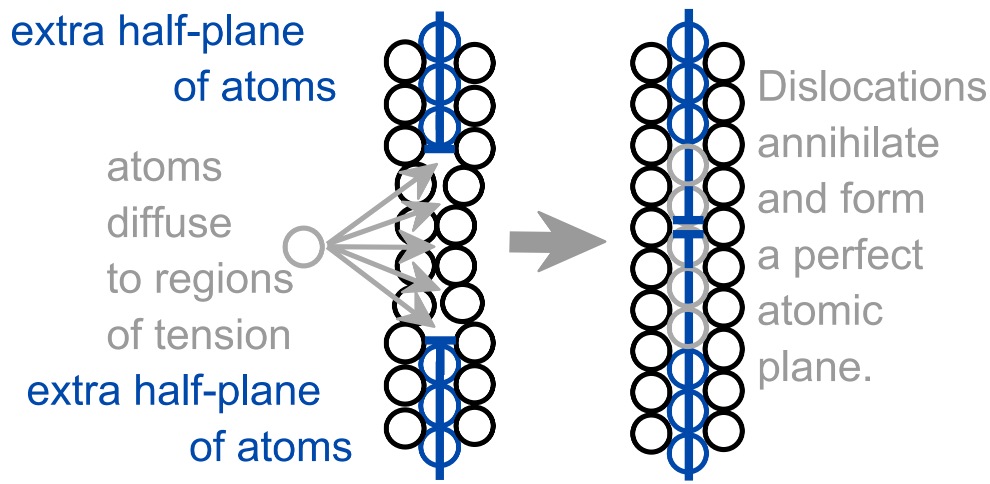
Recovery

- **Scenario 1**

  Results from diffusion

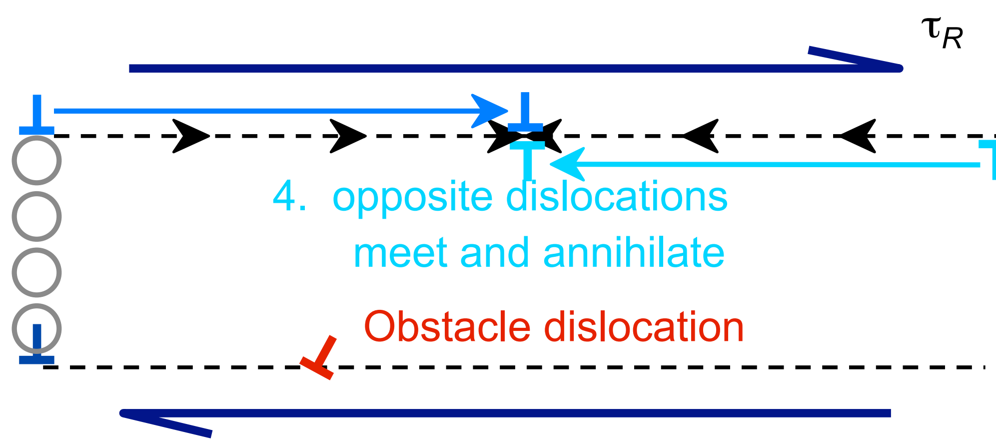


- **Scenario 2**

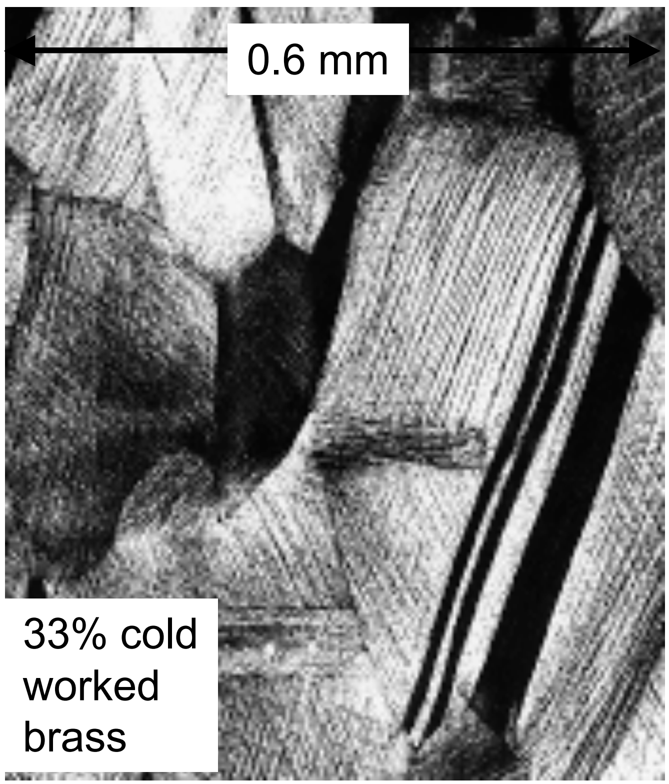
  3. “Climbed” disl. can now move on new slip plane

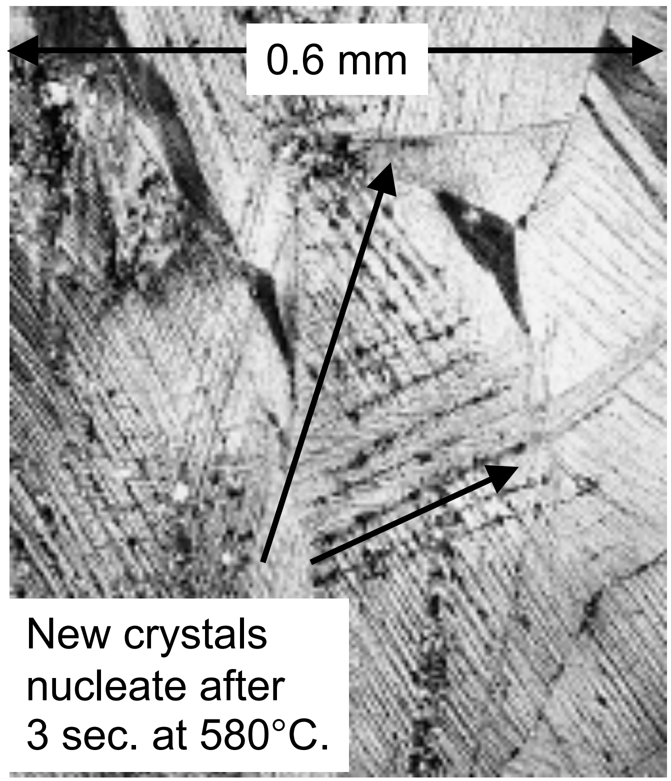
  2. grey atoms leave by vacancy diffusion allowing disl. to “climb”

  1. dislocation blocked; can’t move to the right



Recrystallization

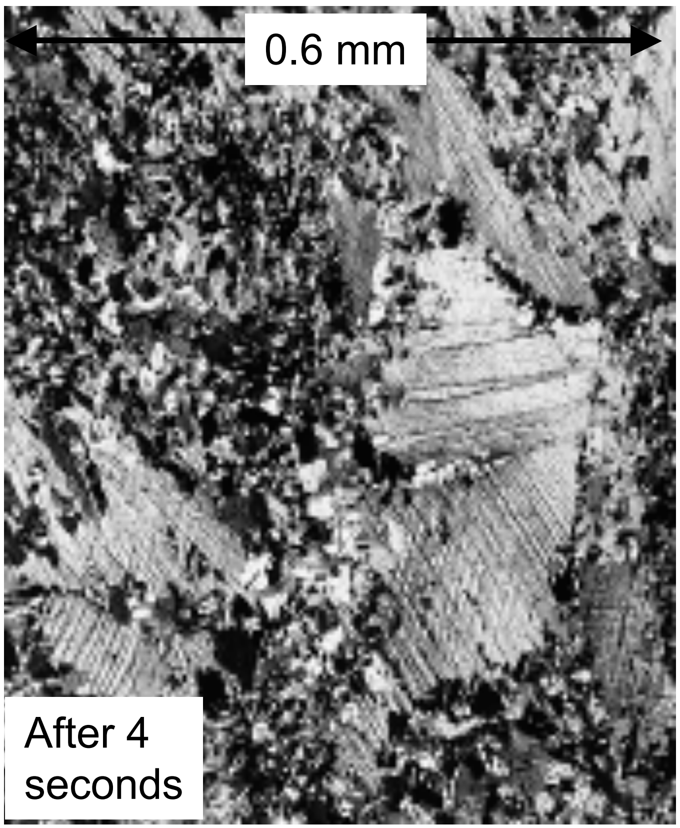


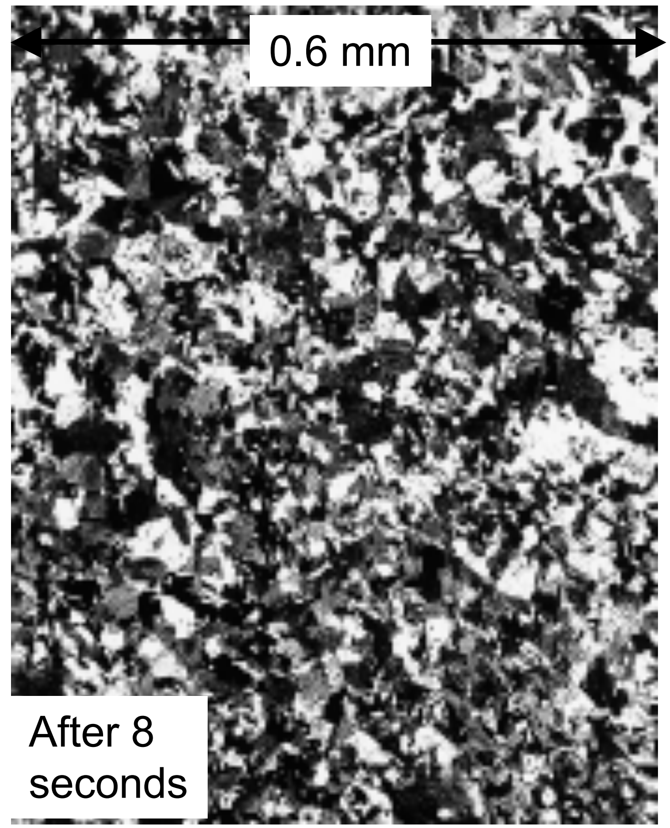


Adapted from Fig. 7.21 (a),(b), *Callister 7e.* (Fig. 7.21 (a),(b) are courtesy of J.E. Burke, General Electric Company.)

Further recrystallization

- All cold-worked grains are consumed.

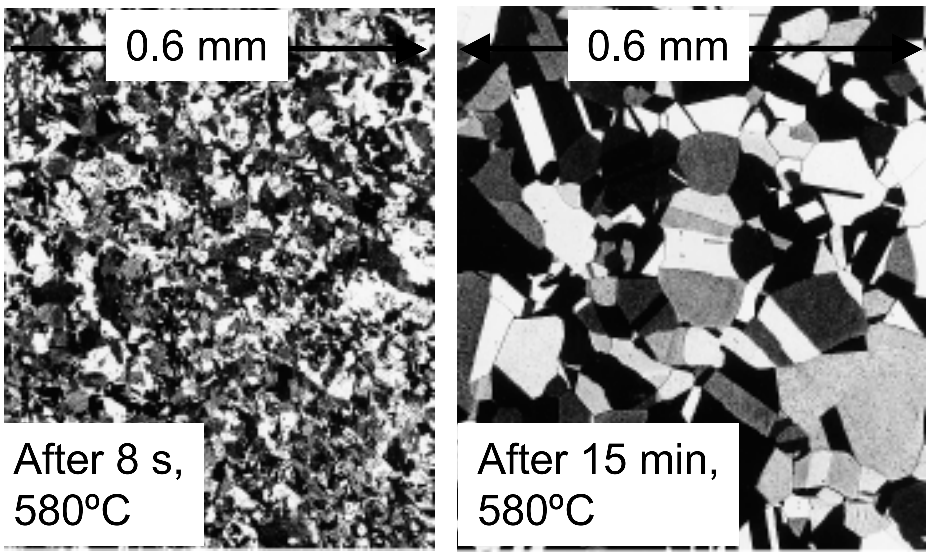




Adapted from
Fig. 7.21 (c),(d),
Callister 7e.
(Fig. 7.21 (c),(d)
are courtesy of
J.E. Burke,
General Electric
Company.)

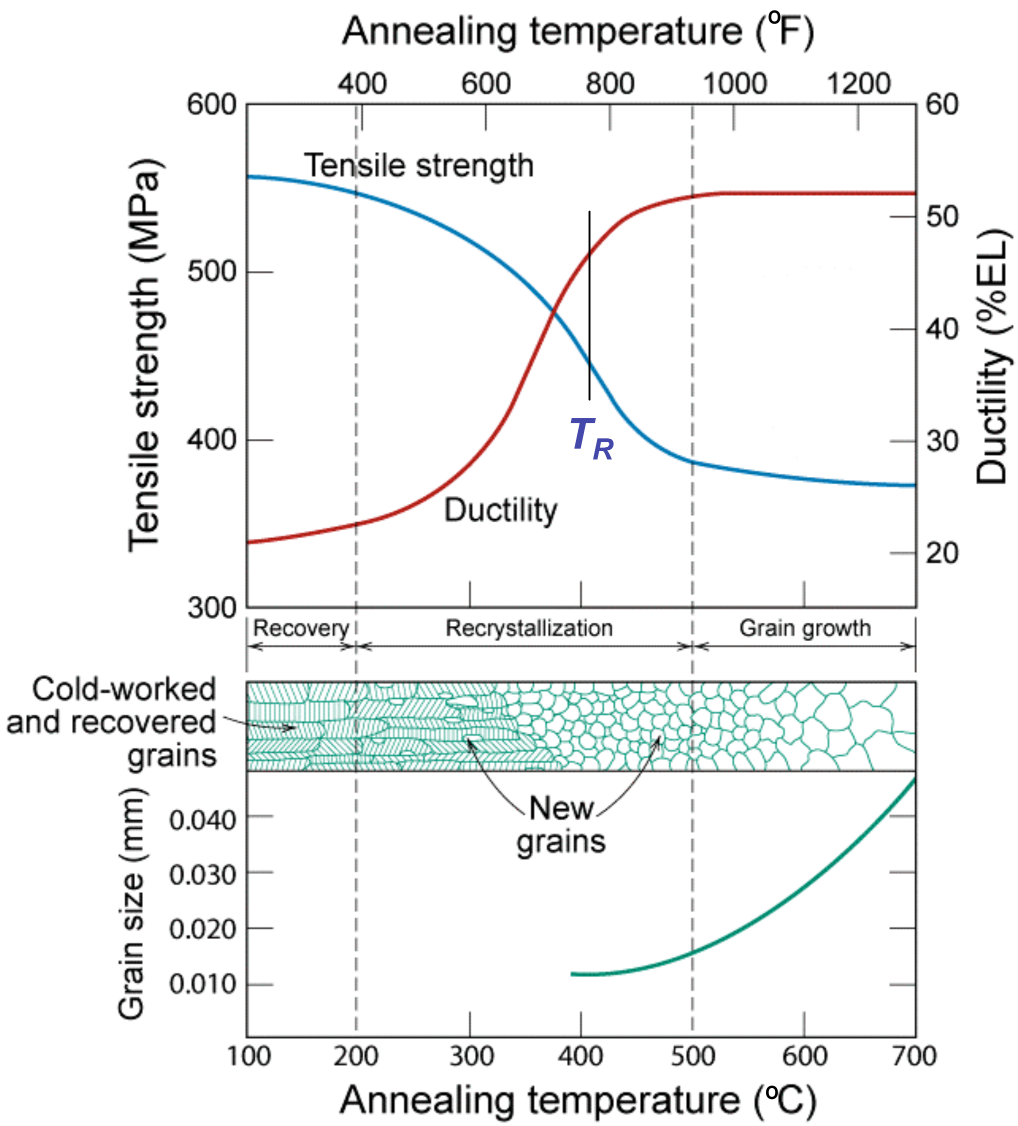
Grain growth

- At longer times, larger grains consume smaller ones.
- Why? Grain boundary area (and therefore energy) is reduced.



Adapted from Fig. 7.21 (d),(e), *Callister 7e.* (Fig. 7.21 (d),(e) are courtesy of J.E. Burke, General Electric Company.)

Influence of temperature on strength and ductility



Adapted from Fig. 7.22, *Callister 7e.*

Influence of temperature on strength and ductility

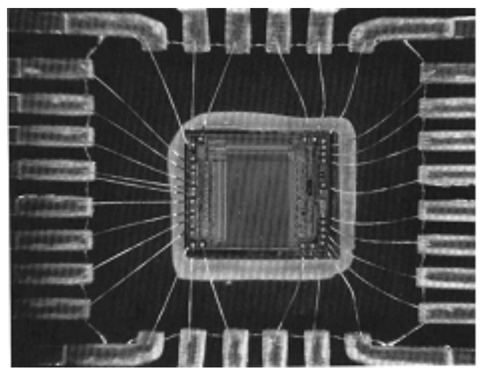
- ***T_R* = recrystallization temperature** **= point of highest rate of property change**

Mechanical failure

- How do flaws in a material initiate failure?
- How is fracture resistance quantified; how do different material classes compare?
- How do we estimate the stress to fracture?
- How do loading rate, loading history, and temperature affect the failure stress?

Ship-cyclic loading from waves.

Adapted from chapter-opening photograph, Chapter 8, *Callister 7e.* (by Neil Boenzi, *The New York Times.*)



Computer chip-cyclic thermal loading.

Adapted from Fig. 22.30(b), *Callister 7e.* (Fig. 22.30(b) is courtesy of National Semiconductor Corporation.)

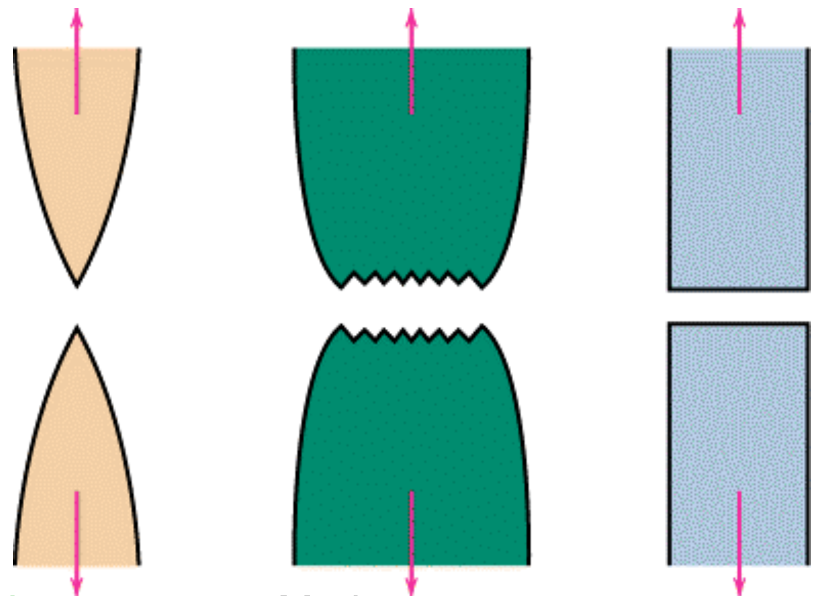
Hip implant-cyclic loading from walking.

Adapted from Fig. 22.26(b), *Callister 7e.*

Ductile vs. brittle failure

- Classification:

Fracture behavior:	Very Ductile	Moderately Ductile	Brittle



Adapted from Fig. 8.1, *Callister 7e.*

%*AR* or %*EL*	Large	Moderate	Small

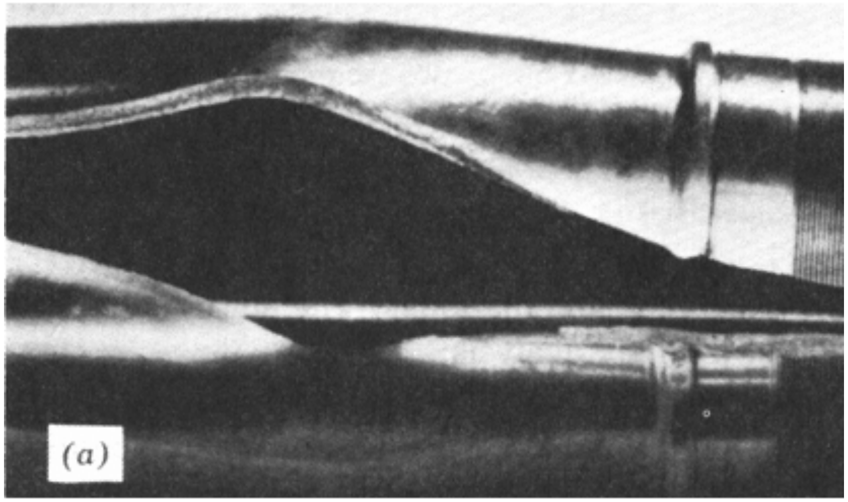
- Ductile fracture is usually desirable!

Ductile: warning before fracture

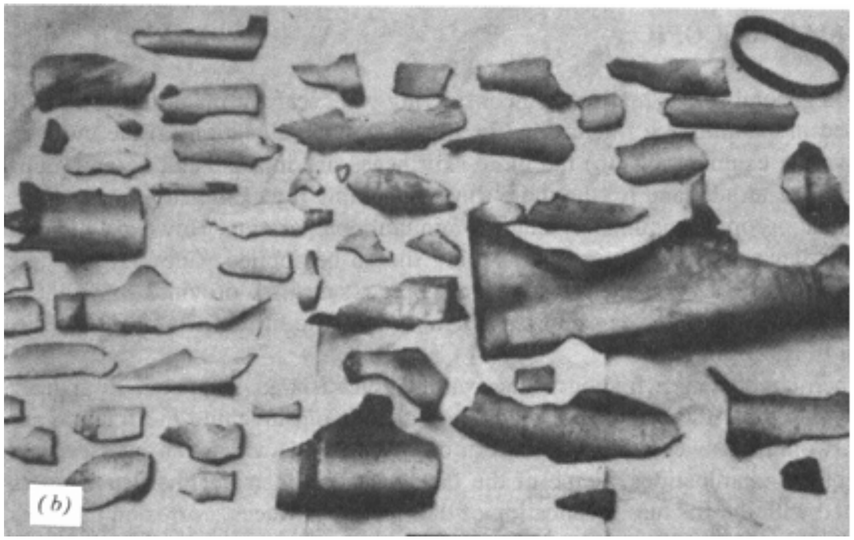
Brittle: No warning

Example: failure of a pipe

- **Ductile failure:**



- **Brittle failure:**



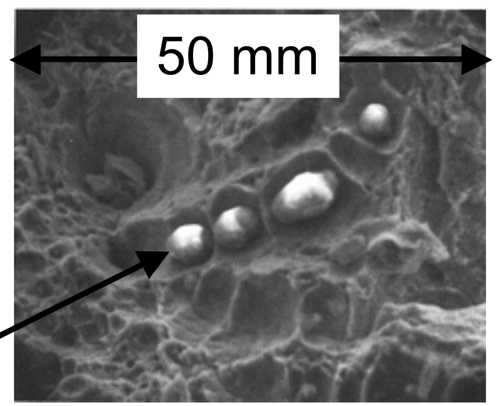
Figures from V.J. Colangelo and F.A. Heiser, *Analysis of Metallurgical Failures* (2nd ed.), Fig. 4.1(a) and (b), p. 66 John Wiley and Sons, Inc., 1987. Used with permission.

Moderately ductile failure

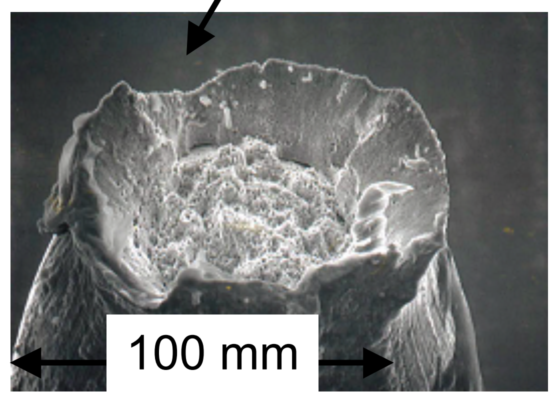
- Evolution to failure:

- Resulting fracture surfaces (steel)

particles serve as void nucleation sites.



From V.J. Colangelo and F.A. Heiser, *Analysis of Metallurgical Failures* (2nd ed.), Fig. 11.28, p. 294, John Wiley and Sons, Inc., 1987. (Orig. source: P. Thornton, *J. Mater. Sci.*, Vol. 6, 1971, pp. 347-56.)



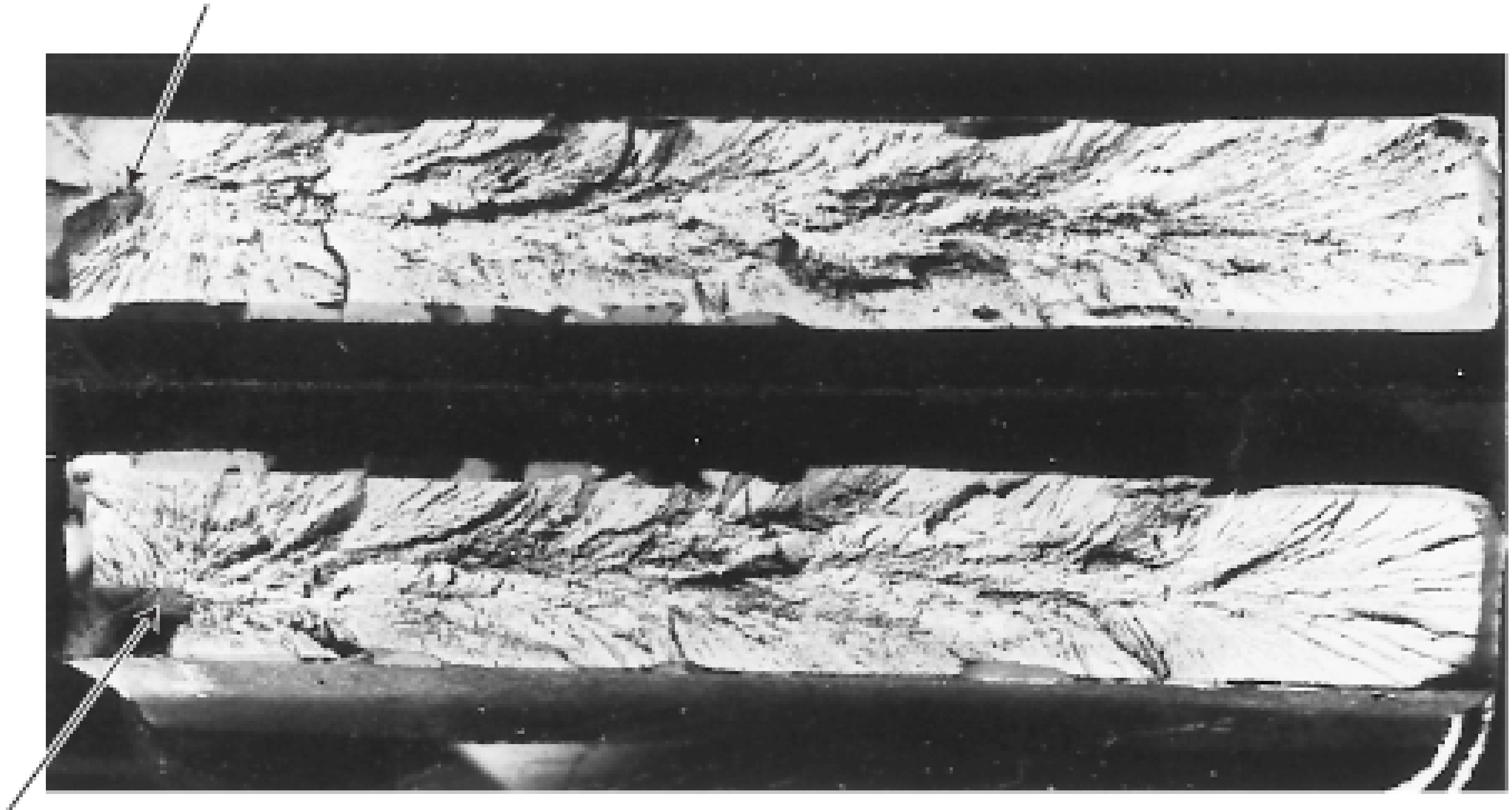
Fracture surface of tire cord wire loaded in tension. Courtesy of F. Roehrig, CC Technologies, Dublin, OH. Used with permission.

Ductile vs. brittle failure

Adapted from Fig. 8.3, *Callister 7e.*

Brittle failure

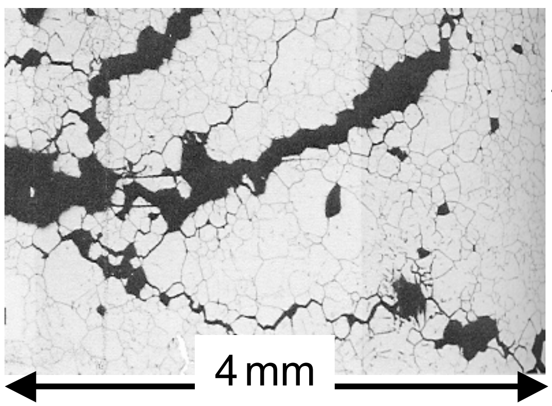
Arrows indicate point at which failure originated



(a)

Adapted from Fig. 8.5(a), *Callister 7e.*

Brittle fracture surfaces



304 S. Steel (metal)

Reprinted w/permission from "Metals Handbook", 9th ed, Fig. 633, p. 650. Copyright 1985, ASM International, Materials Park, OH. (Micrograph by J.R. Keiser and A.R. Olsen, Oak Ridge National Lab.)

316 S. Steel (metal)

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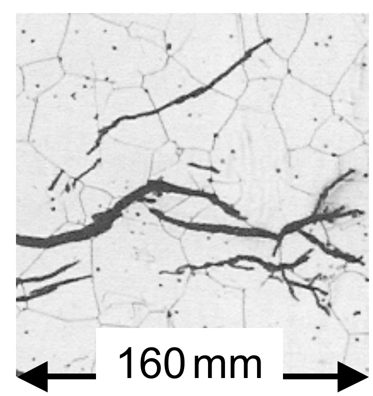
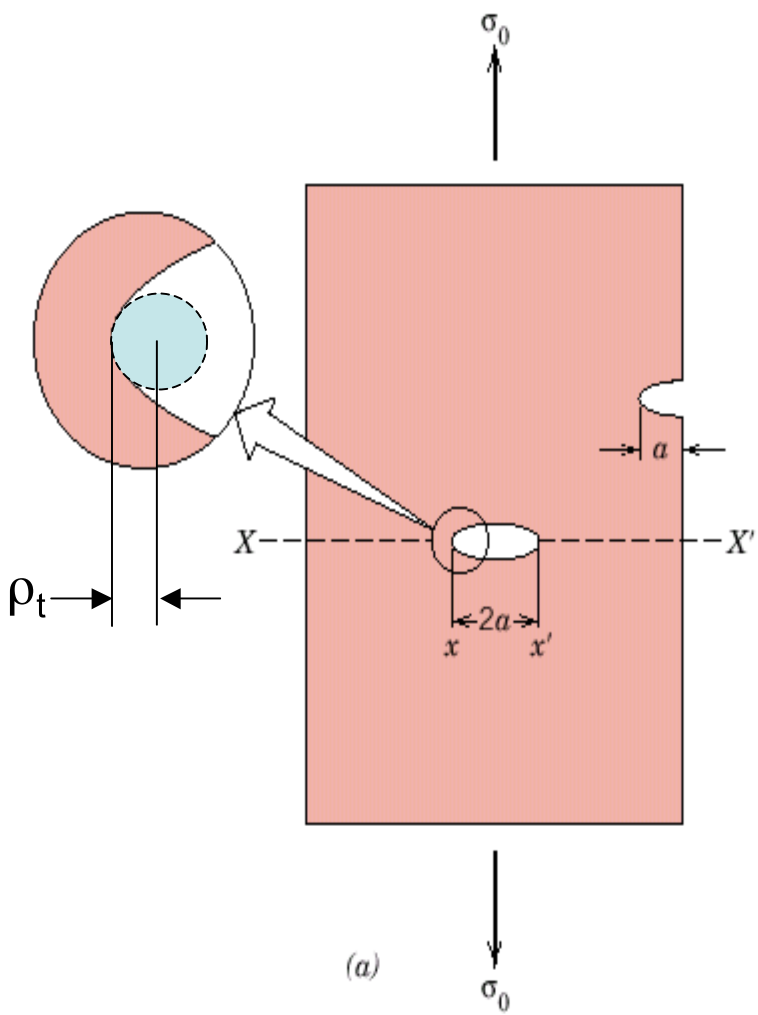


Ideal vs. real materials

- Stress-strain behavior (Room *T*):

Ideal vs. real materials



Adapted from Fig. 8.8(a), *Callister 7e.*

Crack propagation

Crack propagates if above critical stress

where

E = modulus of elasticity

γ_s = specific surface energy

a = one half length of internal crack

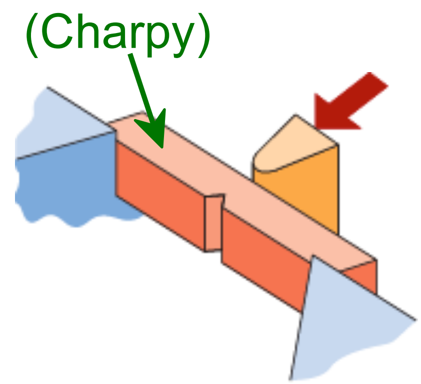
$K_c = \sigma_c / \sigma_0$

For ductile => replace γ_s by $\gamma_s + \gamma_p$

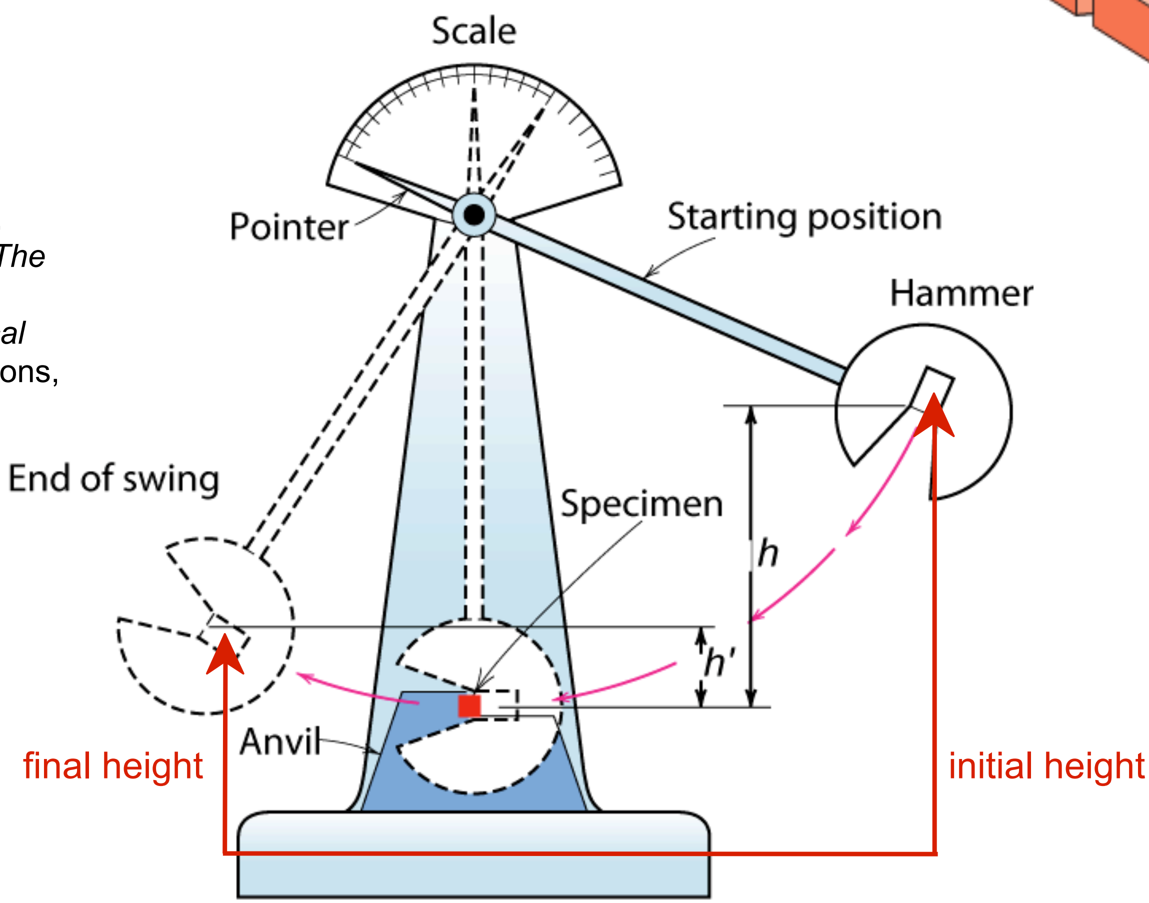
where γ_p is plastic deformation energy

Impact testing

- Impact loading:
  - -- severe testing case
  - -- makes material more brittle
  - -- decreases toughness



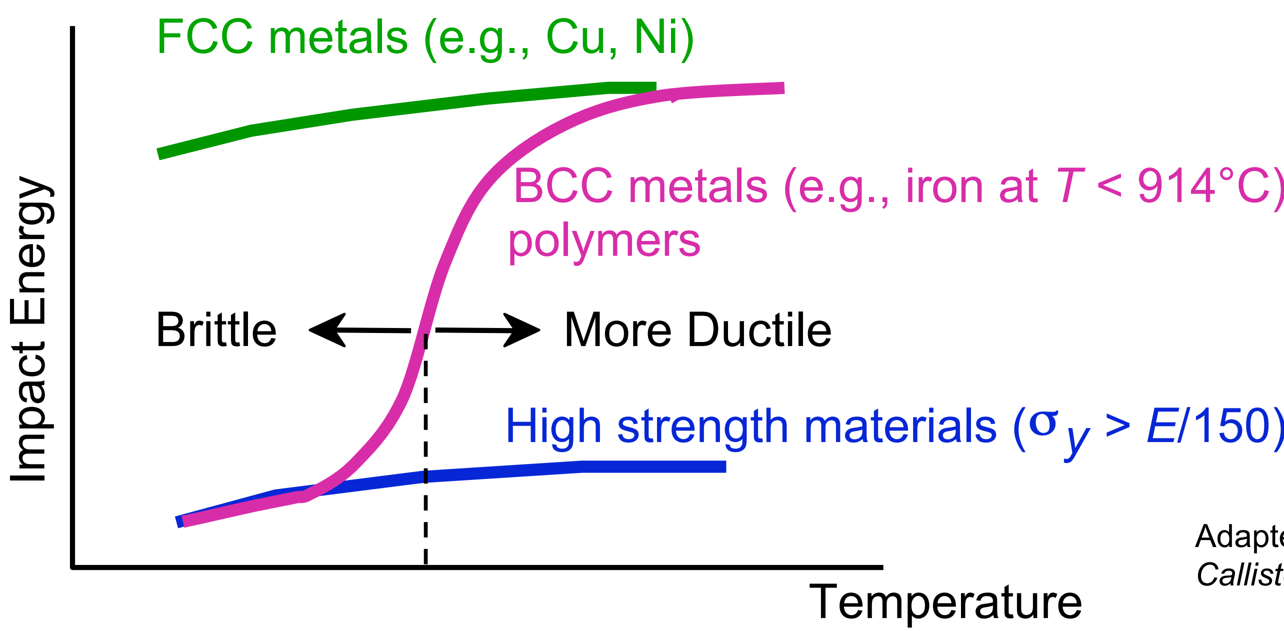
Adapted from Fig. 8.12(b), *Callister 7e.* (Fig. 8.12(b) is adapted from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, John Wiley and Sons, Inc. (1965) p. 13.)



Temperature effects

- **Increasing temperature...**
  --increases %EL and K_c

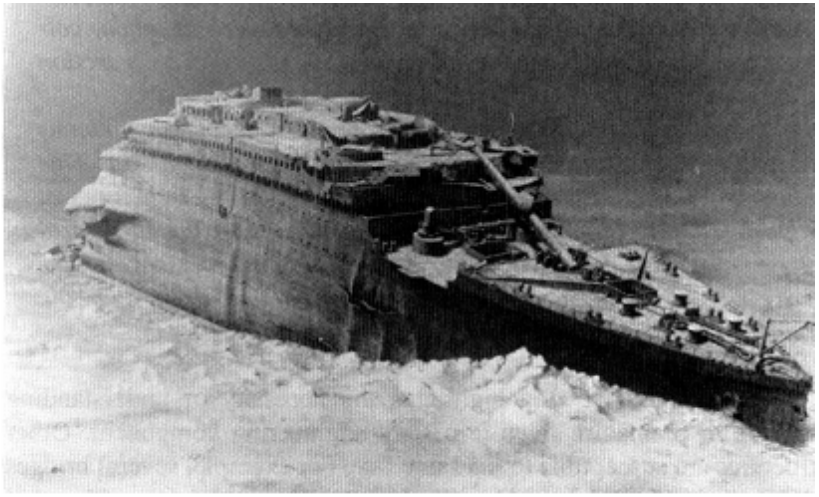
- **Ductile-to-Brittle Transition Temperature (DBTT)...**



Adapted from Fig. 8.15, *Callister 7e.*

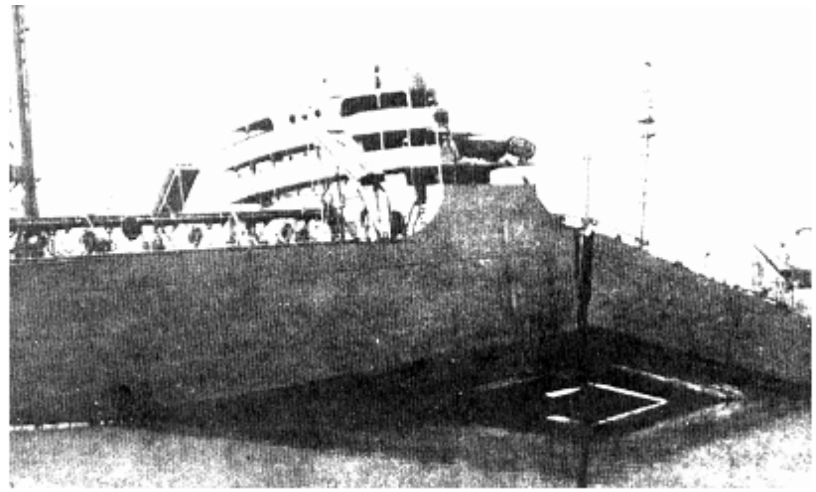
Stay above DBTT

- **Pre-WWII: The Titanic**



Reprinted w/ permission from R.W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials", (4th ed.) Fig. 7.1(a), p. 262, John Wiley and Sons, Inc., 1996. (Orig. source: Dr. Robert D. Ballard, *The Discovery of the Titanic*.)

- **WWII: Liberty ships**



Reprinted w/ permission from R.W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials", (4th ed.) Fig. 7.1(b), p. 262, John Wiley and Sons, Inc., 1996. (Orig. source: Earl R. Parker, "Behavior of Engineering Structures", Nat. Acad. Sci., Nat. Res. Council, John Wiley and Sons, Inc., NY, 1957.)

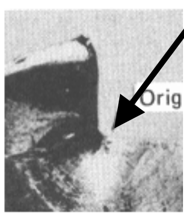
- Problem: Used a type of steel with a DBTT ~ Room temp.

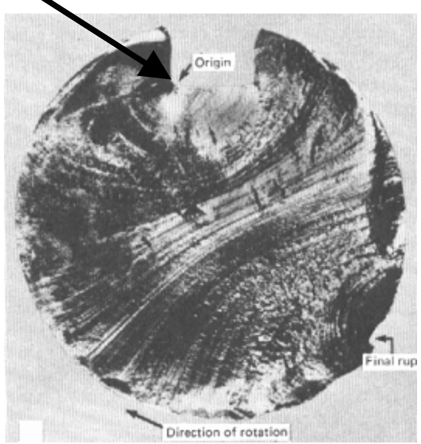
Fatigue

- Fatigue limit, σ_{fat}:
  --no fatigue if $\sigma < \sigma_{fat}$

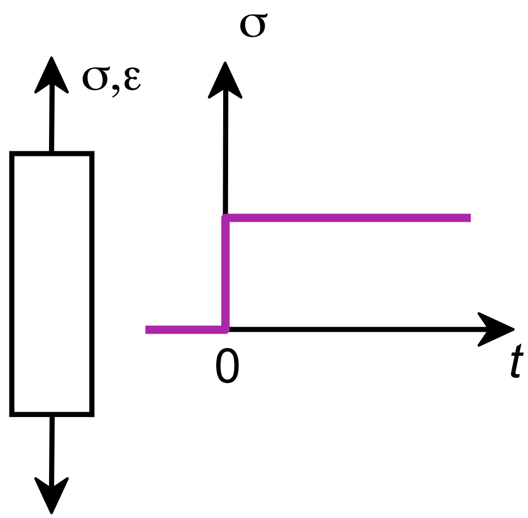
- Sometimes, the
  fatigue limit is zero!

crack origin





Creep

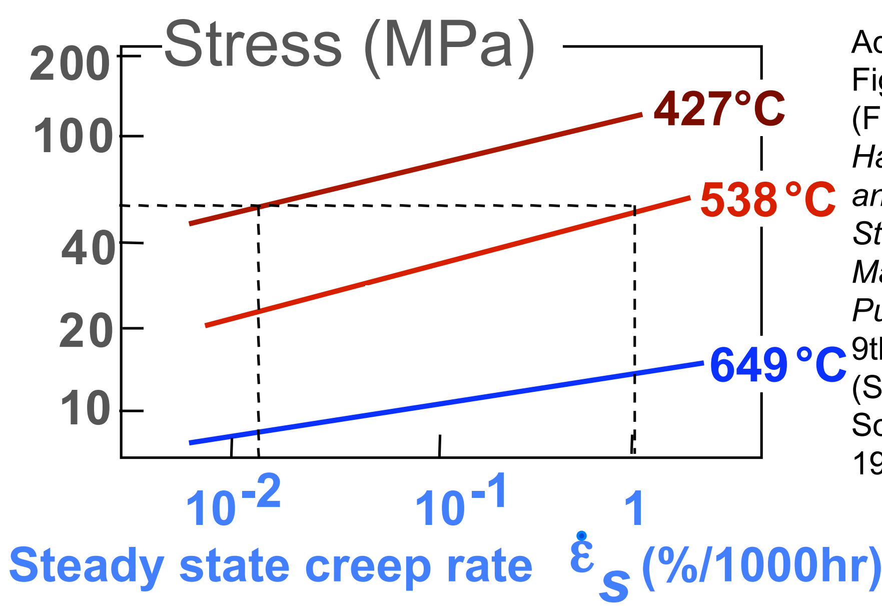


Adapted from
Fig. 8.28, *Callister 7e.*

Secondary creep

- Strain rate is constant at a given *T*, σ
  -- strain hardening is balanced by recovery

- Strain rate increases for higher *T*, σ



Adapted from Fig. 8.31, *Callister 7e.* (Fig. 8.31 is from *Metals Handbook: Properties and Selection: Stainless Steels, Tool Materials, and Special Purpose Metals*, Vol. 3, 9th ed., D. Benjamin (Senior Ed.), American Society for Metals, 1980, p. 131.)