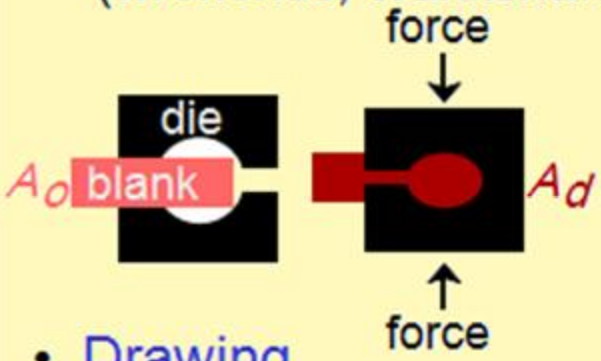
1. Forming Operations
   - Rough stock formed to final shape

Hot working	vs.	**Cold working**
• *T* high enough for recrystallization		• well below T_m • work hardening
• Larger deformations		• smaller deformations

Metal Fabrication Methods - I

FORMING | CASTING | JOINING

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

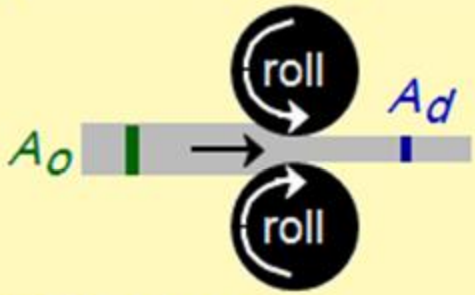


often at elev. T

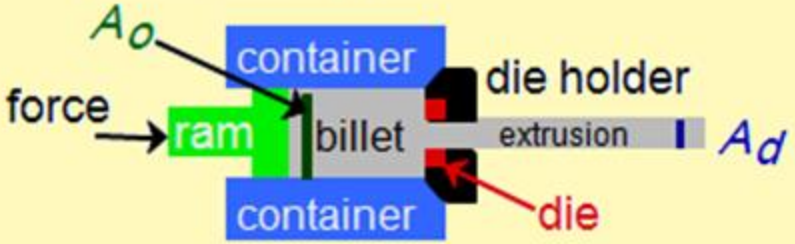
- Drawing
  (rods, wire, tubing)

die must be well lubricated & clean

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

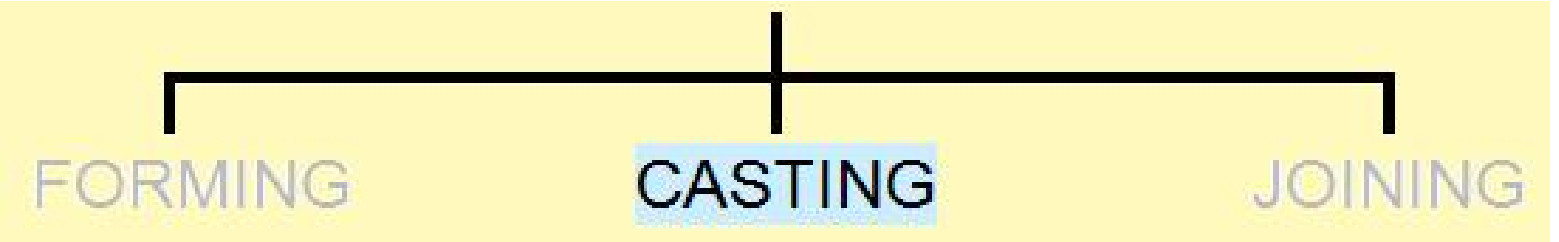


- Extrusion
  (rods, tubing)



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

Metal Fabrication Methods - II

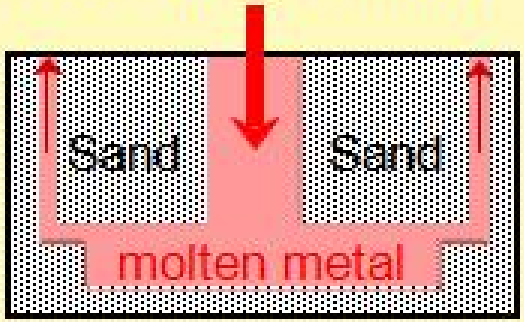


- **Casting**- mold is filled with metal
  - metal melted in furnace, perhaps alloying elements added. Then cast in a mold
  - most common, cheapest method
  - gives good production of shapes
  - weaker products, internal defects
  - good option for brittle materials

Metal Fabrication Methods - II

FORMING | **CASTING** | JOINING

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



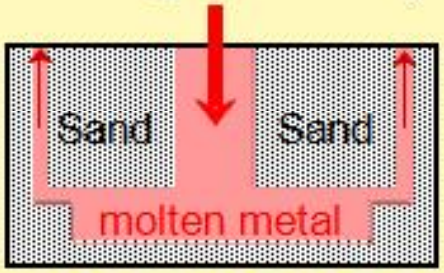
- trying to hold something that is hot
- what will withstand >1600°C?
- cheap - easy to mold => sand!!!
- pack sand around form (pattern) of desired shape

Metal Fabrication Methods - II

FORMING | CASTING | JOINING

- Sand Casting

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



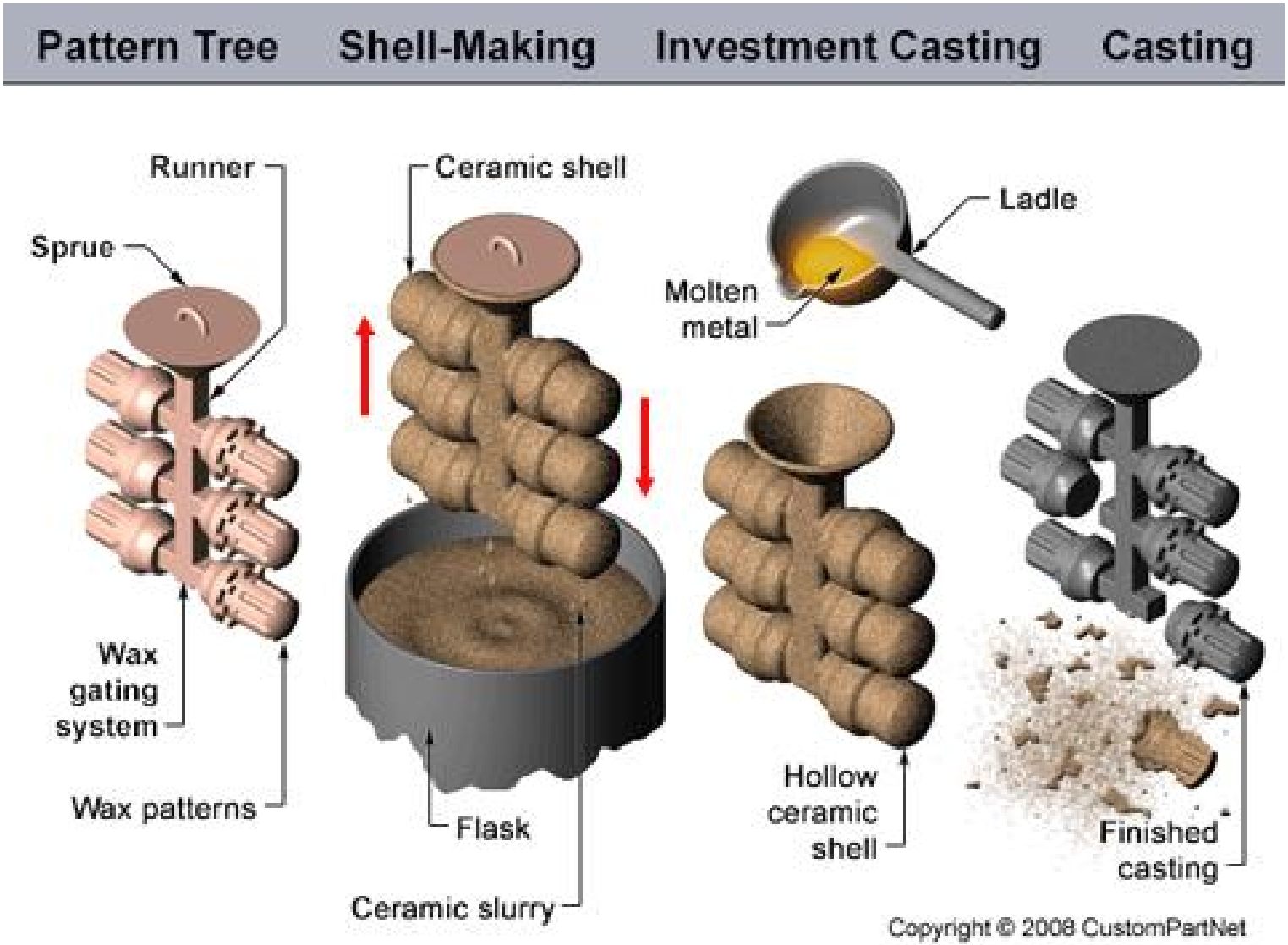
- Investment Casting

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

Investment Casting

- pattern is made from paraffin.
- mold made by encasing in plaster of paris
- melt the wax & the hollow mold is left
- pour in metal

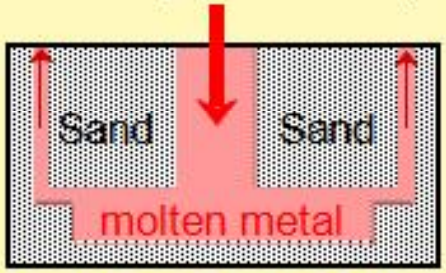
Metal Fabrication Methods - II



Metal Fabrication Methods - II

FORMING | CASTING | JOINING

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



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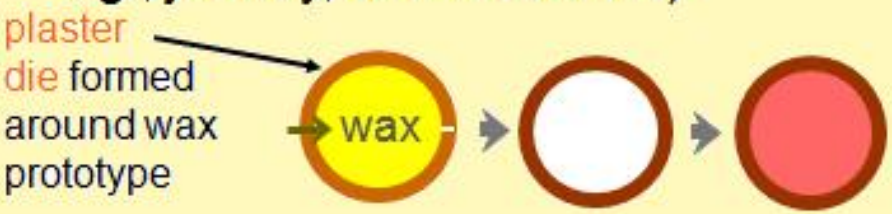
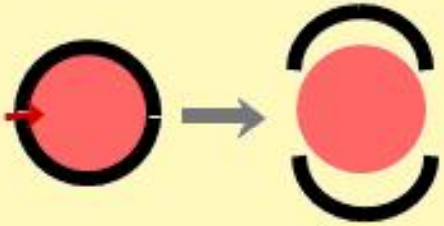


- Die Casting
  (high volume, low T alloys)

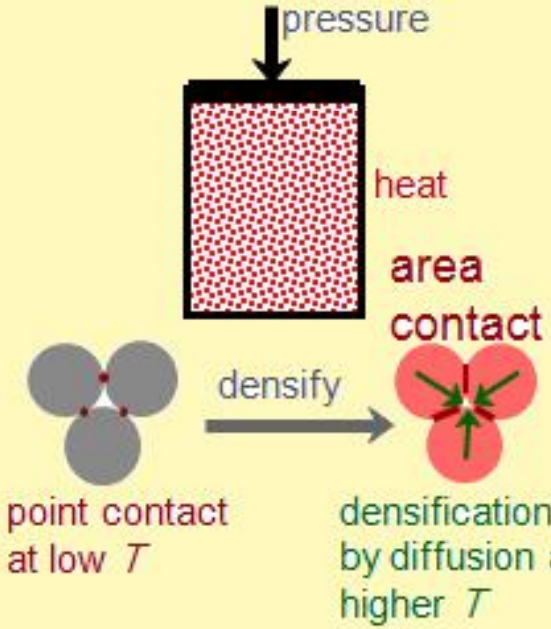


- Continuous Casting
  (simple slab shapes)

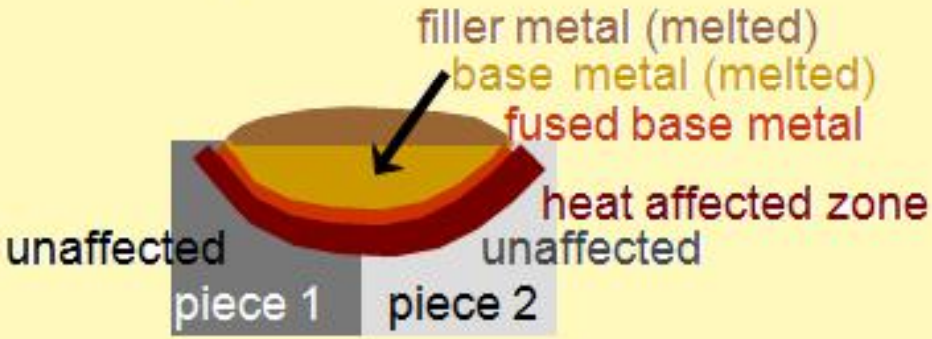
Metal Fabrication Methods - III

FORMING | CASTING | JOINING

- Powder Metallurgy
  (materials w/low ductility)



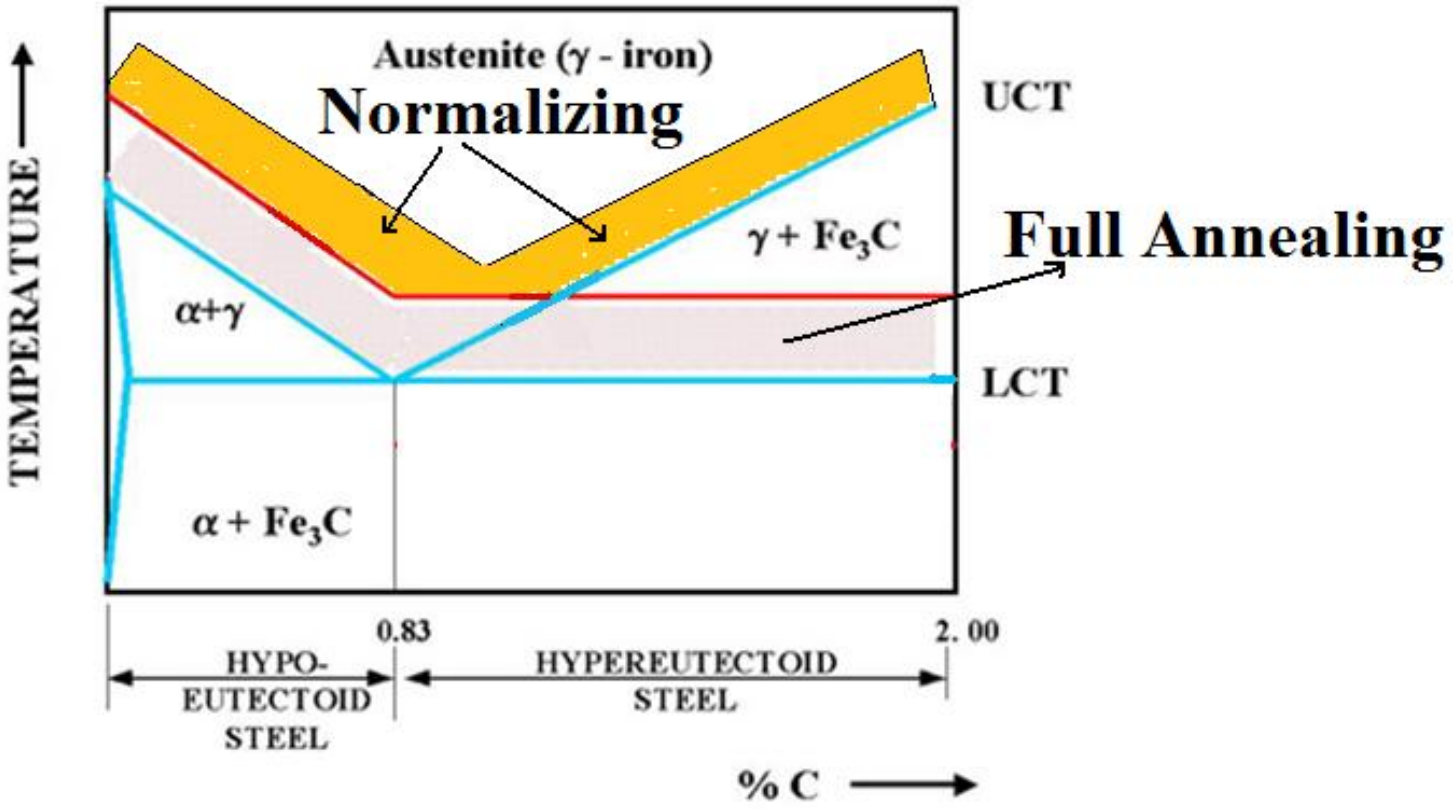
- Welding
  (when one large part is impractical)



- Heat affected zone:
  (region in which the microstructure has been changed).

Thermal Processing of Metals Metal

- Annealing occurs by the **diffusion** of atoms within a solid material, so that the material progresses towards its **equilibrium state**.



Thermal Processing of Metals

- There are three stages in the annealing process:
  1. **Recovery phase**, which results in softening of the metal through removal of crystal defects.
  2. **Recrystallization**, where new strain-free grains nucleate and grow to replace those deformed by internal stresses.
  3. **Grain growth**, in which the microstructure starts to coarsen and may cause the metal to have less than satisfactory mechanical properties.

Types of Annealing

1) Normalization

- Normalization is an annealing process in which a metal is cooled in air after heating.
- It involves heating the steel to just above its upper critical point.
- It is soaked for a short period then allowed to cool in air.
- It is typically confined to hardenable steel.
- It is used to refine grains which have been deformed through cold work.
- Can improve ductility and toughness of the steel.
- Small grains are formed which give a much harder and tougher metal with normal tensile strength and not the maximum ductility achieved by annealing.

2) Process annealing

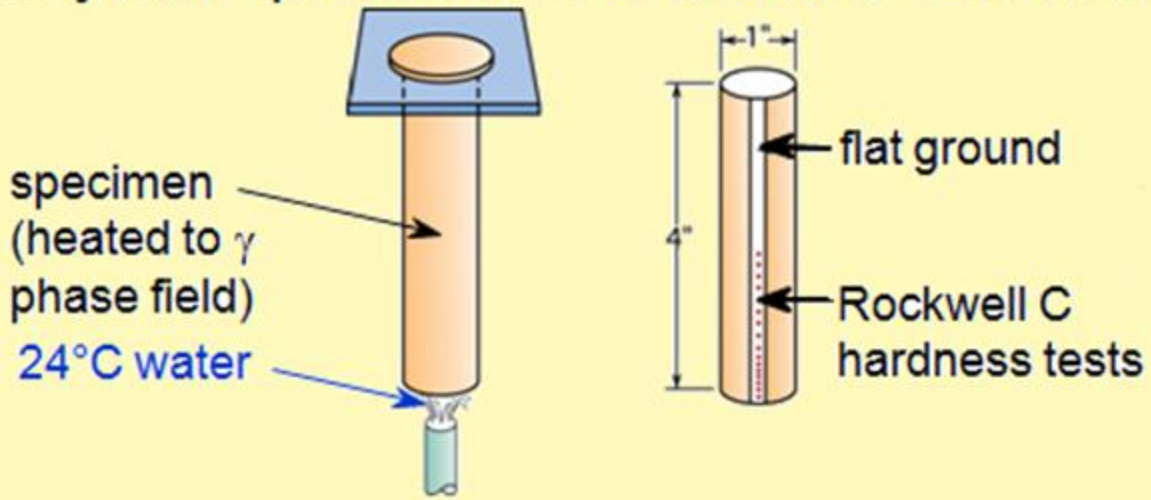
- Process annealing, also called "intermediate annealing", "subcritical annealing", or "in-process annealing", is a heat treatment cycle that restores some of the ductility to a work piece allowing it be worked further without breaking.
- Ductility is important in shaping and creating a more refined piece of work through processes such as rolling, drawing, and extruding.
- The piece is heated to a temperature typically below the austenizing temperature, and held there for long enough to relieve stresses in the metal.
- The piece is finally cooled slowly in to room temperature.
- The temperature ranges from 500 °F to 1400 °F, depending on the alloy in question.

3) Full annealing

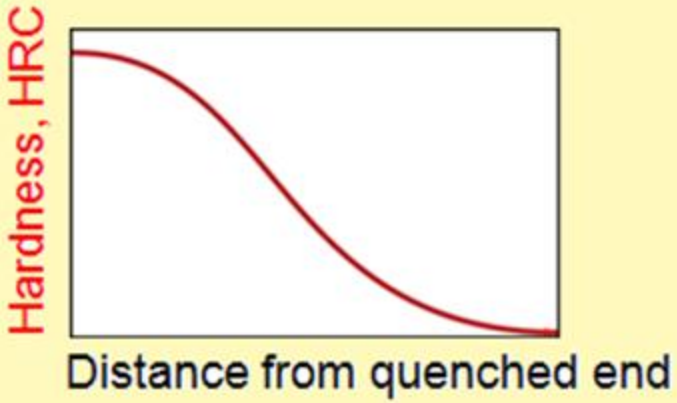
- Full annealing is accomplished by heating a hypoeutectoid steel to a temperature above (50°C) the UCT (Upper Critical Temperature). For hypereutectoid steel the sample should be heated to a temperature above the LUC.
- It is then cooled in the furnace very slowly to room temperature.
- The formation of austenite destroys all structures that have existed before heating.
- Slow cooling yields the original phases of ferrite and pearlite.

Hardenability-Steels

- Ability to form martensite very hard form of steel crytalline structure
- Jominy end quench test to measure hardenability.

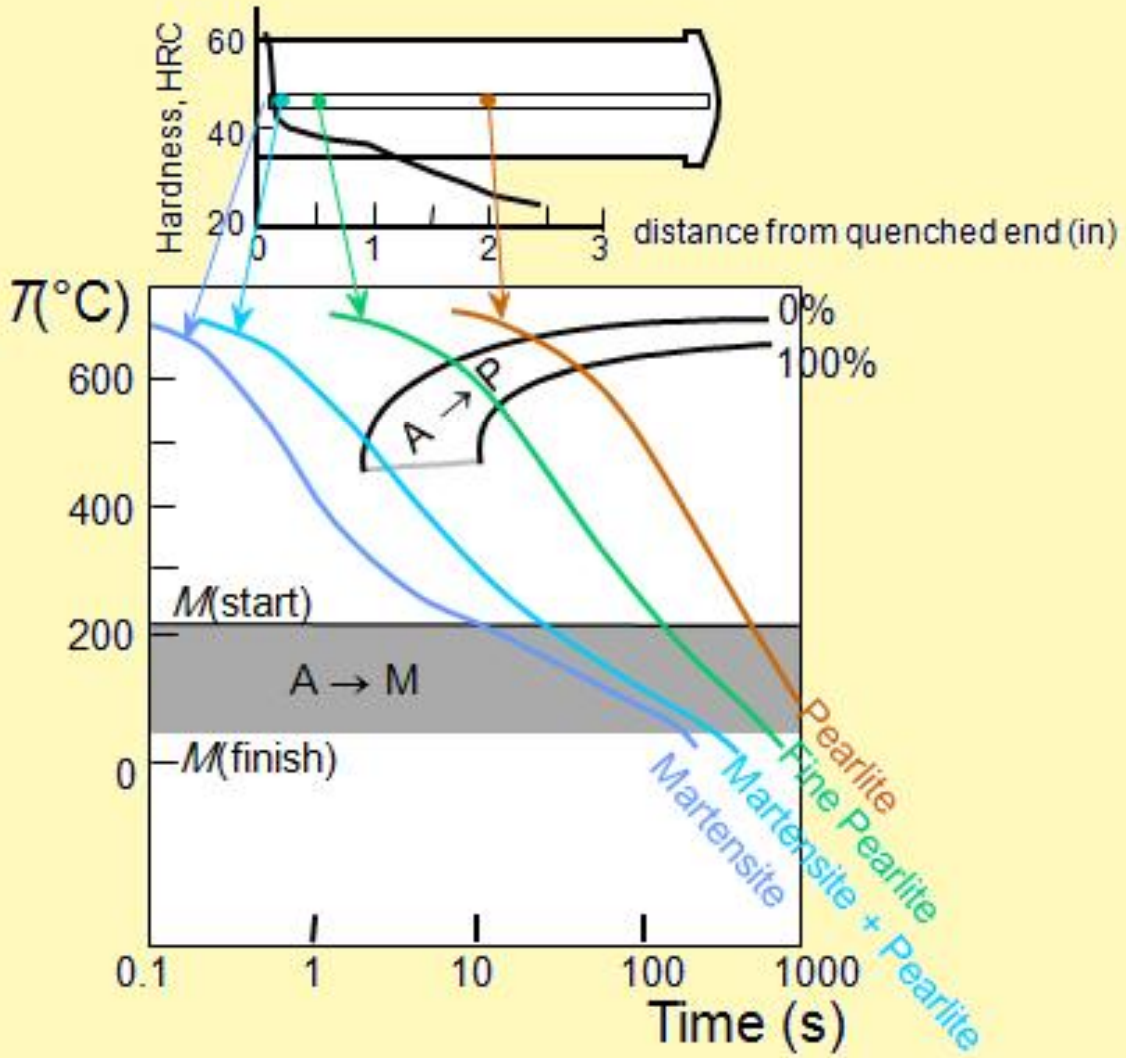


- Hardness versus distance from the quenched end.



Why Hardness Changes W/Position

- The cooling rate varies with position.



Quenching Medium & Geometry

- Effect of quenching medium:

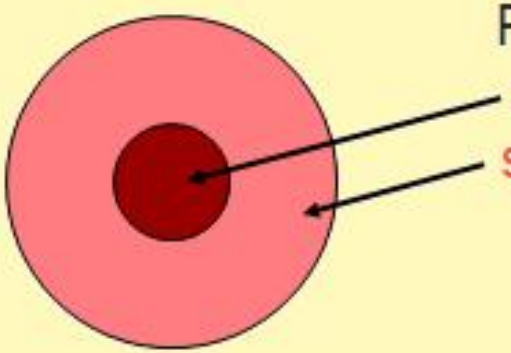
Medium	Severity of Quench	Hardness
air	low	low
oil	moderate	moderate
water	high	high

- Effect of geometry:

  When surface-to-volume ratio increases:

  --cooling rate increases

  --hardness increases



Position	Cooling rate	Hardness
center	low	low
surface	high	high