Chapter 11: Applications and Processing of Metal Alloys

ISSUES TO ADDRESS...

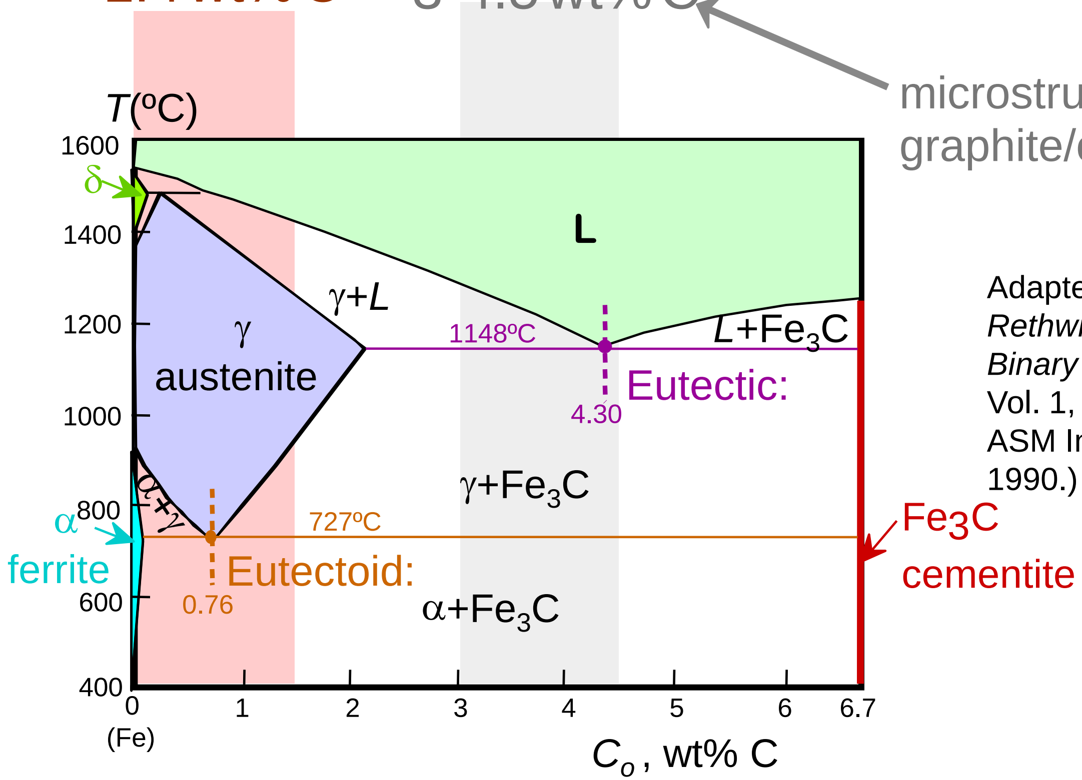
- How are metal alloys classified and what are their common applications?
- What are some of the common fabrication techniques for metals?
- What heat treatment procedures are used to improve the mechanical properties of both ferrous and nonferrous alloys?

Classification of Metal Alloys

Metal Alloys

- Ferrous
  - Steels: <1.4 wt% C
  - Cast Irons: 3-4.5 wt% C — microstructure: ferrite, graphite/cementite
- Nonferrous

Adapted from Fig. 11.1, *Callister & Rethwisch 8e.*



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.)

Ferrous Alloys

Iron-based alloys

- Steels
- Cast Irons

Nomenclature for steels (AISI/SAE)

10xx Plain Carbon Steels

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

Stainless Steel >11% Cr

Steels

Greatest quantity → low carbon

	Low Alloy						High Alloy
	low carbon <0.25 wt% C		Medium carbon 0.25-0.6 wt% C		high carbon 0.6-1.4 wt% C		
Name	plain	HSLA	plain	heat treatable	plain	tool	stainless
Additions	none	Cr,V Ni, Mo	none	Cr, Ni Mo	none	Cr, V, Mo, W	Cr, Ni, Mo
Example	1010	A440	1040	4340	1095	4190	304, 409
Hardenability	0	+	+	++	++	+++	varies
TS (MPa)	180	290	605-780	980-1960	760-1280		varies
EL(%)	28	21	33-19	21-11	26-10		++
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 Very 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 & Rethwisch 8e.*

Low Carbon Steel

- **Carbon content: 0-0.25wt%**
- **Cannot be heat treated to form martensite phase, which are very hard**
- **Properties:**
  - **Relatively soft, weak**
  - **Ductile**
  - **Machinable, weldable**
  - **Low cost**
- **Applications**
  - **Pipelines,**
  - **Tin cans,**
  - **Buildings**

http://www.ansonsteels.com/Low-carbon-steel-from-anson-steel.html

http://www.wisegeek.com/what-are-the-different-uses-of-low-carbon-steel.htm

https://en.wikipedia.org/wiki/Tin_can

High Strength Low Alloy (HSLA) Steel

- Carbon content: 0-0.25wt%
- With alloying elements (Cu, Ni, V, Mo, etc.) to strengthen them
- Can be heat treated to improve mechanical strength somewhat
- Properties
  - More corrosion resistant than low carbon steel
  - Applications
  - Bridges,
  - Buildings
  - Pressure vessels

https://www.chapelsteel.com/A588.html

http://www.imoa.info/molybdenum-uses/molybdenum-grade-alloy-steels-irons/high-strength-low-alloy-steel.php

http://www.hsla-v.org/hsla_video_blast.php

Medium Carbon Steel

- Carbon content: 0.25-0.60 wt% C
- Can be heat treated (from Austenite to Martensite phase) to improve strength and hardness
- Can be alloyed to further improve heat treatment property (i.e., to control microstructure)
- Properties
  - Stronger and harder than low carbon steel
  - Good wear resistance
  - Lower ductility
- Applications
  - Railway wheels and tracks
  - Crank and shafts

http://yu-jei.com.tw/ARCW.html

High Carbon Steel

- Carbon content: 0.60-1.40 wt% C
- Can be heat treated (from Austenite to Martensite phase)
- Can be alloyed to further improve hardness etc.
- Properties
  - Strongest and hardest
  - Good wear resistance
  - Lower ductility
- Applications
  - Cutting and machining tools: knives, razors, saw blades
  - Crankshafts

http://www.dx.com/p/high-carbon-steel-round-shank-woodworking-lip-spur-drill-bit-set-silver-black-369121#.WNAs1k2rOcw

http://www.echefknife.com/blog/high-carbon-steel-white-blue-super/

http://www.tatasteeleurope.com/en/products-and-services/flat/narrow-strip/carbon/carbon

Stainless Steel

- Primary alloying element Cr: at least 11 wt.%, together with other alloying elements (e.g., Ni, W, etc.)
- Structure varies
- Properties
  - Significantly improved corrosion resistance over carbon steel
  - Wide range of mechanical properties
- Applications
  - Pipes/tubings
  - Chemical production reaction vessels
  - Marine applications
  - Jet engine parts

Cast Irons

- Ferrous alloys with > 2.1 wt% C
  - more commonly 3 - 4.5 wt% C
- Low melting – easy to cast
- Generally low cost
- Mechanical property varies

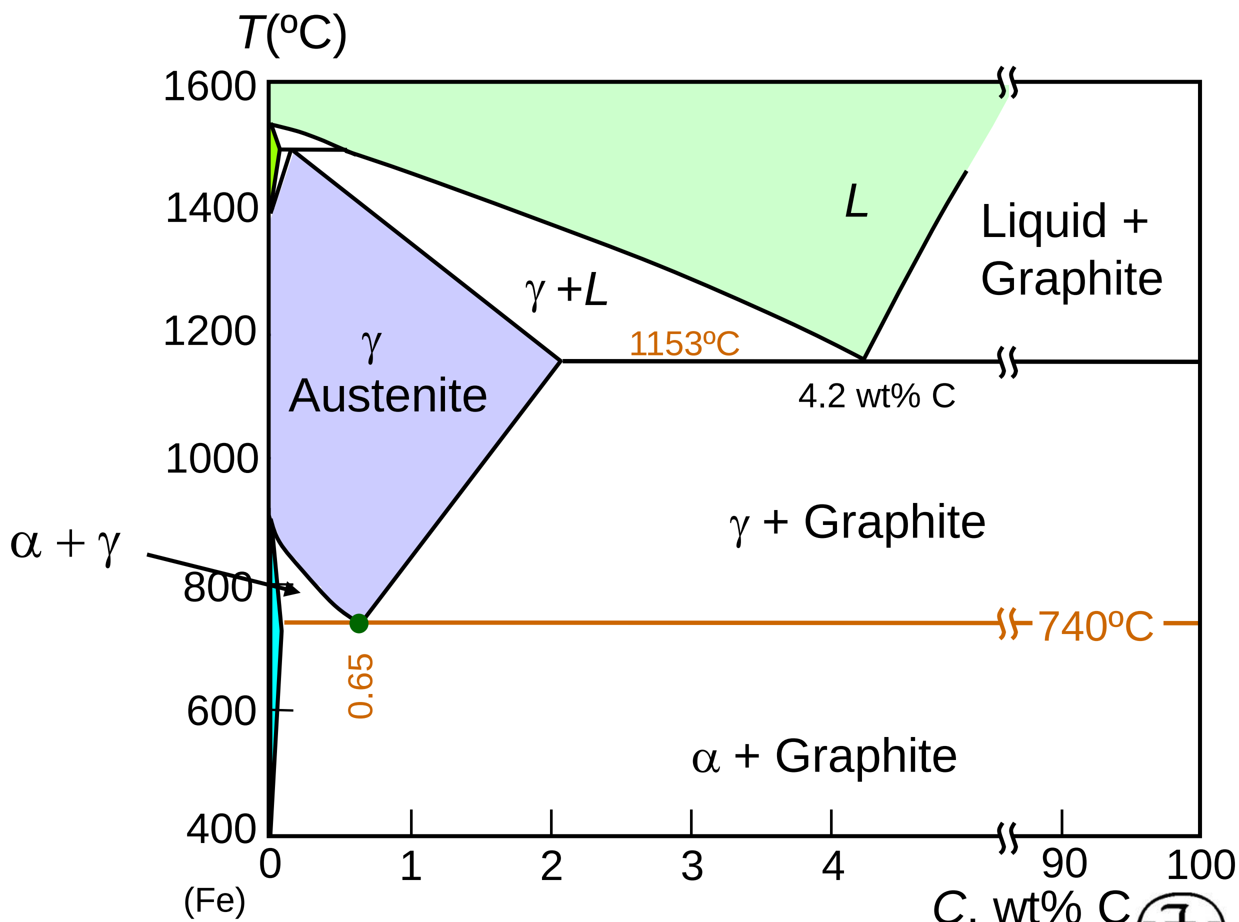
Fe-C (True) Equilibrium Diagram

Fe3C cementite decomposes to ferrite + graphite over long period of time at elevated temperature:

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

Graphite formation promoted by

- Si > 1 wt%
- Slow cooling



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

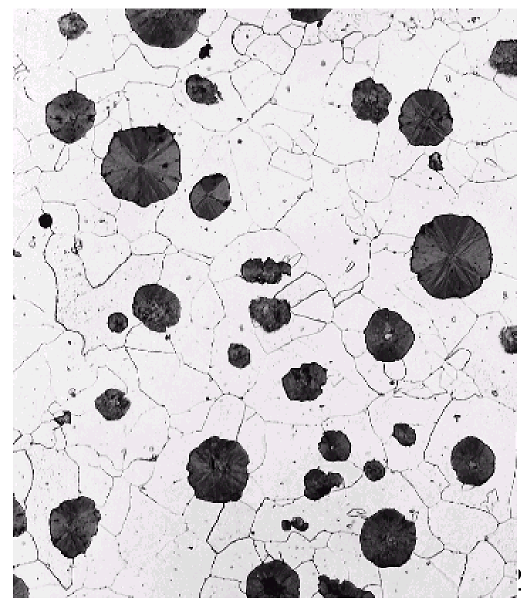
Cast iron - iron with 3-4.5wt% of carbon

Gray iron

- Graphite in flake shape
- Weak & brittle in tension due to sharp tips of graphite phase associated with **many micro-cracks**
- Excellent vibrational **dampening**
- Use for heavy equipment base
- Very low cost

Ductile (or Nodular) iron

- Add Mg and/or Ce
- Graphite in nodule shape
- Matrix often stronger
- Use for valves, pump bodies …



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

Types of Cast Iron (cont.)

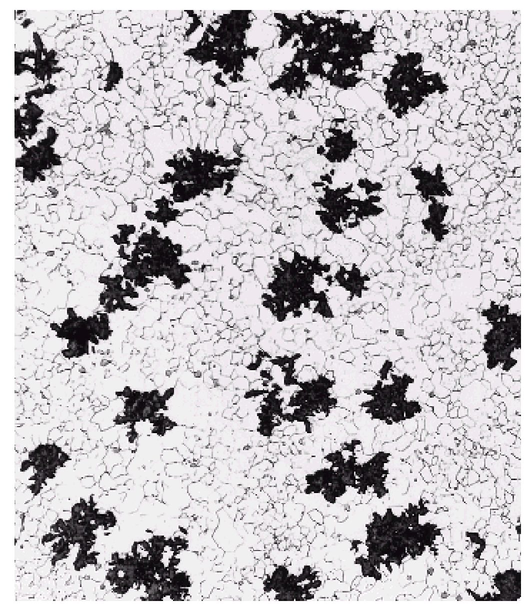
White iron

- < 1 wt% Si
- Carbon exists as cementite (Fe3C)
- Very hard and brittle
- Only as **intermediate** in processing

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

Malleable iron

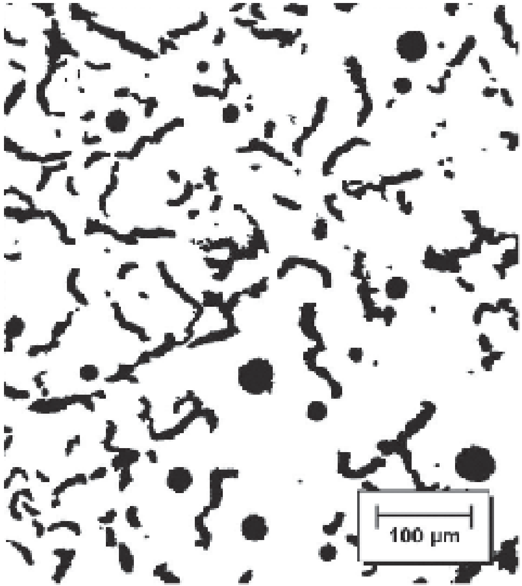
- Heat treat white iron at 800-900ºC
- Graphite in rosettes or clusters
- Reasonably strong and ductile



Types of Cast Iron (cont.)

Compacted graphite iron

- Relatively high thermal conductivity
- Good resistance to thermal shock
- Lower oxidation at elevated temperatures
- Use for diesel engine blocks, exhaust manifolds, etc.

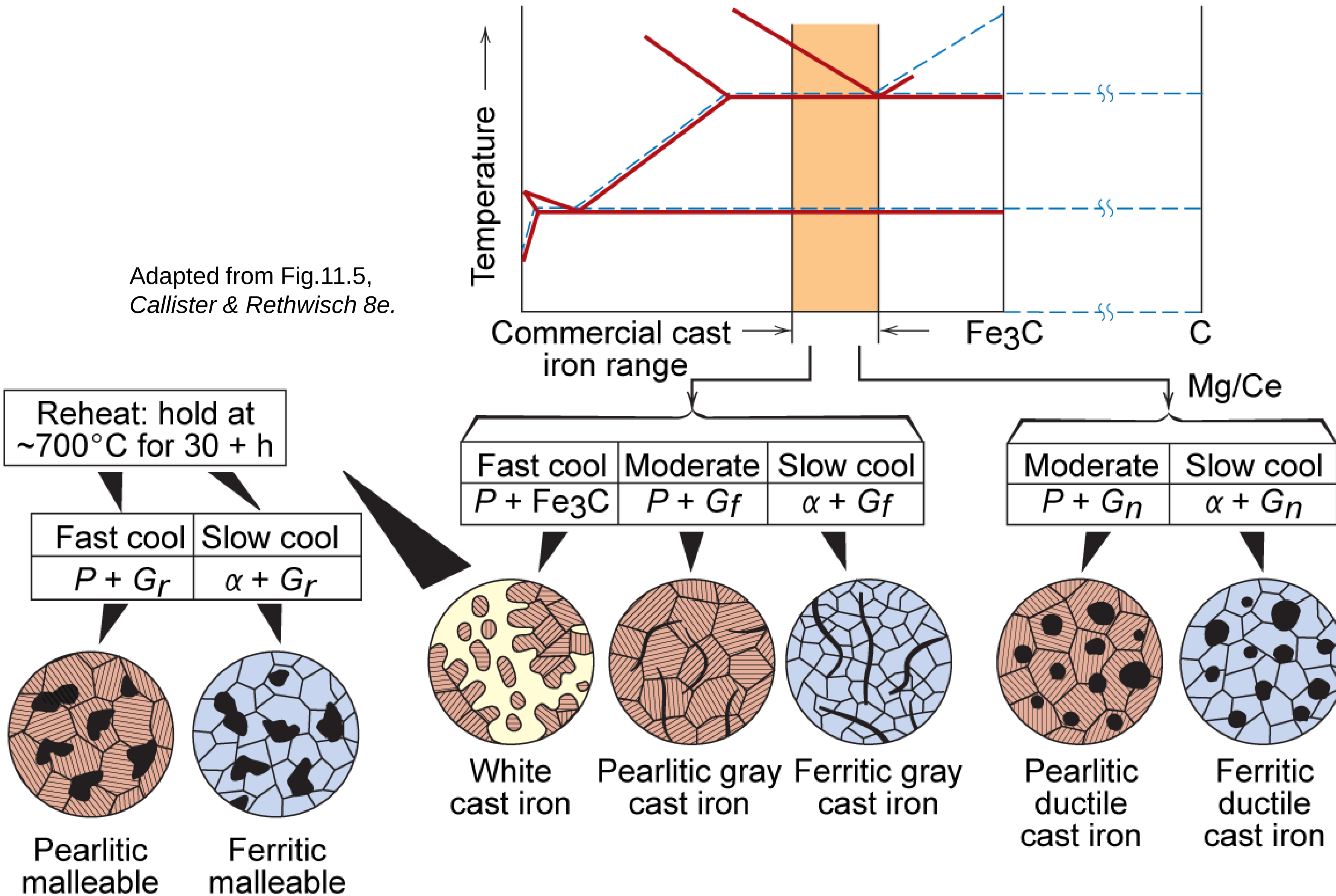


Adapted from Fig. 11.3(e), *Callister & Rethwisch 8e.*

Take-home Message

For iron/steel, even for the same composition, different processing leads to different microstructures (e.g., cementite or graphite shape and distribution), which then influences strongly mechanical properties and their application.

Production of Cast Irons



Adapted from Fig.11.5, *Callister & Rethwisch 8e.*

Limitations of Ferrous Alloys (other than stainless steel)

1) Relatively high densities
2) Relatively low electrical conductivities
3) Generally poor corrosion resistance
    - For **stainless steel**, significant Cr (>10 at.%) and other elements such as Ni, W, etc. added to improve corrosion resistance

Nonferrous Alloys

NonFerrous Alloys

- **Cu Alloys**

Brass: Zn is subst. impurity (costume jewelry, coins, corrosion resistant)

Bronze : Sn, Al, Si, Ni are subst. impurities (bushings, landing gear)

Cu-Be: precip. hardened for strength

- **Al Alloys**

-low ρ: 2.7 g/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**

-relatively low ρ: 4.5 g/cm^3 vs 7.9 for steel

-reactive at high *T's*

-space applic.

- **Noble metals**

-Ag, Au, Pt

-oxid./corr. resistant

- **Refractory metals**

-high melting *T's*

-Nb, Mo, W, Ta

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

Summary

- Ferrous alloys: steels and cast irons
- Non-ferrous alloys:
  -- Cu, Al, Ti, and Mg alloys; refractory alloys; and noble metals.
- Hardenability of metals
  -- measure of ability of a steel to be heat treated to improve mechanical strength
  -- increases with alloy content.
- Precipitation hardening
  --hardening, strengthening due to formation of precipitate particles.
  --Al, Mg alloys precipitation hardenable.