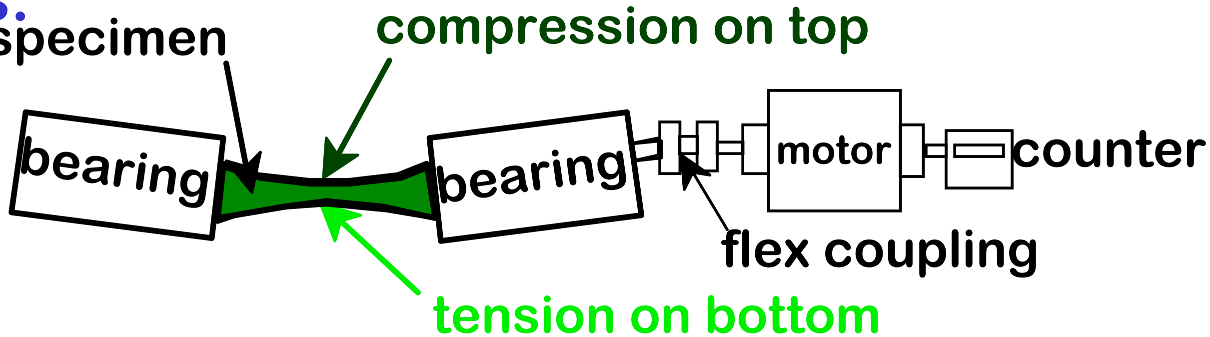
Chapter 8 Failure (Fatigue and creep)

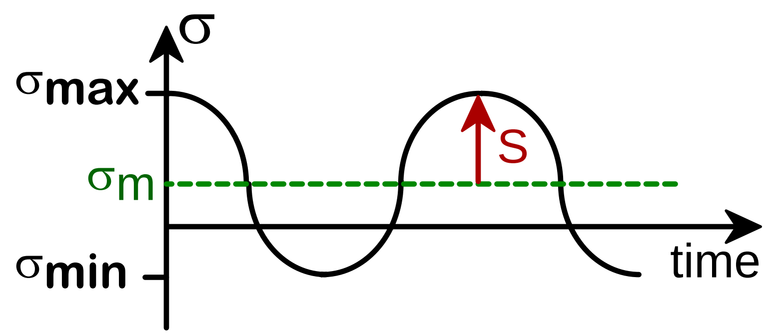
- Fatigue
- Fatigue life and design
- Fatigue mechanisms
- Factors that affect fracture life
- Generalized creep behavior
- Stress and temperature effects

Fatigue

- **Fatigue = failure under cyclic stress.**



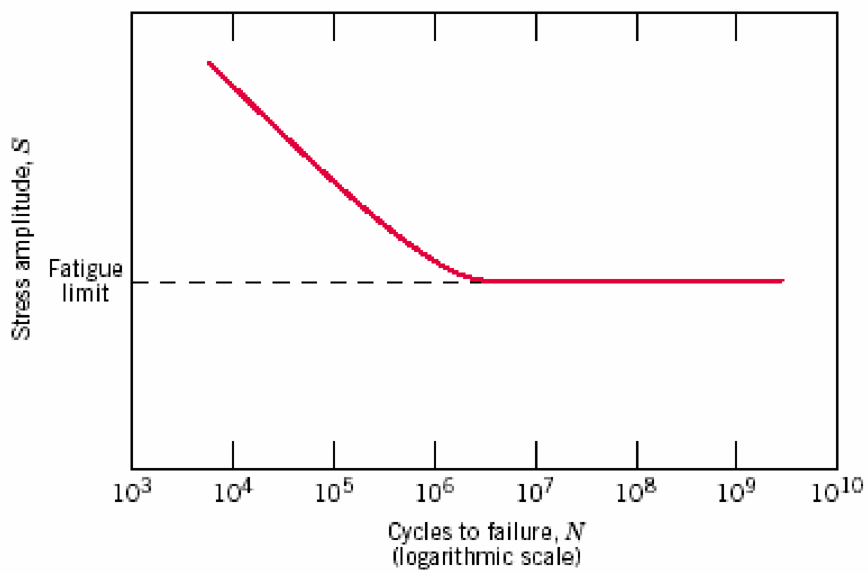
- **Stress varies with time.**
  - **--key parameters are S and σ_m**



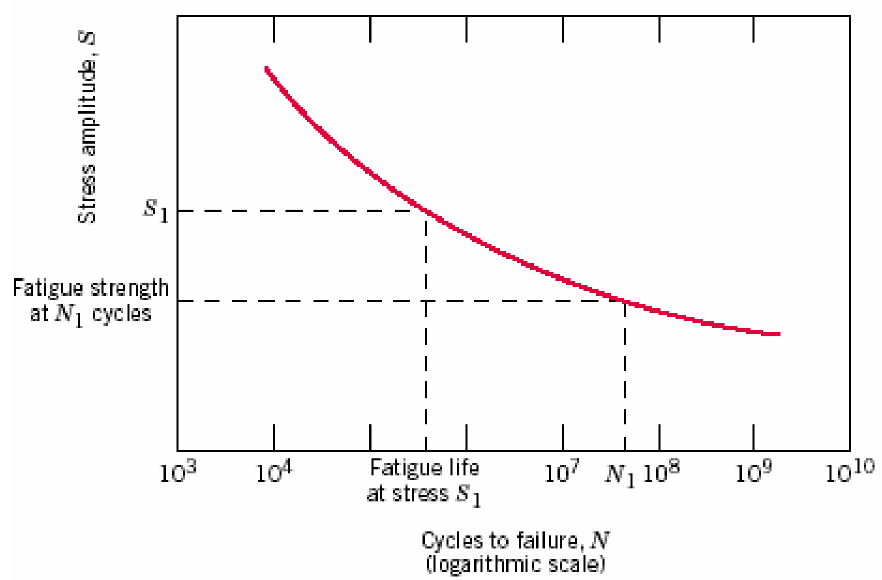
- **Key points: Fatigue...**
  - **--can cause part failure, even though $\sigma_{max} < \sigma_c$.**
  - **--causes ~ 90% of mechanical engineering failures.**

Fatigue life

- Stress amplitude (S) versus number of cycles to fatigue failure
- σ_{max}=2/3 σ
- Fatigue limits =35-60% of tensile strength
- Fatigue life



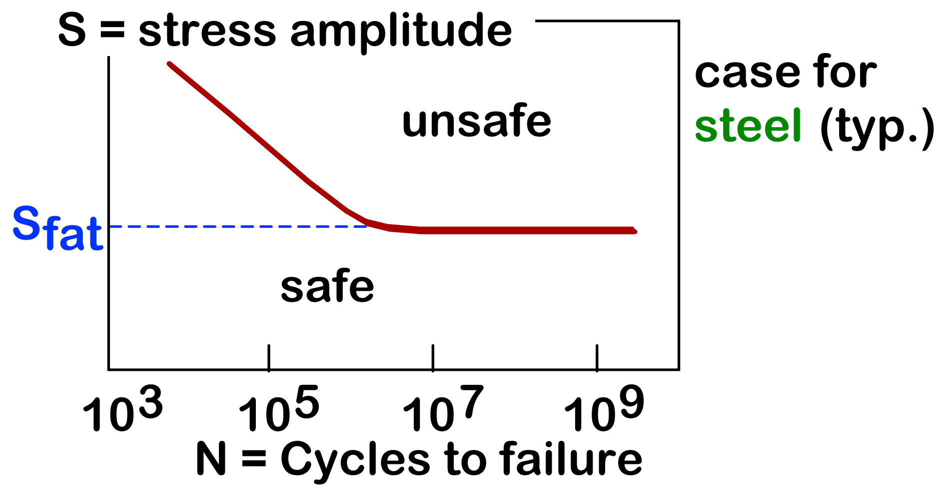
(a)



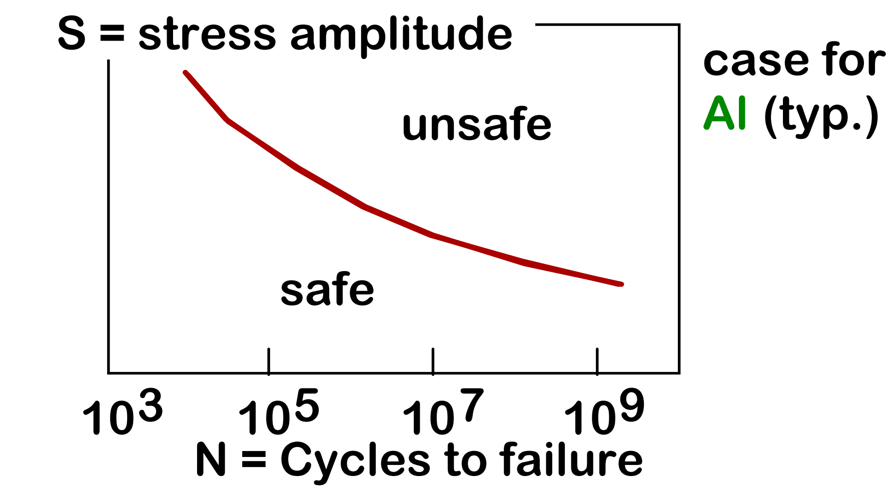
(b)

Fatigue design parameters

- Fatigue limit, S_{fat}:
  --no fatigue if $S < S_{fat}$



- Sometimes, the fatigue limit is zero!



Fatigue mechanism

- Crack grows *incrementally*

$$\frac{da}{dN} = (\Delta K)^m$$

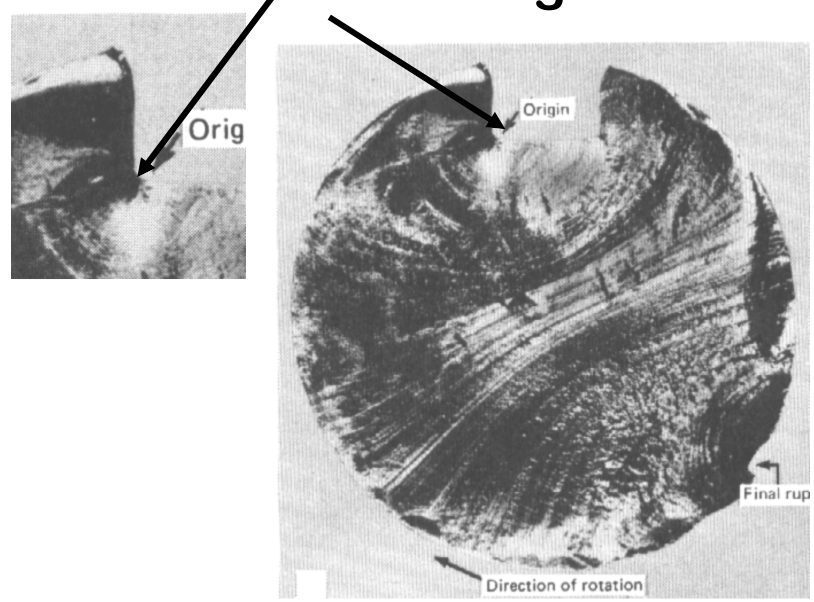
m: typ. 1 to 6

$\Delta K \sim (\Delta\sigma)\sqrt{a}$

$\frac{da}{dN}$: increase in crack length per loading cycle

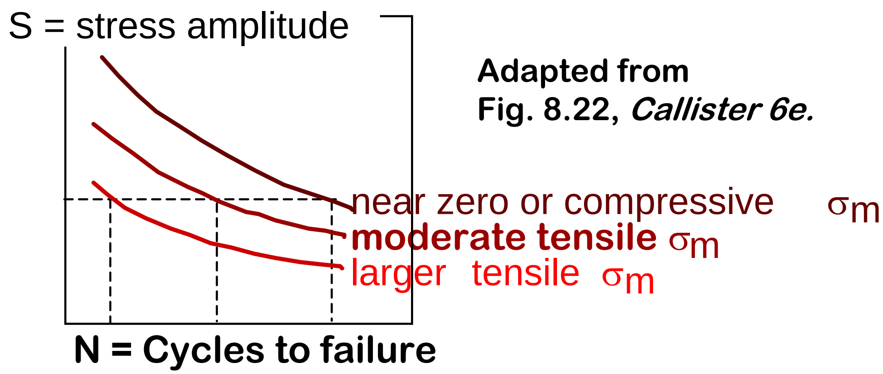
- Failed rotating shaft
  - --crack grew even though
    - $K_{max} < K_c$
  - --crack grows faster if
    - $\Delta\sigma$ increases
    - crack gets longer
    - loading freq. increases.

crack origin



Improving fatigue life

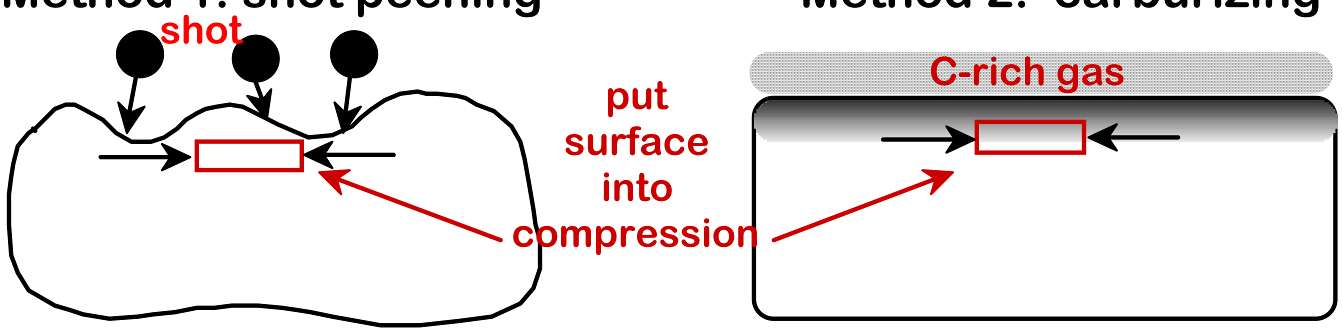
- Impose a compressive surface stress (to suppress surface cracks from growing)



Adapted from Fig. 8.22, *Callister 6e.*

--Method 1: shot peening

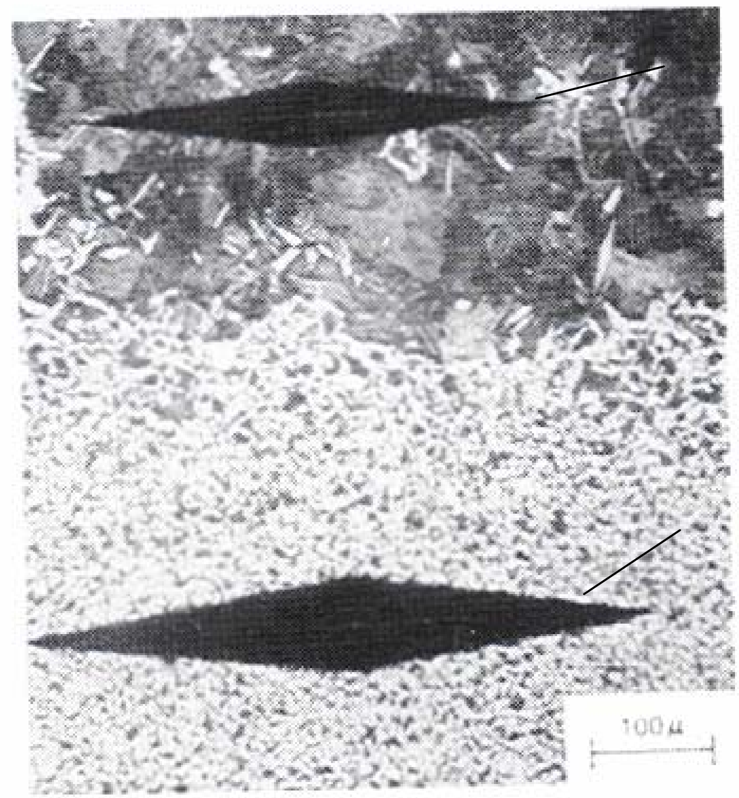
--Method 2: carburizing



- Remove stress concentrators

Factors that affect fatigue life

- Mean stress
- Surface effects
  - Design factors
  - Surface treatments
  - Case hardening



Carburized steel

Core steel

Environmental effects

- Thermal fatigue: induced at elevated temperatures by fluctuating thermal stresses.

$$\sigma = \alpha_l E \Delta T$$

- Corrosion fatigue: failure occurs by the simultaneous action of a cyclic stress and chemical attack

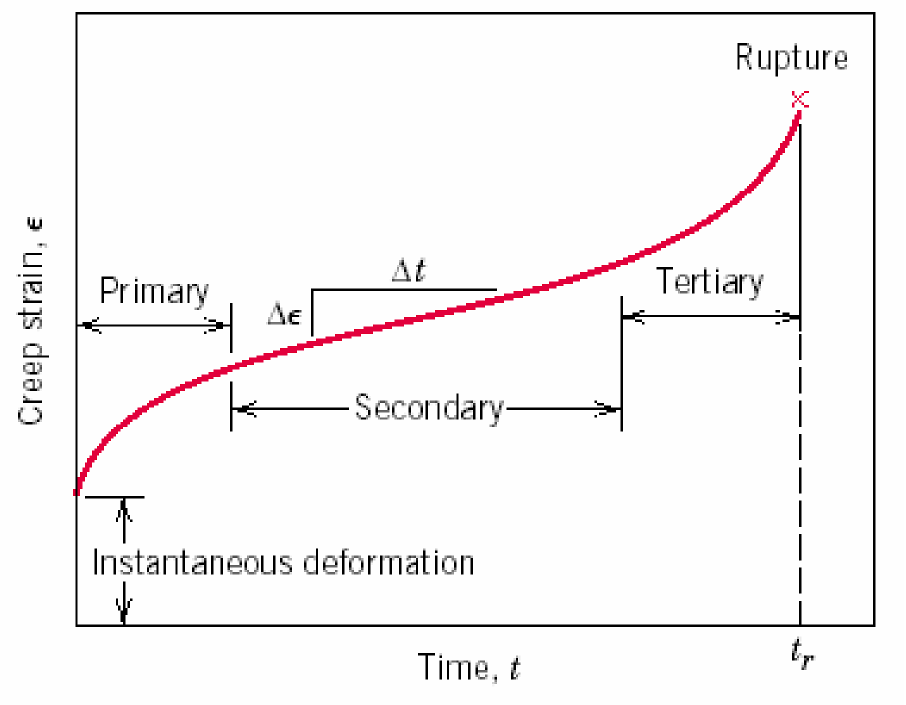
Generalized creep behavior

Conditions for creep to occur

- elevated temperature
- static mechanical stresses

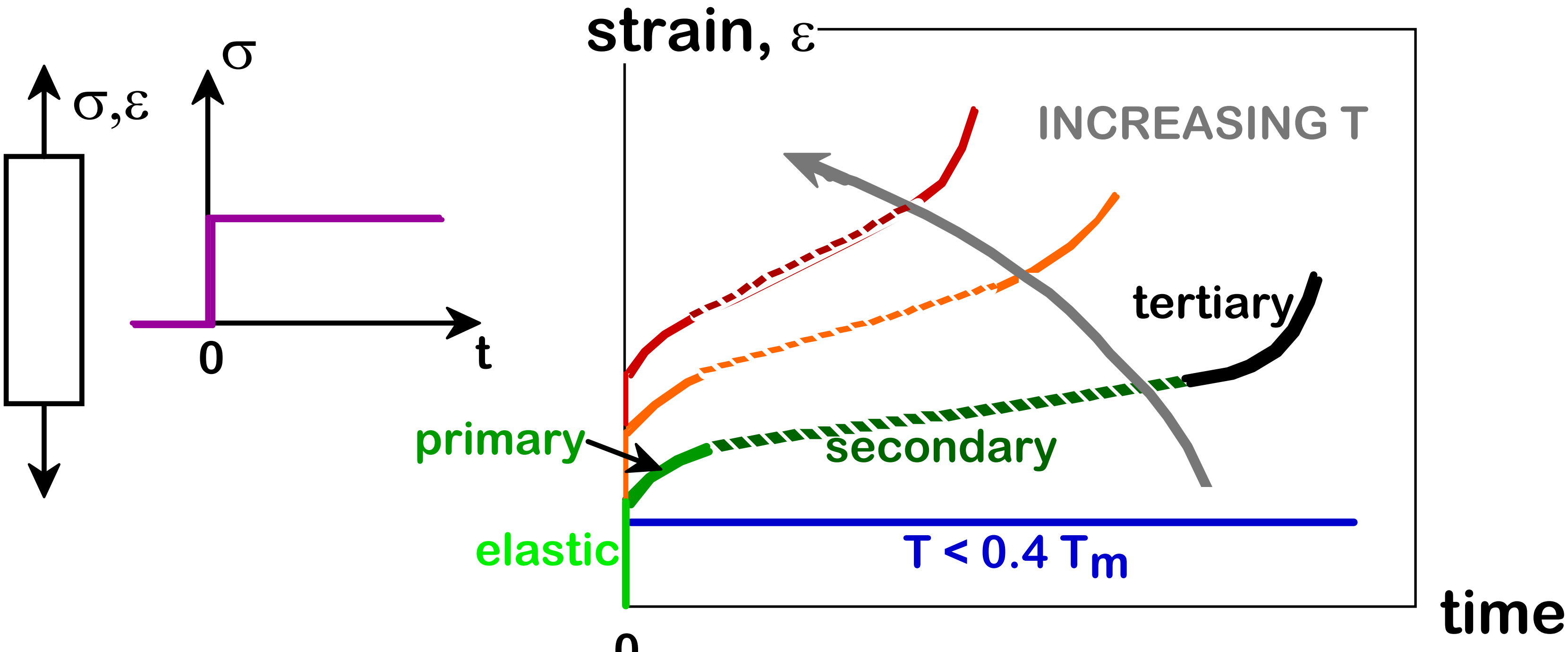
Creep behavior

- primary creep
- steady-state creep
- tertiary creep
- rupture



Creep

- Occurs at elevated temperature, $T > 0.4\ T_{melt}$
- Deformation changes with time.



Adapted from Figs. 8.26 and 8.27, *Callister 6e.*

Creep Failure

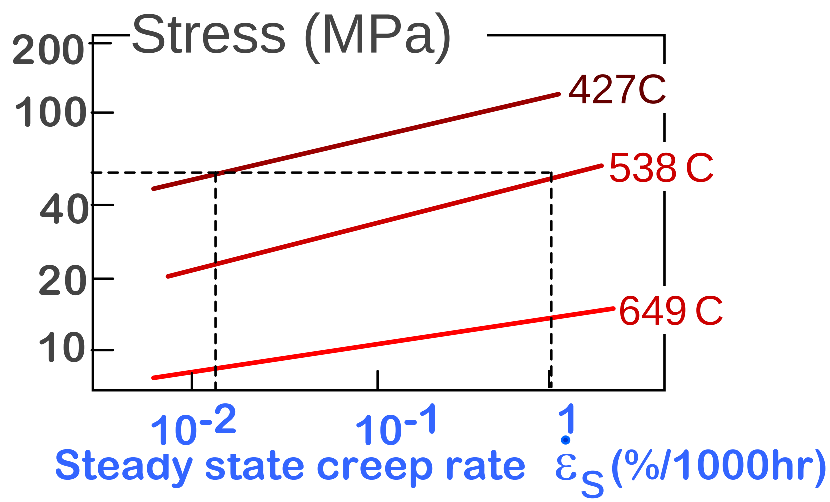
- Most of component life spent here.
- Strain rate is constant at a given T, σ

--strain hardening is balanced by recovery

$$\dot{\varepsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

strain rate ($\dot{\varepsilon}_s$); material const. (K_2); applied stress (σ); stress exponent (material parameter) (n); activation energy for creep (material parameter) (Q_c)

- Strain rate increases for larger T, σ

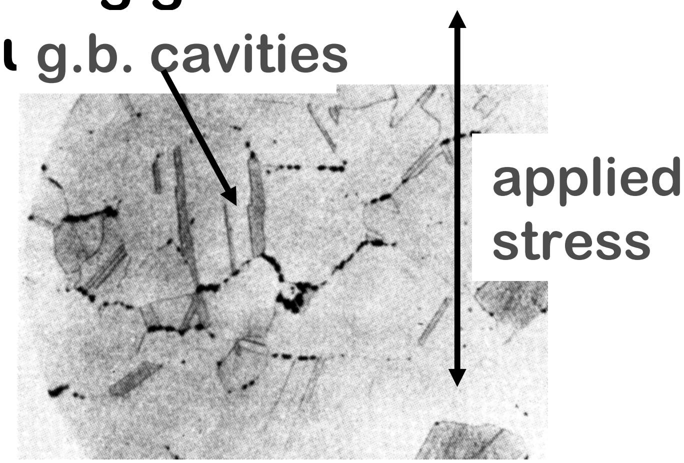


Examples

□ **Failure:**

along grain

bou



- **Time to rupture, t_r**

$$T(20 + \log t_r) = L$$

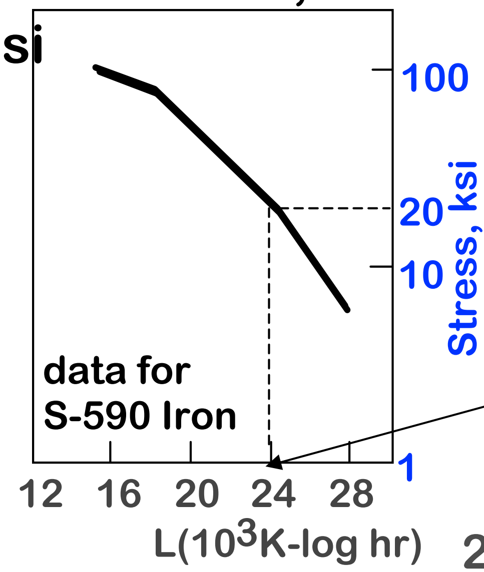
temperature

time to failure (rupture)

function of applied stress

□ **Estimate rupture time**

S 590 Iron, T = 800C, σ = 20 ksi



24×10^3 K-log hr

$$T(20 + \log t_r) = L$$

1073K

Ans: t_r = 233hr

Summary

- ☐ **Failure type depends on T and stress:**

  - for noncyclic σ and $T < 0.4T_m$, failure stress decreases with:
    increased maximum flaw size,
    decreased T,
    increased rate of loading.
  - for cyclic σ:
    cycles to fail decreases as $\Delta\sigma$ increases.
  - for higher T ($T > 0.4T_m$):
    time to fail decreases as σ or T increases.