Aalto University
School of Engineering

COE-C2004 - Materials Science and Engineering

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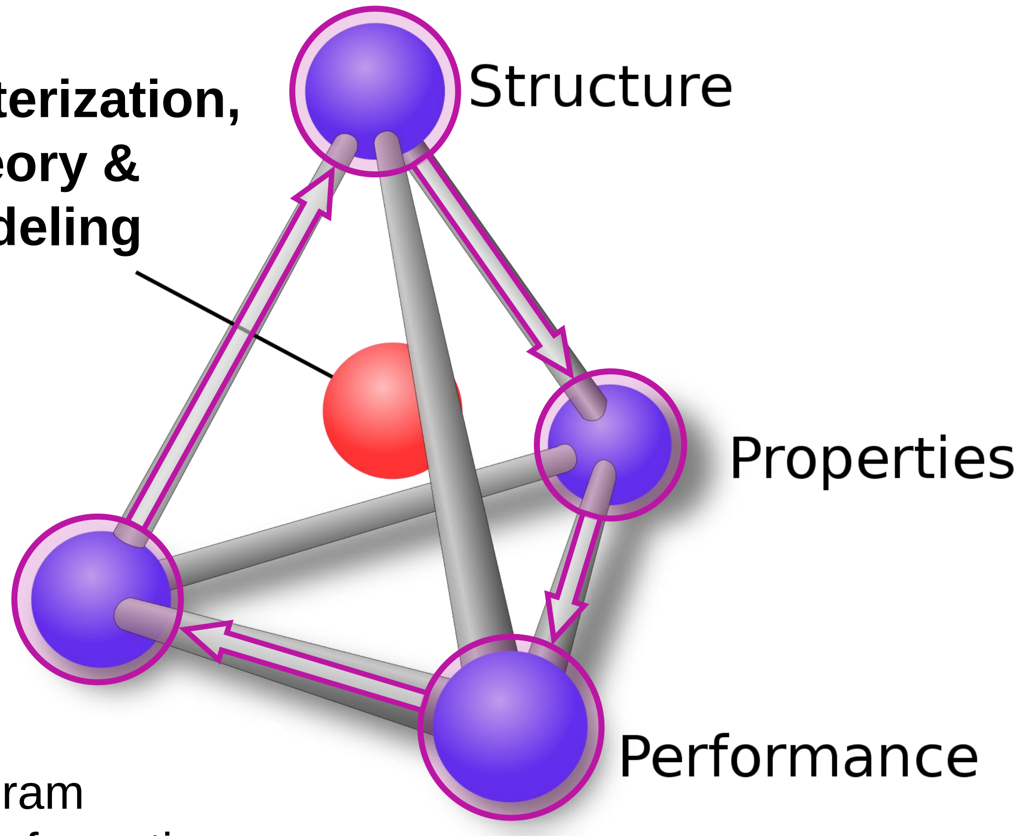
Processes

Previously



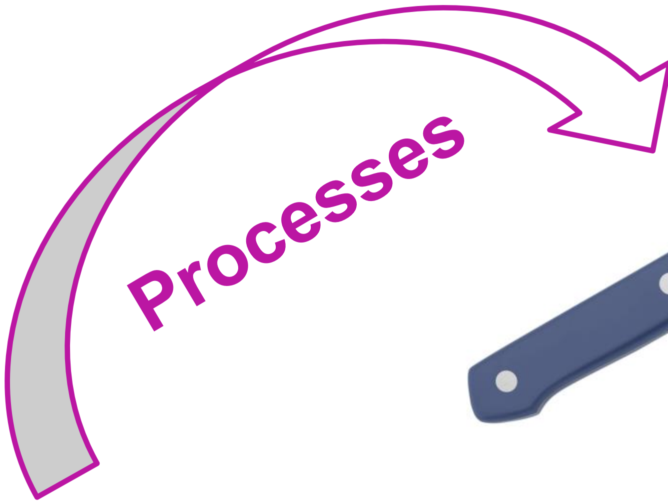
- Diffusion
- Phase Diagram
- Phase Transformation
- **Processes**

Learning Objectives

After studying this chapter you should be able to do the following:

- Name and describe four casting techniques.
- Name and describe four forming operations that are used to shape metal alloys.
- State the purposes of and describe procedures for the four heat treatments: process annealing, stress relief annealing, full annealing, and spheroidizing.
- Correlate the processes with structure of materials.

How to produce a kitchen knife?



https://misen.com/products/chefs-knife-alternate

- ❑ List the processes
- ❑ Name the purposes of the processes

https://www.indiamart.com/proddetail/mineral-iron-ore-11649466430.html

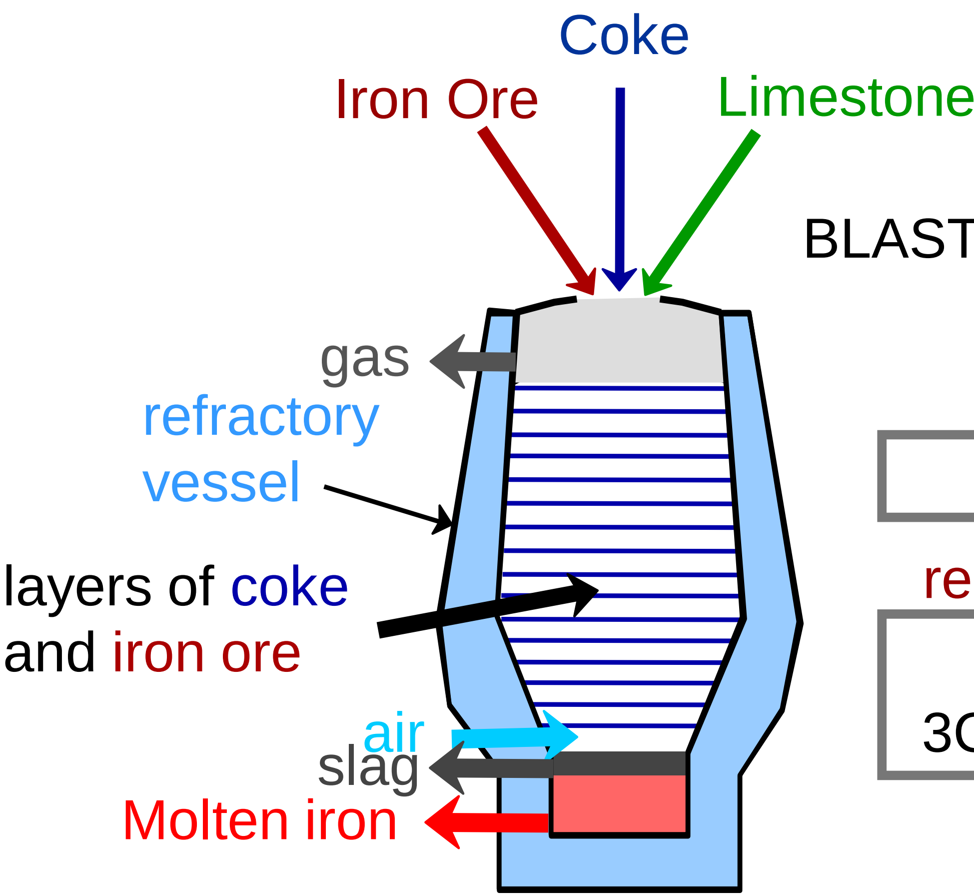
Group work

- **Four groups** are will be created by Zoom, leading you to Four separate rooms.
- Each group will **decorate** your "**FLINGA Wall**". (Post-it, Figures, and Drawings, etc.)
- Following the **guiding question** on FLINGA, discuss and work together.
- After the discussion, **present** your wall to all of us.

- Discussion duration: ~10 mins.
- Moderator: max{Birth month(day)}
- Presenter: decided by the group.

Group 1: https://flinga.fi/s/FHDJCE2
Group 2: https://flinga.fi/s/FMKHY8B
Group 3: https://flinga.fi/s/FWP9EC6

Metal Making from Ore



BLAST FURNACE

heat generation

$$C + O_2 \rightarrow CO_2$$

reduction of iron ore to metal

$$CO_2 + C \rightarrow 2CO$$

$$3CO + Fe_2O_3 \rightarrow 2Fe + 3CO_2$$

Metal Fabrication Methods (i)

CASTING FORMING

Casting

- mold is filled with molten metal
- metal melted in furnace, perhaps alloying elements added, then cast in a mold

- common and inexpensive
- gives good production of shapes
- good option for brittle materials without forming
- weaker products, internal defects

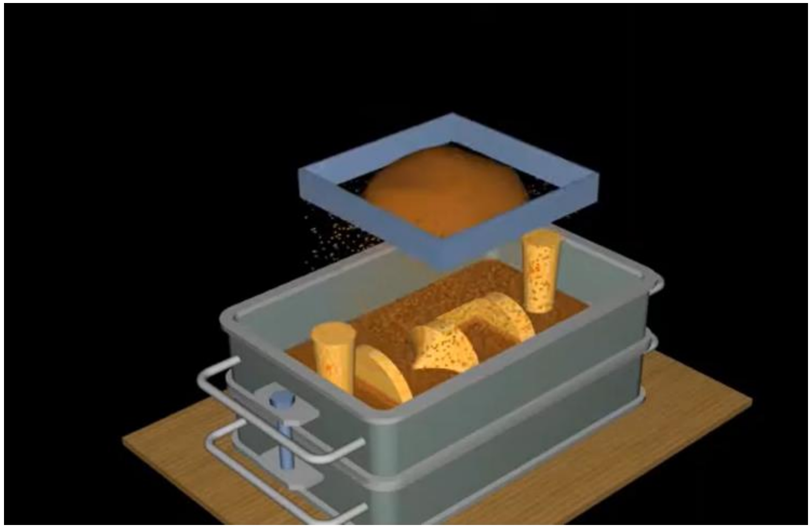
Metal Fabrication Methods (ii)

CASTING

FORMING

- Sand Casting

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



https://www.youtube.com/watch?v=7BI4v0Gqc7k

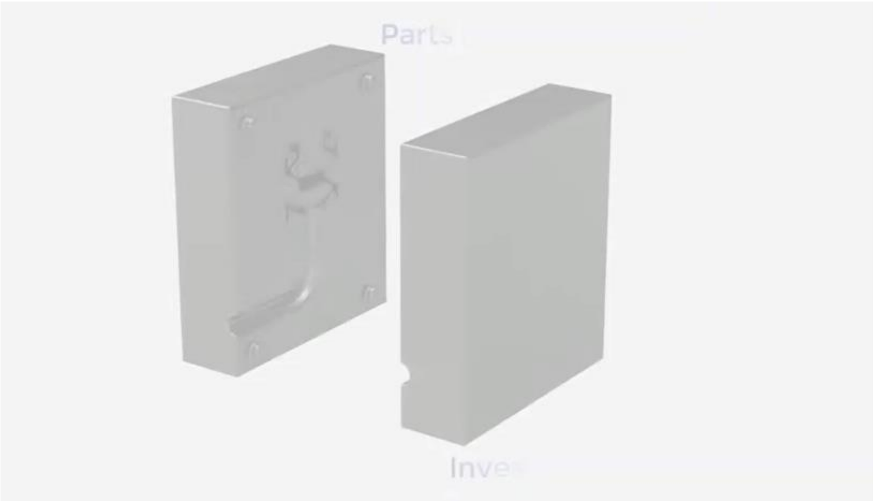
- What material will withstand T >1600°C and is inexpensive and easy to mold?
- Answer: sand!!!
- To create mold, pack sand around form (pattern) of desired shape

Metal Fabrication Methods (iii)

CASTING

FORMING

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



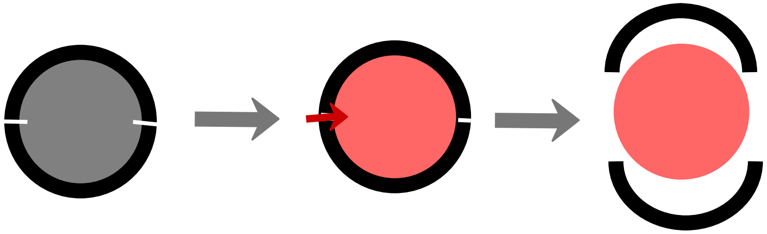
- Stage 0 — Preparing wax patterns.
- Stage I — Mold formed by pouring plaster of paris around wax pattern. Plaster allowed to harden.
- Stage II — Wax is melted and then poured from mold—hollow mold cavity remains.
- Stage III — Molten metal is poured into mold and allowed to solidify.

https://youtu.be/S4WuKJF_76c

Metal Fabrication Methods (iv)

CASTING

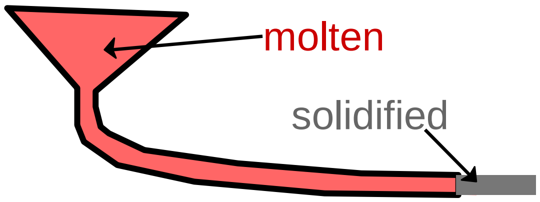
- Die Casting
  -- high volume
  -- for alloys having low melting temperatures (Al, Zn, Mg)



Recommended to watch:
[What is die casting process?]

FORMING

- Continuous Casting
  -- simple shapes (e.g., rectangular slabs, cylinders)



Recommended to watch:
[Continuous Casting Process]

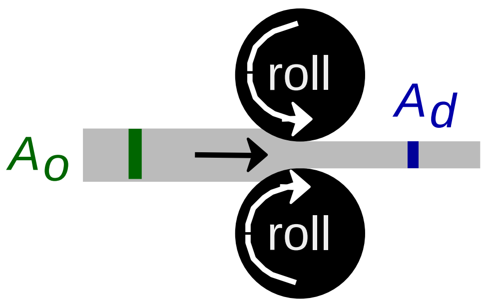
Metal Fabrication Methods (v)

CASTING

FORMING

- Rolling (Hot or Cold Rolling)

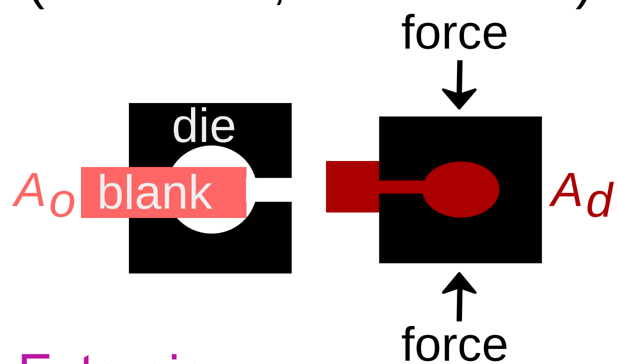
  (I-beams, rails, sheet & plate)



Adapted from Fig. 11.9, *Callister & Rethwisch 10e.*

- Forging (Hammering; Stamping)

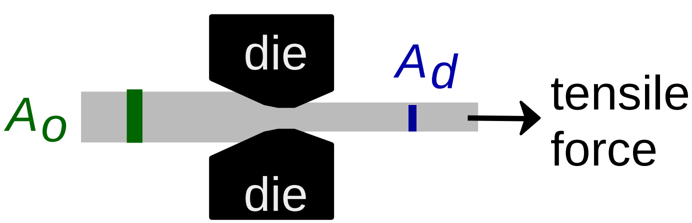
  (wrenches, crankshafts)



often at elev. *T*

- Drawing

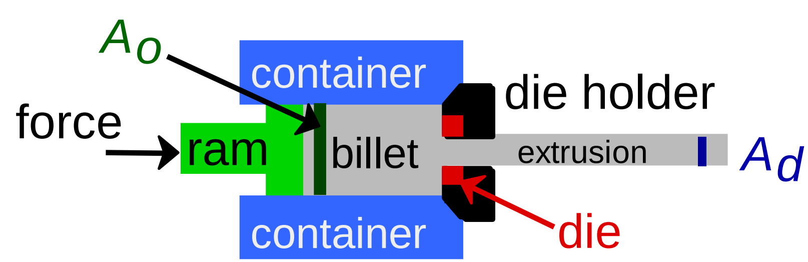
  (rods, wire, tubing)



die must be well lubricated & clean

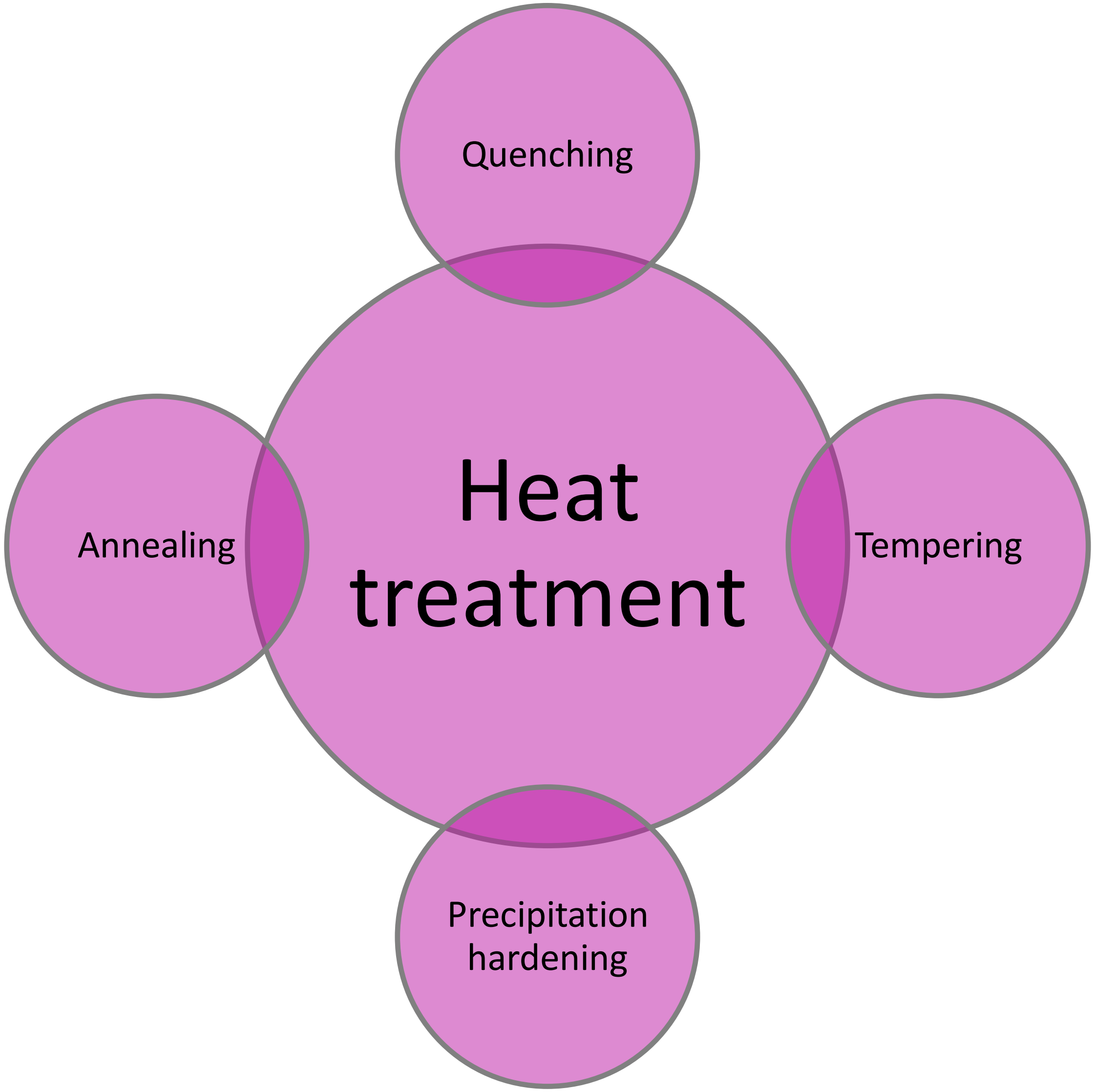
- Extrusion

  (rods, tubing)



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

Heat treatment types



Thermal Processing of Metals

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

Types of Annealing

- **Stress Relief**: Reduce stresses resulting from:
  - plastic deformation
  - nonuniform cooling
  - phase transform.
- **Spheroidize** (steels): Make very soft steels for good machining. Heat just below $T_{eutectoid}$ & hold for 15-25 h.
- **Process Anneal**: Negate effects of cold working by (recovery, recrystallization, [grain growth])
- **Full Anneal** (steels): Make soft steels for good forming. Heat to get γ, then furnace-cool to obtain coarse pearlite.

Based on discussion in Section 11.8, *Callister & Rethwisch 10e*.

Spheroidite: Another Microstructure for the Fe-Fe_3C System

- Spheroidite:
  -- Fe_3C particles within an α-ferrite matrix
  -- formation requires diffusion
  -- heat bainite or pearlite at temperature
  just below eutectoid for long times
  -- driving force – reduction
  of α-ferrite/Fe_3C interfacial area

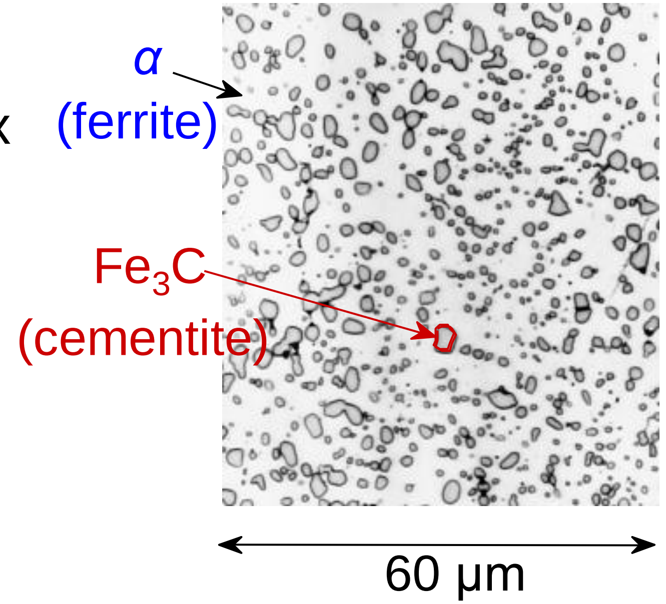
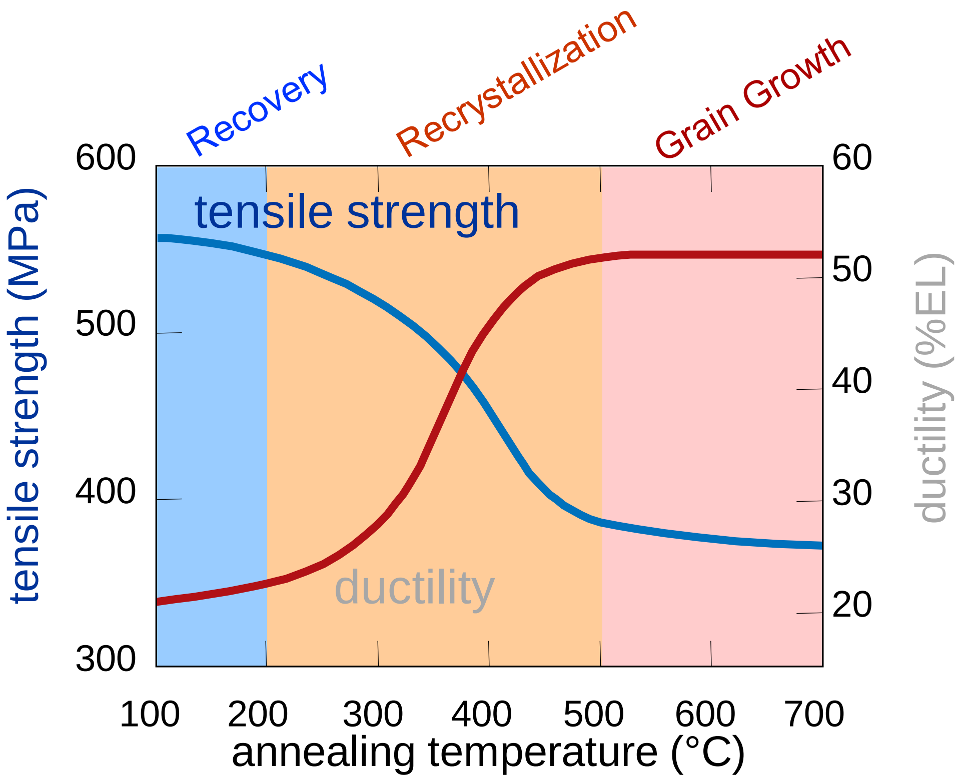


Fig. 10.19, *Callister & Rethwisch 10e.* (Copyright United States Steel Corporation, 1971.)

Process Annealing of Cold-Worked Alloys

- Heat treating cold worked metals brings about changes in structure and properties
- As a result, effects of cold work are nullified!
- This type of heat treatment often termed "annealing"
- 1 hour treatment at T_{anneal} decreases tensile strength & increases %EL



Three Annealing stages:

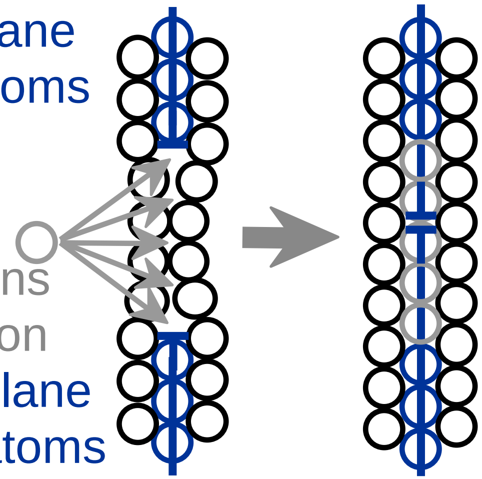
1. Recovery (100-200°C)
2. Recrystallization (200-500°C)
3. Grain Growth (> 500°C)

Fig. 7.22, *Callister & Rethwisch 10e.* (Adapted from G. Sachs and K. R. Van Horn, *Practical Metallurgy, Applied Metallurgy and the Industrial Processing of Ferrous and Nonferrous Metals and Alloys*, 1940. Reproduced by permission of ASM International, Materials Park, OH.)

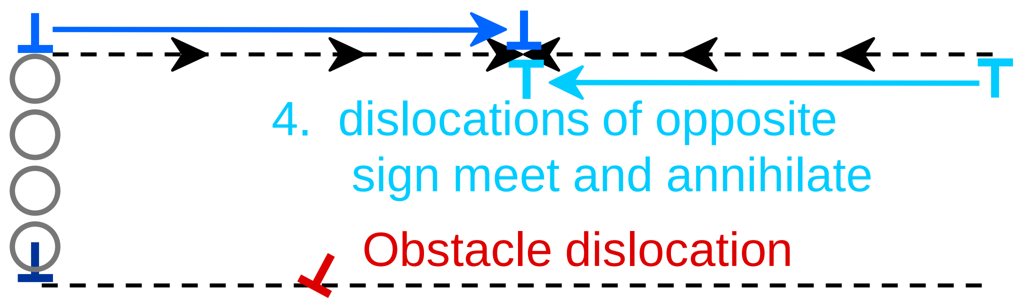
Recovery

During recovery – reduction in disl. density – annihilation of disl.

- Scenario 1

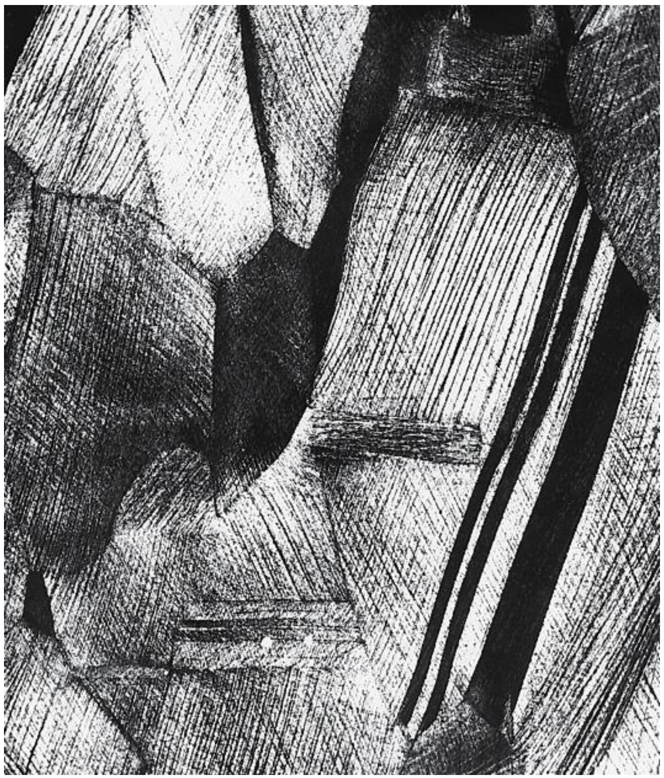


- Scenario 2

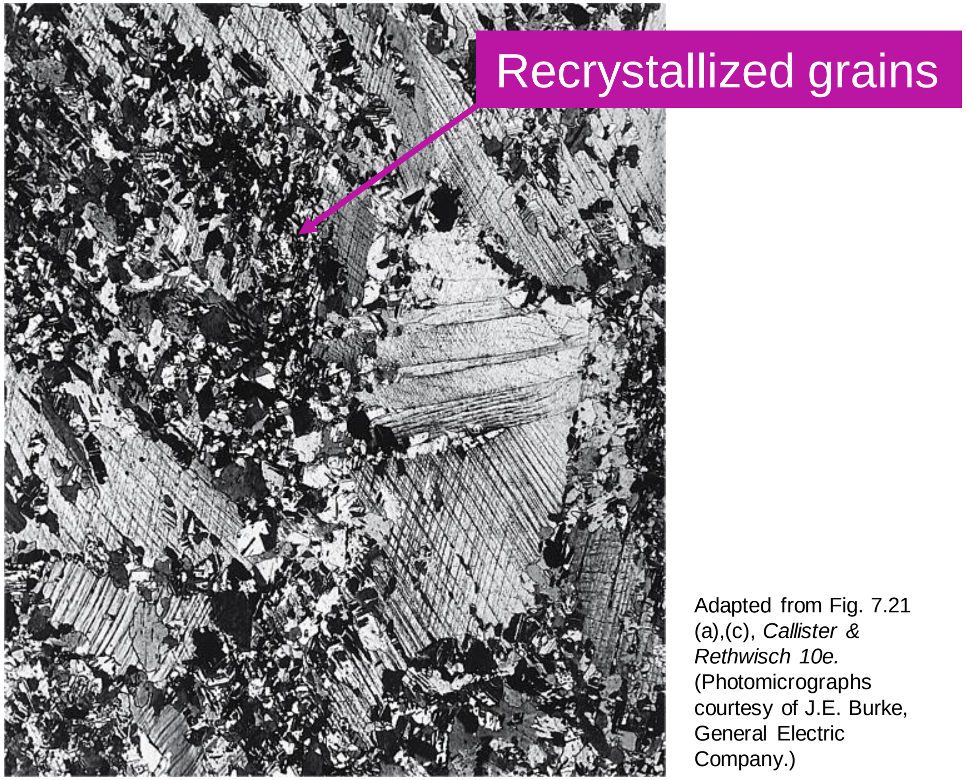


Recrystallization

- New grains form that:
  -- have low dislocation densities
  -- are small in size
  -- consume and replace parent cold-worked grains.



33%CW brass before heat treatment

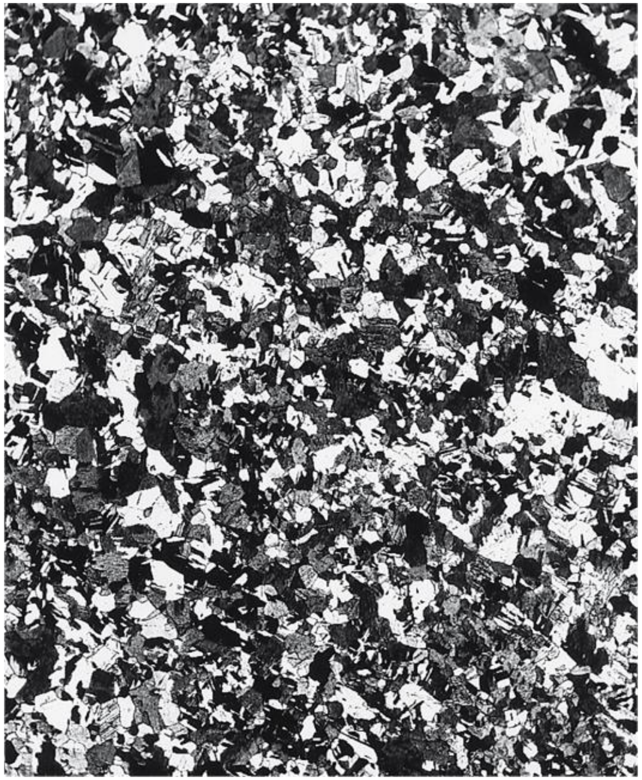


After 4 sec. at 580°C

Adapted from Fig. 7.21 (a),(c), *Callister & Rethwisch 10e.* (Photomicrographs courtesy of J.E. Burke, General Electric Company.)

Recrystallization (cont.)

- All grains in cold-worked material have been consumed/replaced.



After 8 sec. at 580°C

Adapted from Fig. 7.21 (d), *Callister & Rethwisch 10e.* (Photomicrographs courtesy of J.E. Burke, General Electric Company.)

Recrystallization Temperature

T_R = recrystallization temperature = temperature at which recrystallization just reaches completion in 1 h.

$$0.3T_m < T_R < 0.6T_m$$

For a specific metal/alloy, T_R depends on:

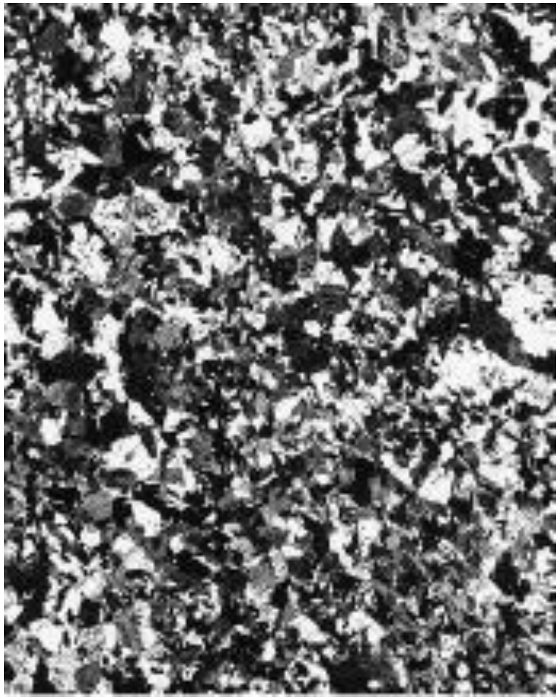
- %CW -- T_R decreases with increasing %CW
- Purity of metal -- T_R decreases with increasing purity

Cold work vs. Hot working

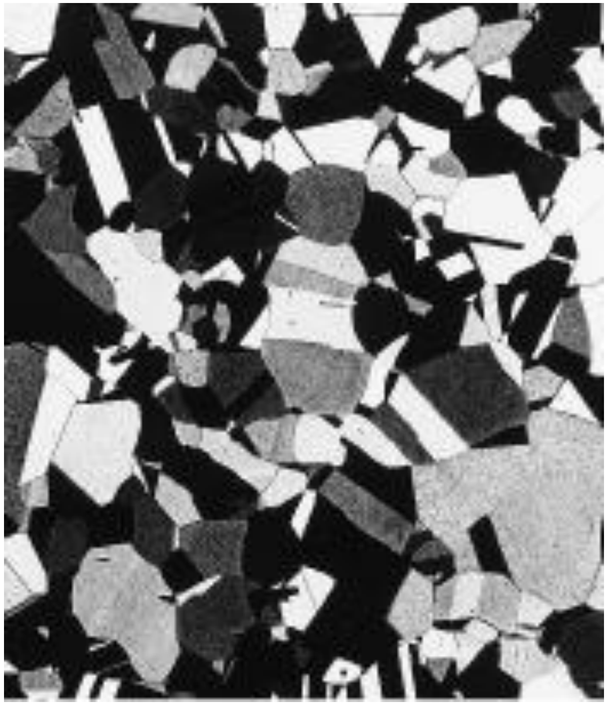
- Hot working → deformation above T_R
- Cold working → deformation below T_R

Grain Growth

- Grain growth occurs as heat treatment continues.
  - -- Average grain size increases
  - -- Small grains shrink (and ultimately disappear)
  - -- Large grains continue to grow



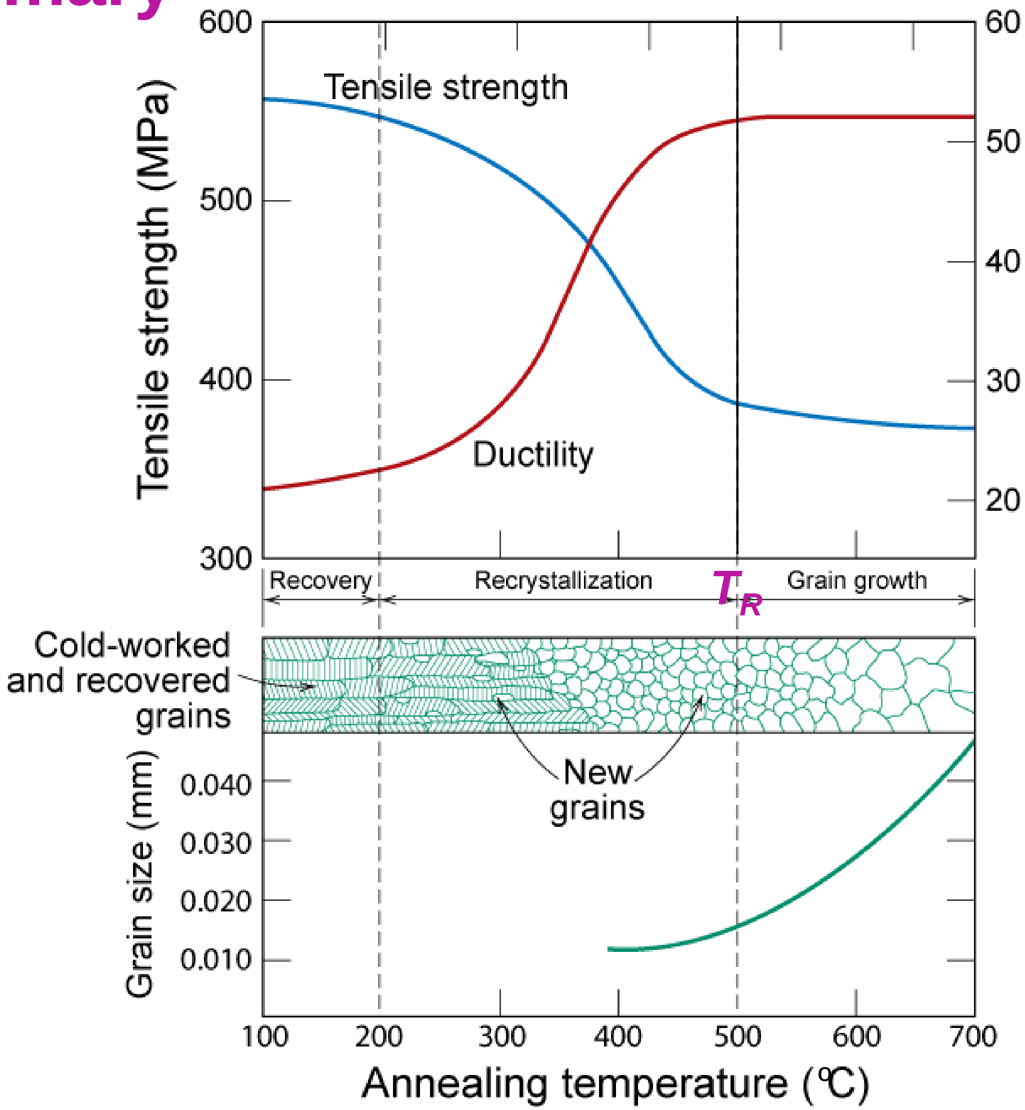
After 8 sec. at 580°C



After 15 min. at 580°C

Adapted from Fig. 9.21 (d),(e), *Callister & Rethwisch 10e.* (Photomicrographs courtesy of J.E. Burke, General Electric Company.)

Recovery, Recrystallization, & Grain Growth Summary



T_R = recrystallization temperature

annealing time = 1 h

Fig. 7.22, *Callister & Rethwisch 10e.* (Adapted from G. Sachs and K. R. Van Horn, *Practical Metallurgy, Applied Metallurgy and the Industrial Processing of Ferrous and Nonferrous Metals and Alloys*, 1940. Reproduced by permission of ASM International, Materials Park, OH.)

Grain Size Influences Properties

Recrystallization vs. Grain Growth

- Metals having small grains – relatively strong and tough at low temperatures
- Metals having large grains – good creep resistance at relatively high temperatures

https://www.worldpipelines.com/project-news/29112019/balticconnectors-offshore-pipeline-filled-with-gas-and-ready-for-use/

https://www.solartronmetrology.jp/product-application/aerospace/profile-analysis-of-complex-curves-such-as-airfoils

Other Heat Treatment Processes

Temperature – Time Paths

a) Full Annealing

b) Quenching

c) Tempering (Tempered Martensite)

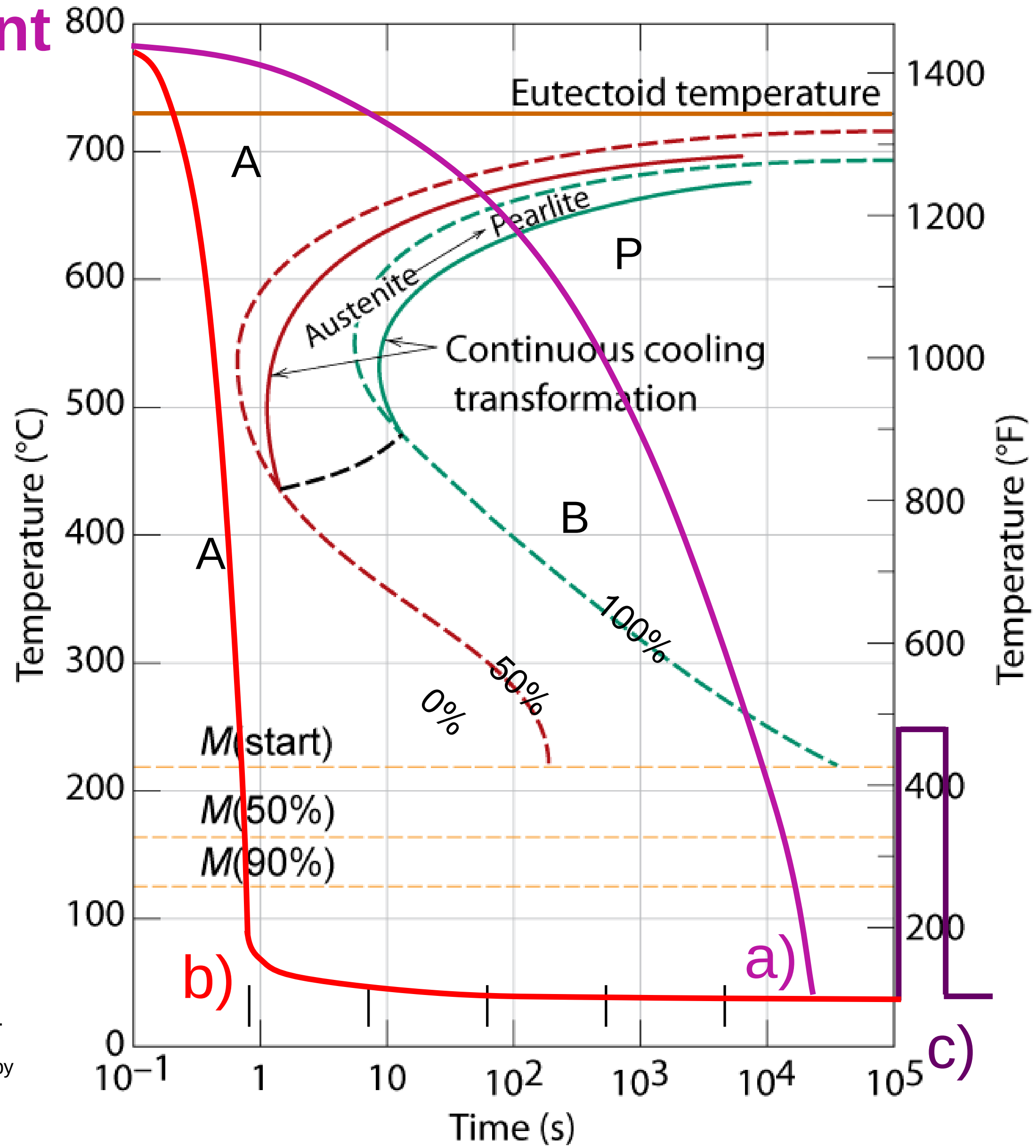


Fig. 10.25, *Callister & Rethwisch 10e*. [Adapted from H. Boyer (Editor), Atlas of Isothermal Transformation and Cooling Transformation Diagrams, 1977. Reproduced by permission of ASM International, Materials Park, OH.]

Influences of Quenching Medium & Specimen Geometry

- Effect of quenching medium:

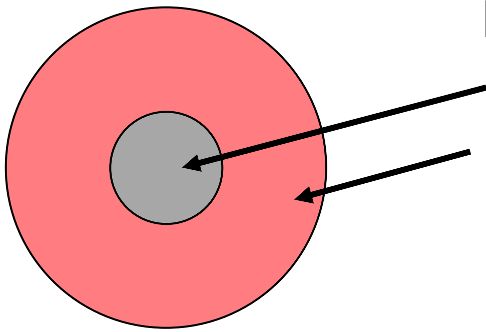
Medium	Severity of Quench	Hardness
air	low	low
oil	moderate	moderate
water	high	high

- 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 dislocation motion.
- Ex: Al-Cu system
- Procedure:
  - -- Pt A: solution heat treat (get α solid solution)
  - -- Pt B: quench to room temp. (retain α solid solution)
  - -- Pt C: reheat to nucleate small θ particles within α phase.

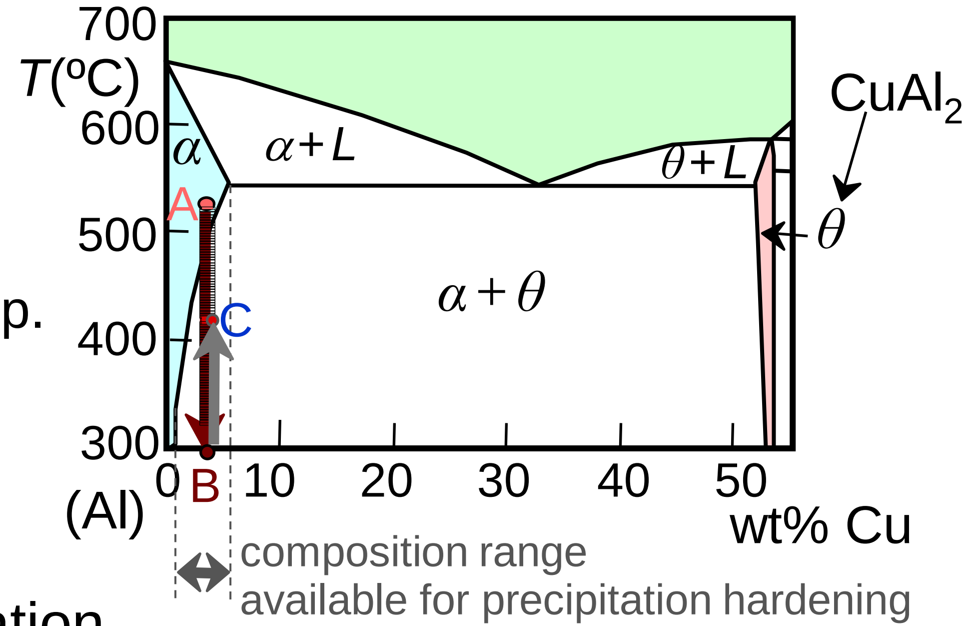
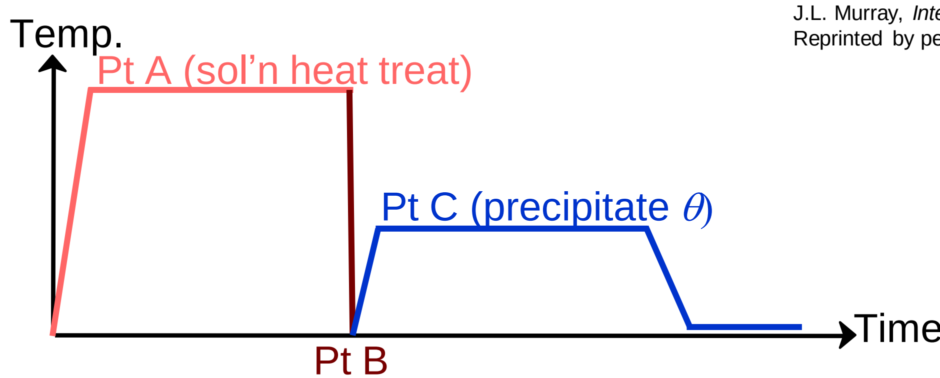


Fig. 11.29, *Callister & Rethwisch 10e*. (Adapted from J.L. Murray, *International Metals Review* **30**, p.5, 1985. Reprinted by permission of ASM International.)

- Other alloys that precipitation harden:
  - Cu-Be
  - Cu-Sn
  - Mg-Al



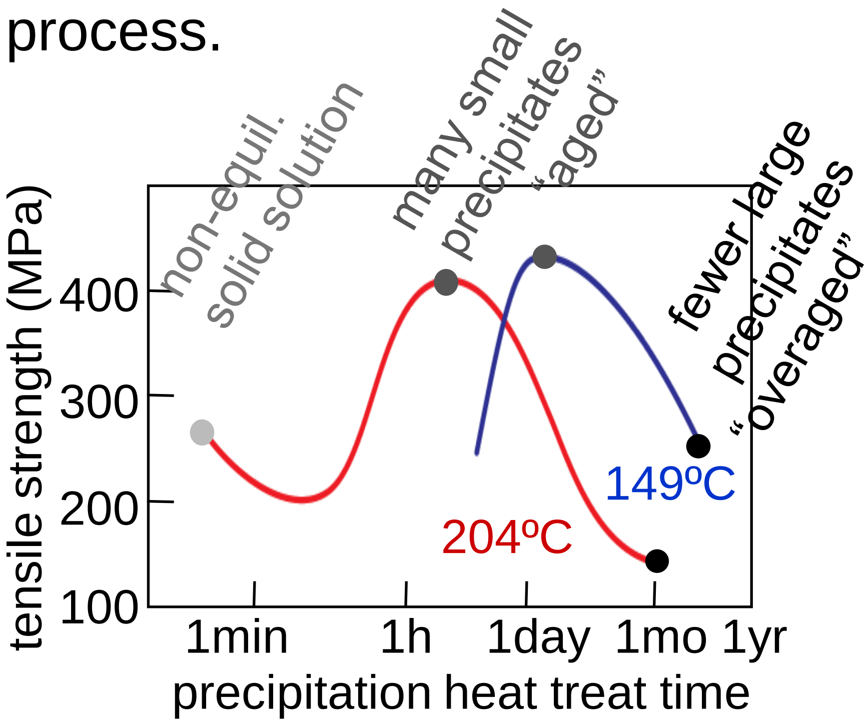
Adapted from Fig. 11.27, *Callister & Rethwisch 10e*.

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

- 2014 Al Alloy:

- Maxima on *TS* curves.
- Increasing *T* accelerates process.

- Minima on *%EL* curves.



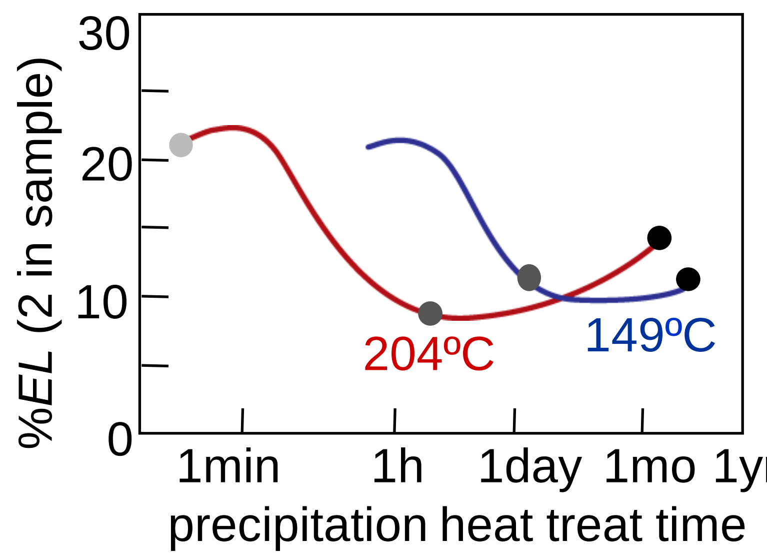


Fig. 11.32, *Callister & Rethwisch 10e.* [Adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker (Managing Ed.), 1979. Reproduced by permission of ASM International, Materials Park, OH.]

Summary

- Reduction action is applied to most metal making processes.
- Four casting methods: sand casting, investment casting, die casting, continuous casting.
- Four forming methods: forging, rolling, drawing and extrusion.
- Four important heat treatments: annealing, quenching, tempering, aging (precipitation hardening).
- Annealing includes stress relief, spheroidization, full annealing, process annealing.
- Quenching & Tempering are typically combined to produce high strength and balanced toughness of materials.
- Precipitation hardening or aging is strengthening materials due to formation of precipitate particles.

How to produce a kitchen knife?

Metal Making

Casting

Hot Rolling

Cold Rolling

Heat Treatment

Forming

Heat Treatment

Finishing

Questions?