Chapter 11: Metal Alloys Applications and Processing

- How are metal alloys classified and how are they used?
- How do properties vary throughout a piece of material that has been quenched, for example?
- How can properties be modified by post heat treatment?

Taxonomy of Metals

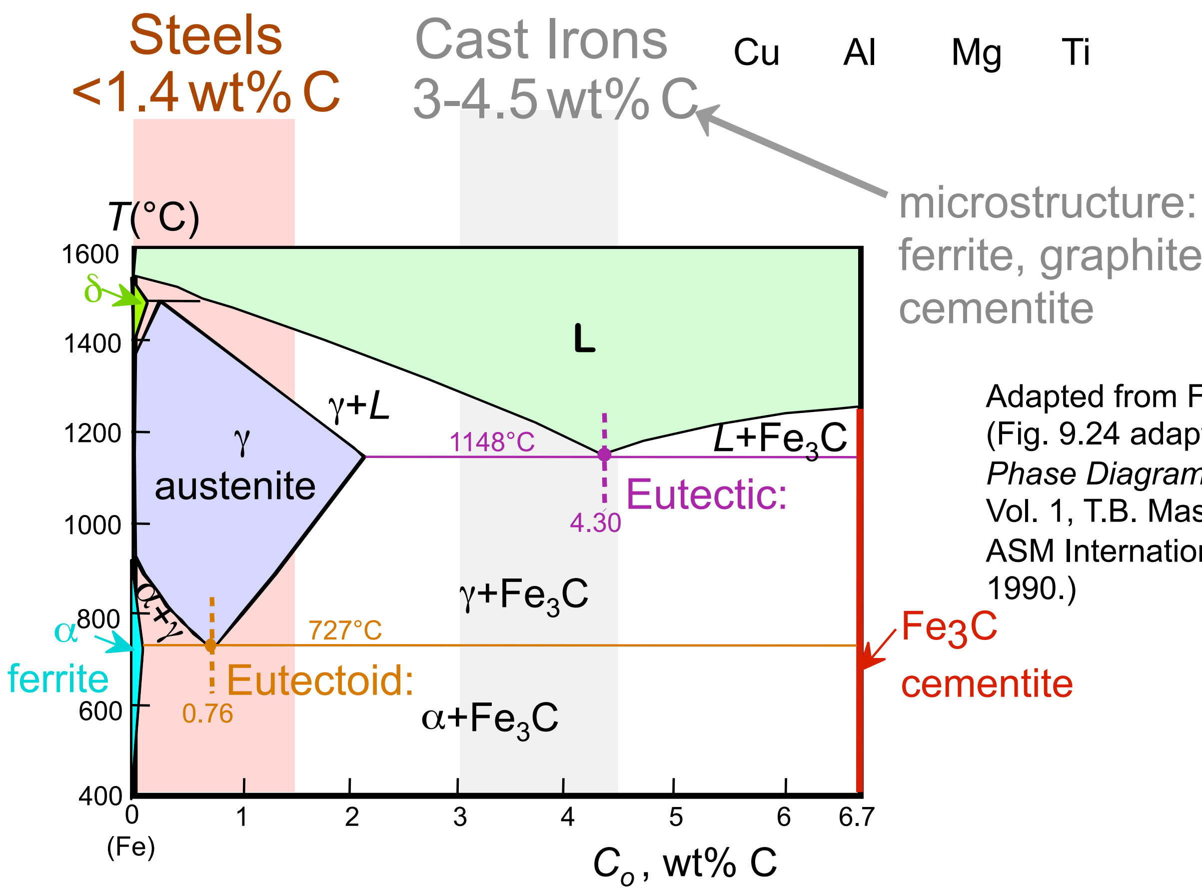
Metal Alloys

Ferrous

Nonferrous

Adapted from Fig. 11.1, *Callister 7e*.

Cu Al Mg Ti



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*.

Nonferrous 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*.

Basic concepts

- Annealing: a heat treatment
  - heat up
  - hold for for an extended time period
  - cool

- Function of annealing:
  - relieve stress
  - increase softness, ductility and toughness
  - produce specific microstructure

Thermal Processing of Metals

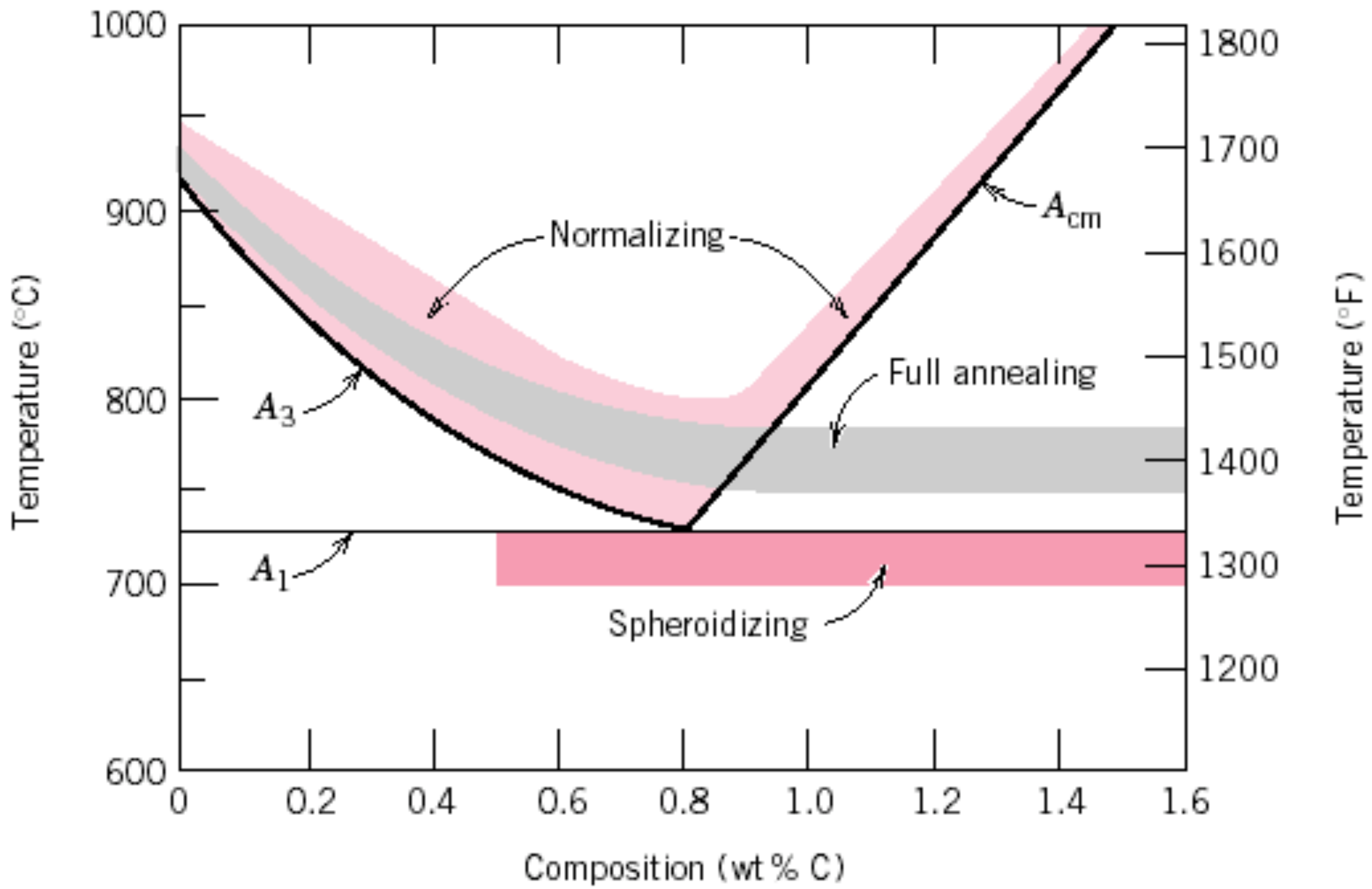
Annealing: Heat to T_{anneal}, then cool slowly.

Types of Annealing

- 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.
- 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 Treatment

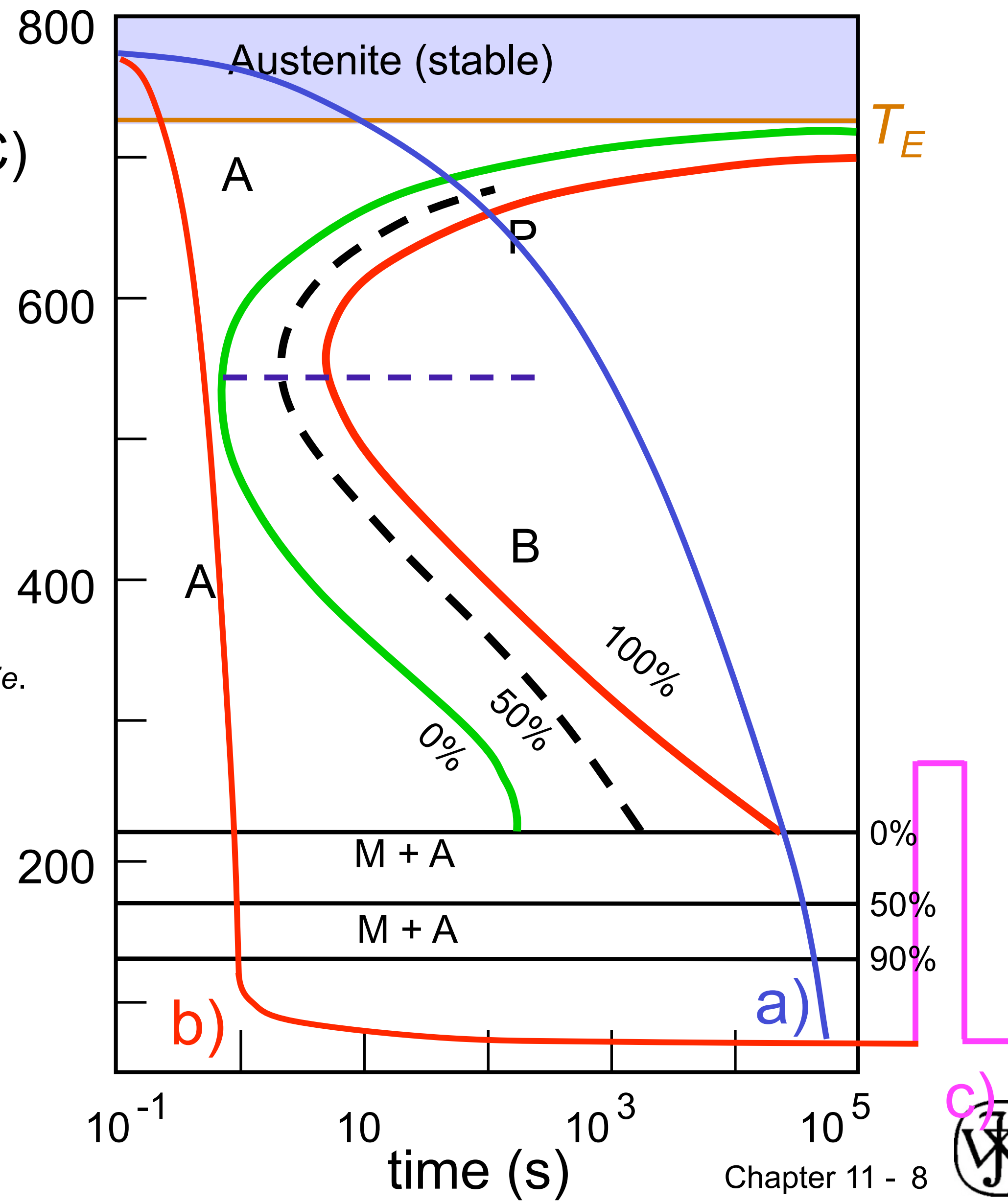


Heat Treatments

a) Annealing

b) Quenching

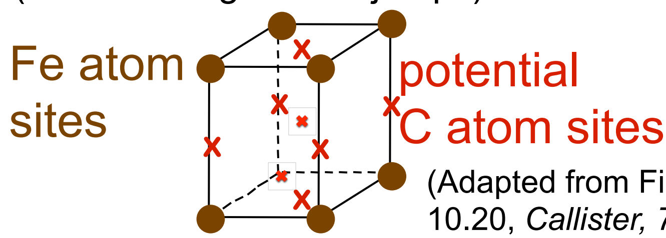
c) Tempered Martensite



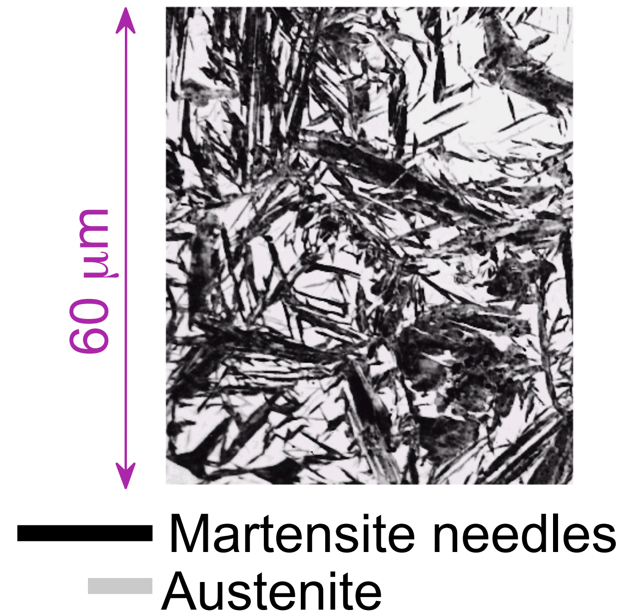
Adapted from Fig. 10.22, *Callister 7e*.

Martensite: Fe-C System

- Martensite:
  --γ(FCC) to Martensite (BCT)
  (involves single atom jumps)

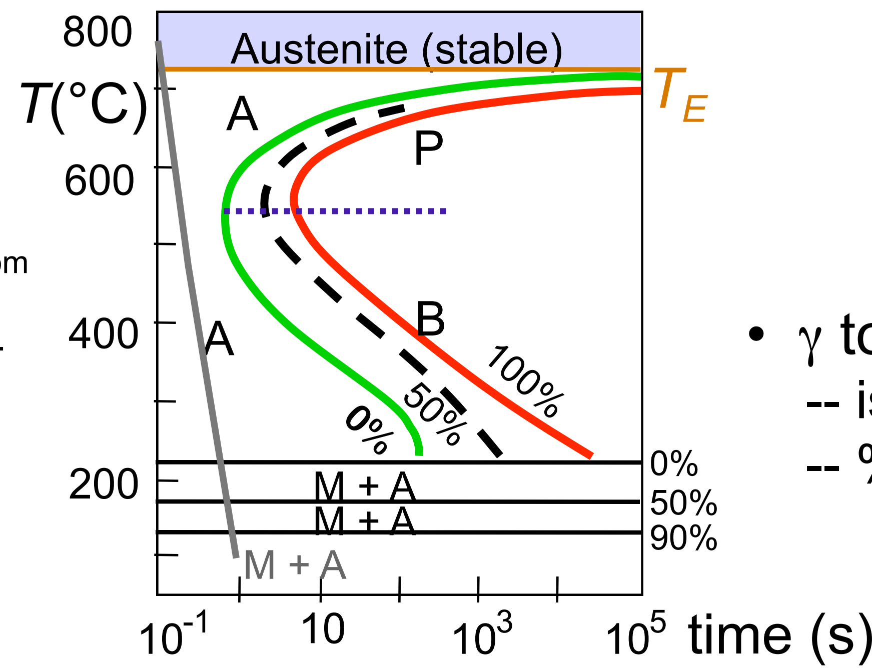


(Adapted from Fig. 10.20, *Callister, 7e*.



(Adapted from Fig. 10.21, *Callister, 7e*. (Fig. 10.21 courtesy United States Steel Corporation.)

- Isothermal Transf. Diagram

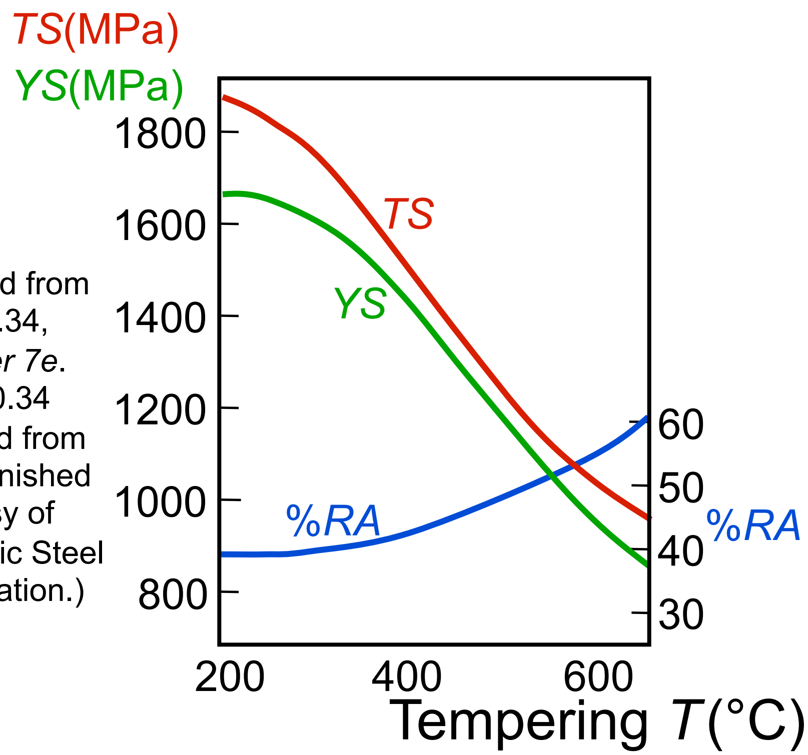


Adapted from Fig. 10.22, *Callister 7e*.

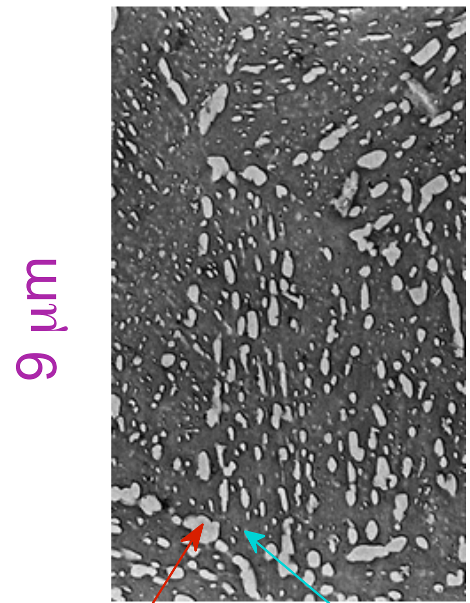
- γ to M transformation..
  -- is rapid!
  -- % transf. depends on T only.

Tempering Martensite

- reduces brittleness of martensite,
- reduces internal stress caused by quenching.



Adapted from Fig. 10.34, *Callister 7e*. (Fig. 10.34 adapted from Fig. furnished courtesy of Republic Steel Corporation.)

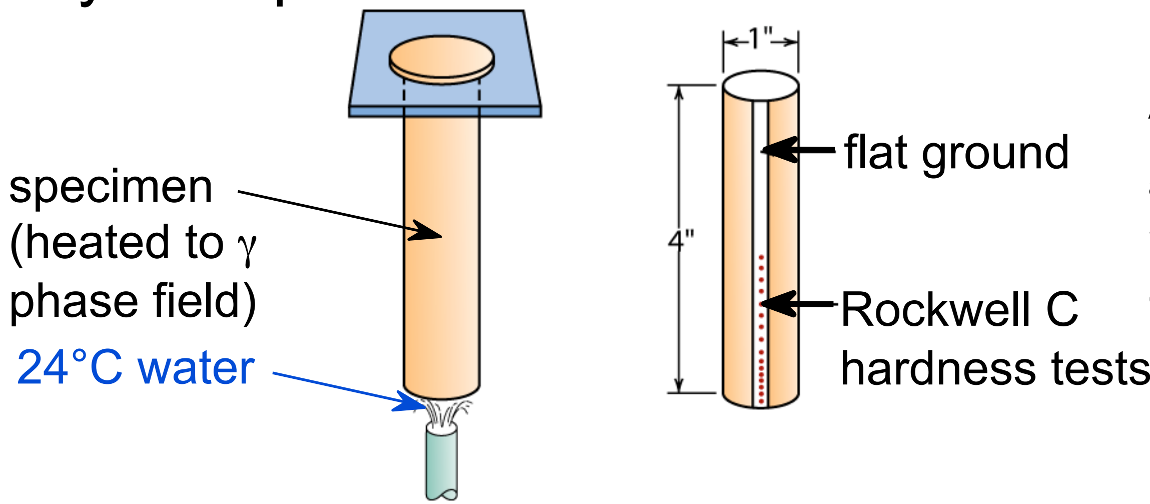


Adapted from Fig. 10.33, *Callister 7e*. (Fig. 10.33 copyright by United States Steel Corporation, 1971.)

- produces extremely small Fe_3C particles surrounded by α.
- decreases *TS*, *YS* but increases %*RA*

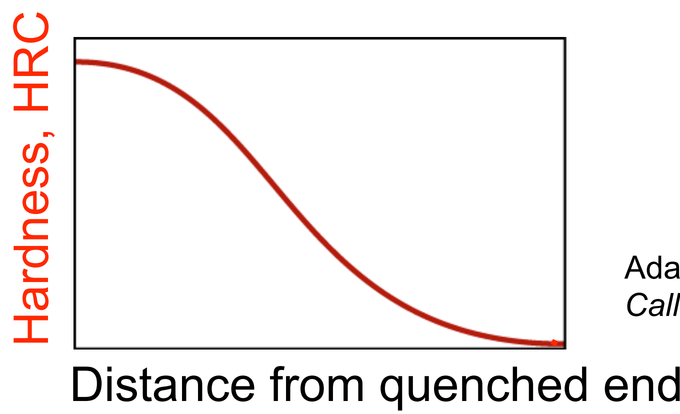
Hardenability--Steels

- Ability to form martensite
- Jominy end quench test to measure hardenability.



Adapted from Fig. 11.11, *Callister 7e*. (Fig. 11.11 adapted from A.G. Guy, *Essentials of Materials Science*, McGraw-Hill Book Company, New York, 1978.)

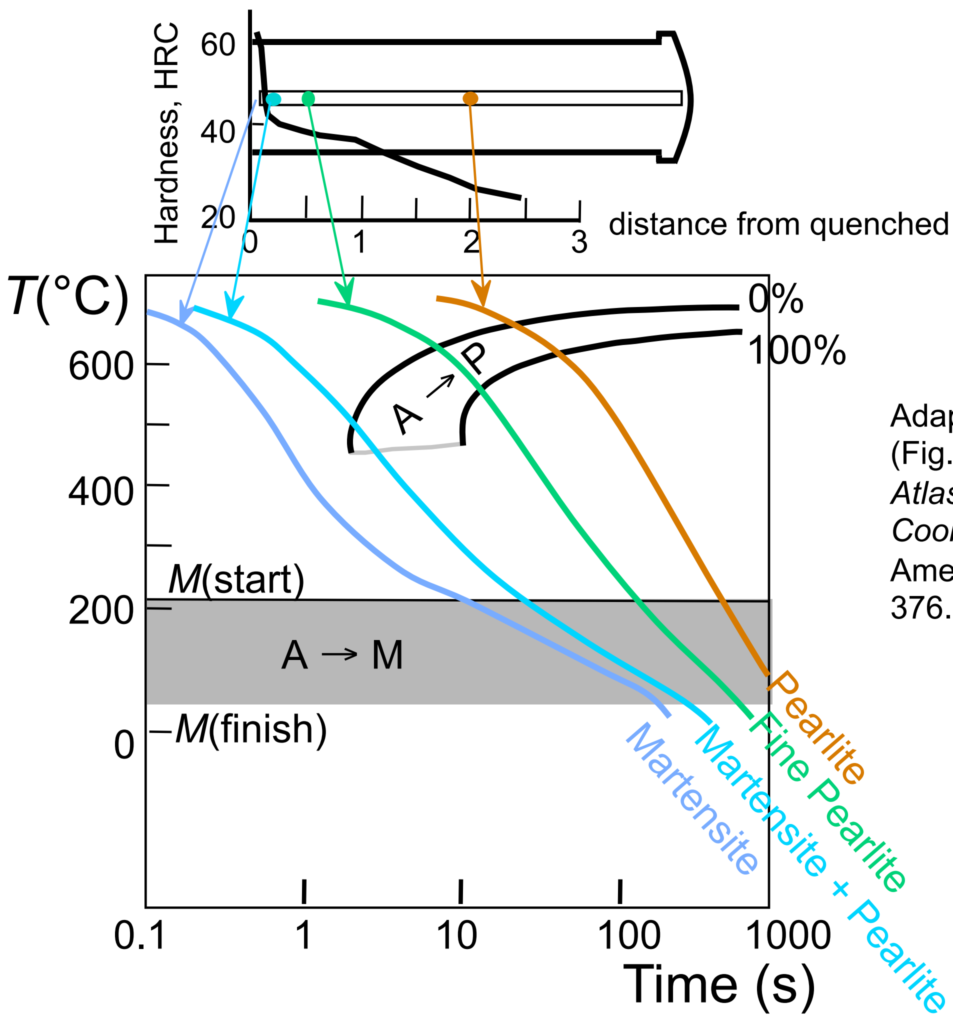
- Hardness versus distance from the quenched end.



Adapted from Fig. 11.12, *Callister 7e*.

Why Hardness Changes W/Position

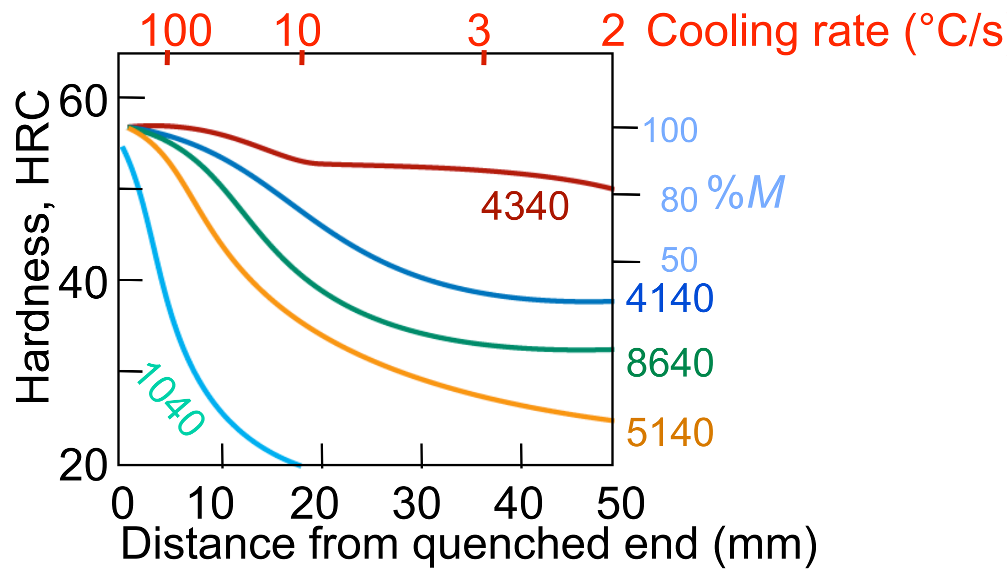
- The cooling rate varies with position.



Adapted from Fig. 11.13, *Callister 7e*. (Fig. 11.13 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1977, p. 376.)

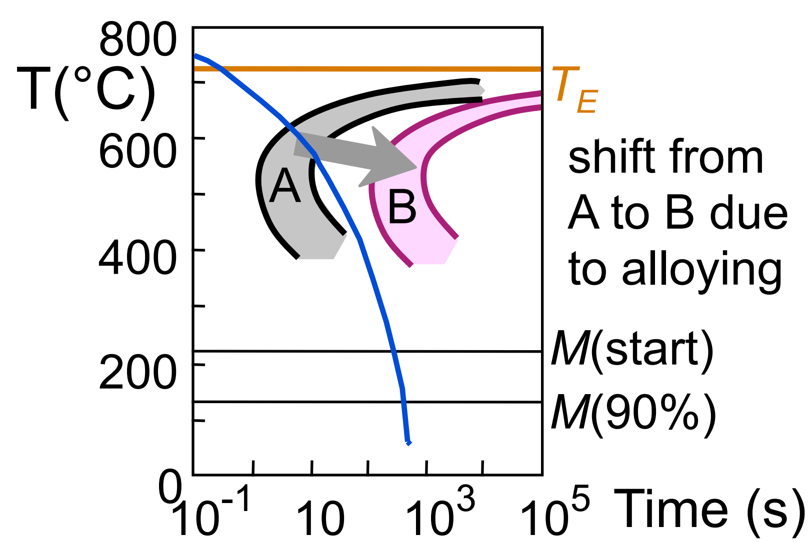
Hardenability vs Alloy Composition

- Jominy end quench results, $C = 0.4$ wt% C



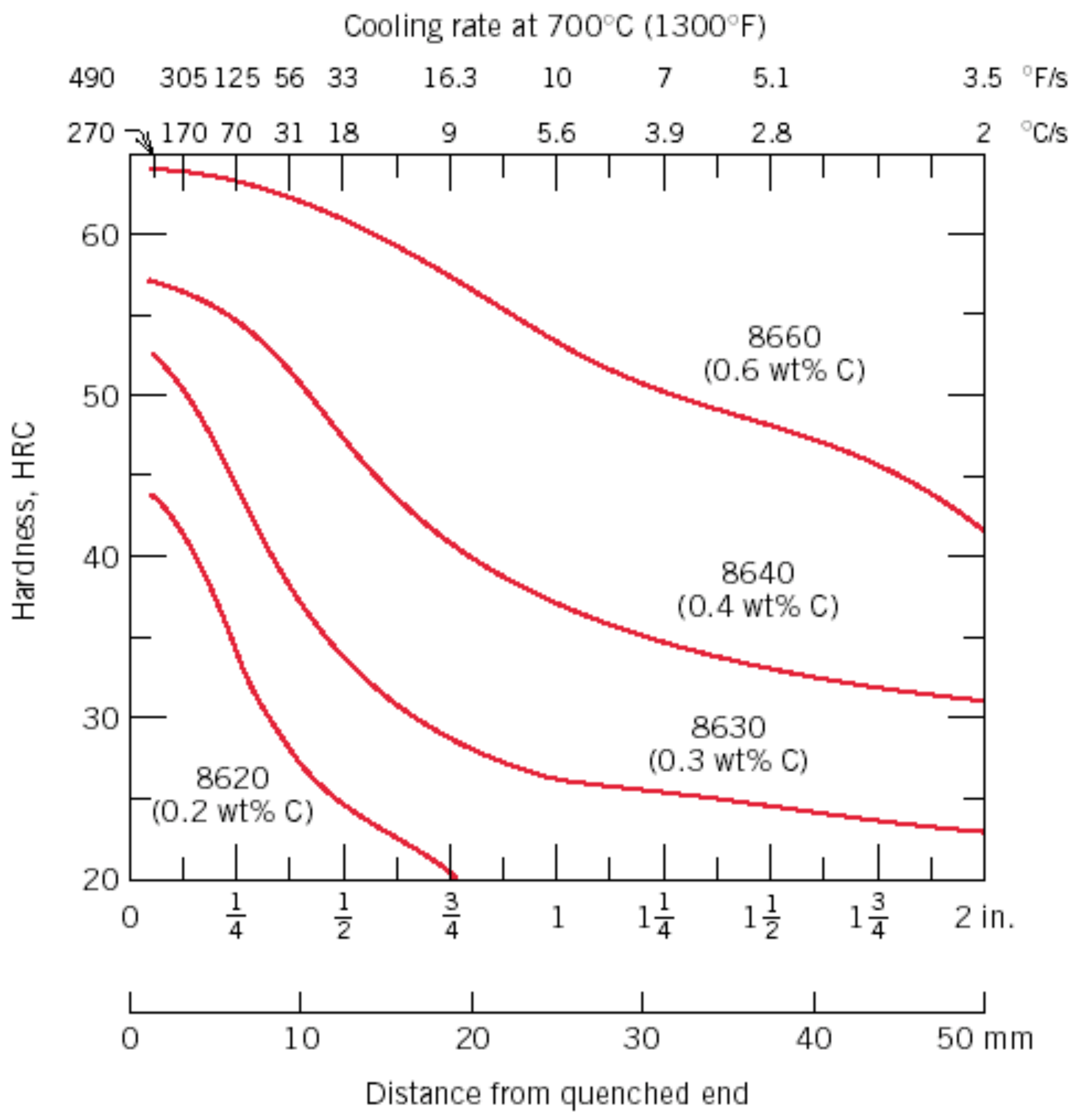
Adapted from Fig. 11.14, *Callister 7e*.
(Fig. 11.14 adapted from figure furnished courtesy Republic Steel Corporation.)

- "Alloy Steels"
  (4140, 4340, 5140, 8640)
  --contain Ni, Cr, Mo
  (0.2 to 2wt%)
  --these elements shift the "nose".
  --martensite is easier to form.



Hardenability vs carbon content

- Jominy end quench results, 8600 series
- Hardenability increases as wt%C increase



Quenching Medium & Geometry

- Effect of quenching medium:

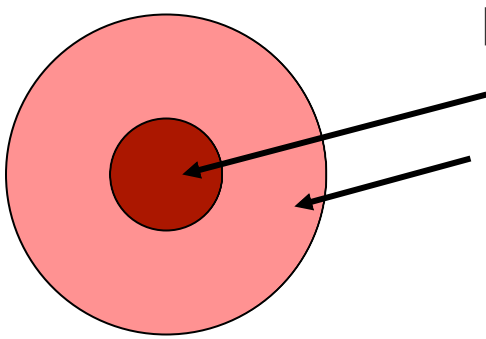
Medium	Severity of Quench	Hardness
air	low	low
oil	moderate	moderate
water	high	high

- Effect of geometry:

When surface-to-volume ratio increases:

--cooling rate increases

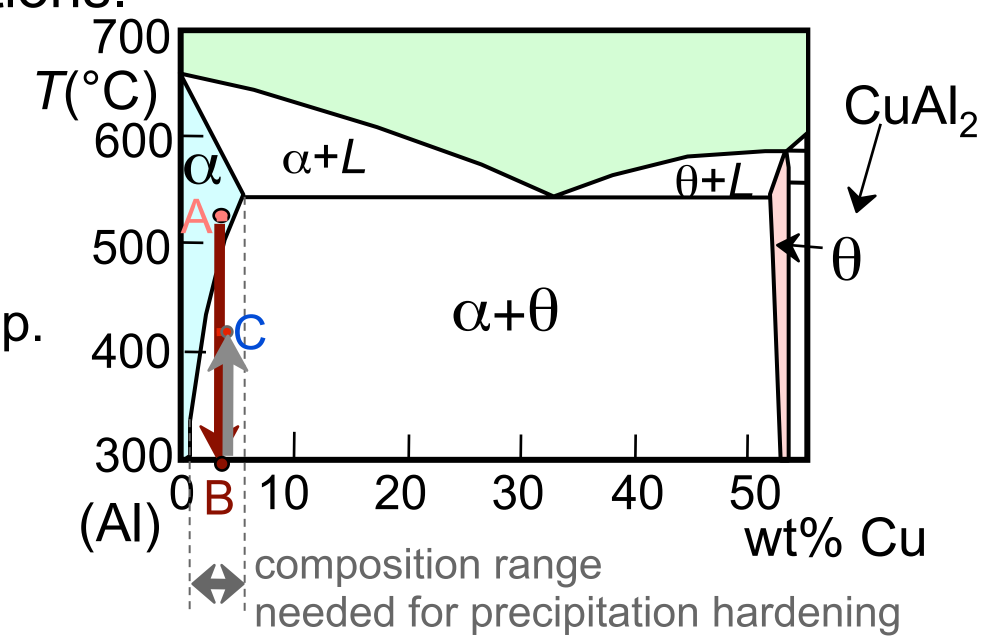
--hardness increases



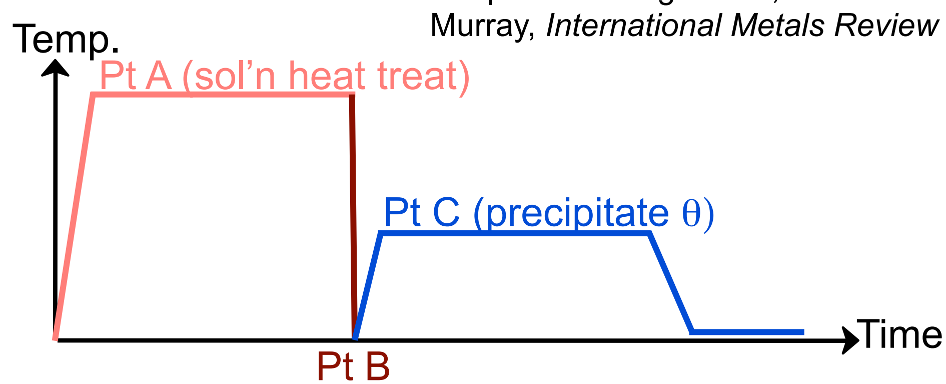
Position	Cooling rate	Hardness
center	low	low
surface	high	high

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.)



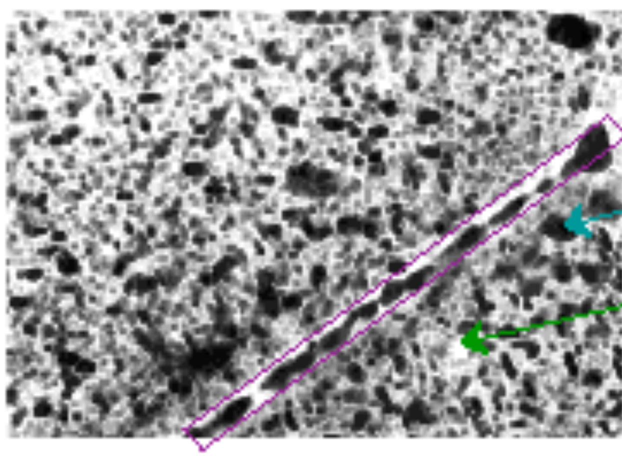
Adapted from Fig. 11.22, *Callister 7e*.

Example: 7150-T651 Al alloy

- **Boeing 757**

Callister, Fig. 11.0(a)

- **Microstructure: $MgZn_2$ particles**



Callister, Fig. 11.0(b)

Summary

- Steels: increase *TS*, Hardness (and cost) by adding
  --C (low alloy steels)
  --Cr, V, Ni, Mo, W (high alloy steels)
  --ductility usually decreases w/additions.
- Non-ferrous:
  --Cu, Al, Ti, Mg, Refractory, and noble metals.
- Hardenability
  --increases with alloy content.
- Precipitation hardening
  --effective means to increase strength in
  Al, Cu, and Mg alloys.