Lecture 21

November 13, 2003
Fracture embrittlement

- High strain rate
- Low temperature
- Environmental effect (stress corrosion)
  - water, chemical vapor or solution
Stress corrosion: a story

• Cracking of brass cartridges in stables

• Causes of cracking:
  – Residual stress (due to manufacturing process)
  – Ammonia from horse urine

• Engineering solution:
  – Proper heat treatment to reduce stress
Stress corrosion: mechanism

- Stress: open cracks to allow environmental species to attack the crack tip

- Corrosion: chemical reaction to reduce the bond strength

- With the “help” of the environment, crack grows slowly under static loading even though $K < K_c$ (subcritical cracking).
Environmentally assisted crack growth

- For a given environment, crack growth rate depends on the stress intensity factor $K$.

\[
\frac{da}{dt} = f(K)
\]

$f(K)$ is to be determined experimentally for a specific material in a specific environment.
Crack growth regions

- Region I: diffusion controls. Very sensitive to $K$, moderately sensitive to environment.

- Region II: insensitive to $K$, but sensitive to environment.

- Region III: fast fracture, insensitive to environment.
Design rules

- For infinite lifetime, use $K_{th}$.

- For finite lifetime, use the crack growth law for Region I.

\[
\frac{da}{dt} = AK^n \quad (n \sim 10)
\]
Lifetime prediction

\[ K = \sigma \sqrt{\pi a} \quad \rightarrow \quad a_c = \frac{1}{\pi} \left( \frac{K_c}{\sigma_{\text{max}}} \right)^2 \]

Assume \( W >> a_c >> a_0 \)

\[ t_f = \int_{a_0}^{a_c} \frac{da}{AK^n} = \frac{2}{A \sigma^n \pi^{n/2} (n-2)} \left[ \frac{1}{a_0^{n/2-1}} - \frac{1}{a_c^{n/2-1}} \right] \]

The lifetime is sensitive to both the stress and the initial crack length.
Crack arresting

- Stress intensity factor decreases as the crack grows.
- Crack arrests when SIF drops below the threshold value.

\[ K = \frac{3.975M}{a^{3/2}} \]