

# Chapter 11: Thermal Processing-Metals and Alloys

Issues to address...

## STEELS...

- **Annealing:** Why do we do it?
- **Martensite formation:** It seems desirable, but we can't always produce it throughout an entire part.
- **Part geometry, alloy content, quenching medium:** How are they important in forming martensite?

## OTHER SYSTEMS...

- **Precipitate Strengthening:** How do we get it?

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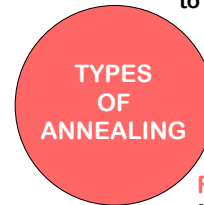


**Annealing:** heat up a material to  $T_{\text{anneal}}$  for an extended period, then slowly cool.

**Process Anneal:** Negate effect of cold working by (recovery/recrystallization)

**Normalize (steels):** Deform steel with large grains, then **normalize** to make grains small.

**Stress Relief:** Reduce stresses caused by  
-plastic deformation  
-nonuniform cooling  
-phase transform.



(heat up to get , then cool in air to get fine P)

**Spheroidize (steels):** Make very soft steels for good machining. Heat just below  $T_E$  and hold for 15-25h.

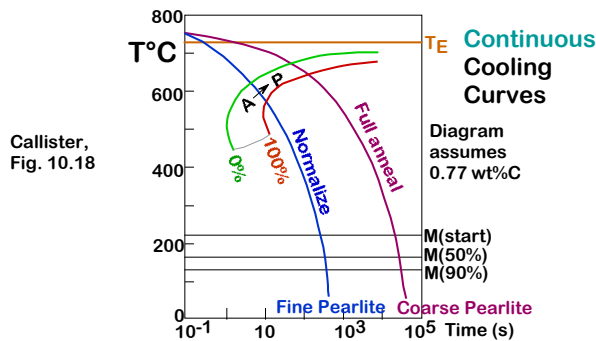
**Full Anneal (steels):** Make soft steels for good forming by heating to get , then cool in furnace to get coarse P.

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## Continuous Cooling Curves: Fe-C System

- **Normalize:** fine pearlite
- **Full anneal:** coarse pearlite

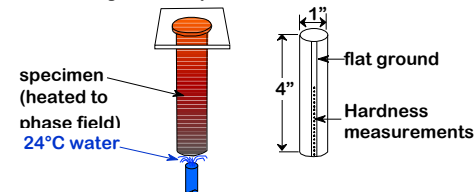


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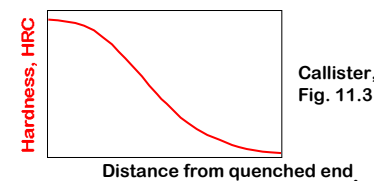


**Hardenability:** Ability of a material to form martensite

- **Jominy end quench test of hardenability**



- **Hardness vs distance from quenched end**

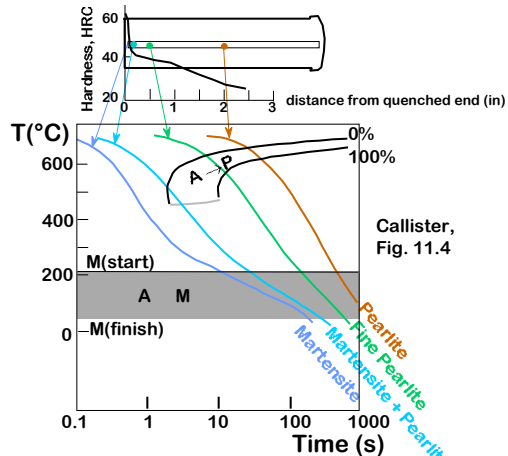


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## Why does hardness changes with position?

- The cooling rate varies with position

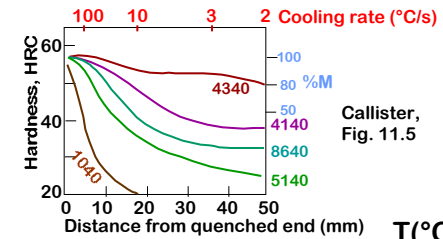


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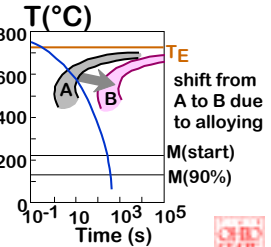
## Hardenability vs Alloy Content

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



Callister, Fig. 11.5

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

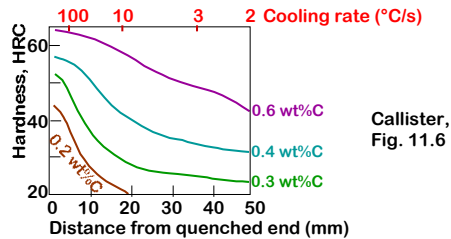


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## Hardenability vs Carbon Content

- Jominy end quench results, 8600 series



Callister, Fig. 11.6

- Hardenability as wt%C

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## Quenching Medium and Geometry

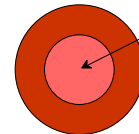
- Effect of Quenching Medium:

Medium	Severity of Quench	Hardness
air	small	small
oil	moderate	moderate
water	large	large

- Effect of geometry

-When surface-to-volume ratio , cooling rate , hardness  
 -Typical results

Position	Cooling Rate	Hardness
center	small	small
surface	large	large

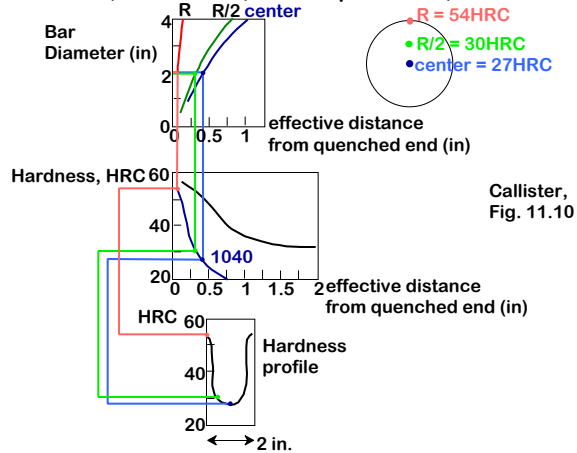


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# Predicting Hardness Profiles

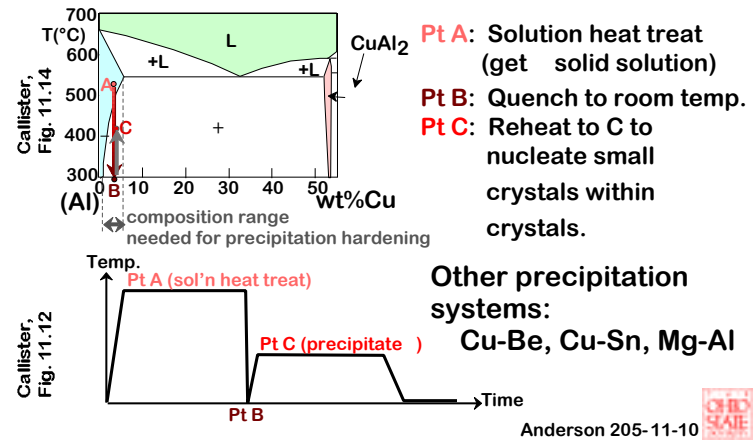
- Ex: -round bar, 1040 steel, water quenched, 2" diameter



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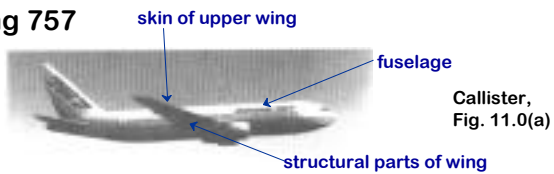
# Precipitation Hardening

- Particles impede dislocations
- Ex. Al-Cu system

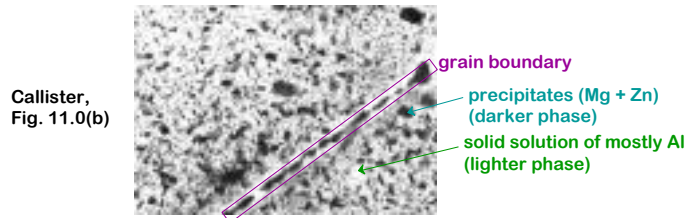


# Example: 7150-T651 Al Alloy

- Boeing 757



- Microstructure: MgZn<sub>2</sub> particles



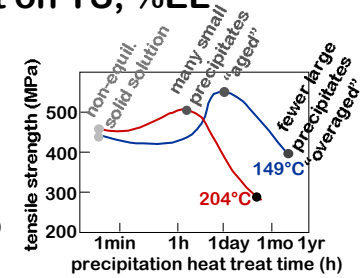
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# Precipitate effect on TS, %EL

- 2014 Aluminum Alloy

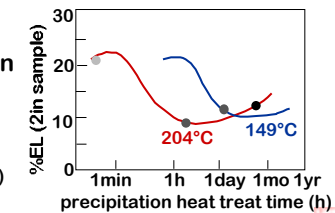
- TS peaks w/precipitation time
- increasing T accelerates process

Callister, Fig. 11.16(a)



- %EL bottoms out w/precipitation time

Callister, Fig. 11.16(b)



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