# ASE324: Aerospace Materials Laboratory

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# Lecture 18

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# Fracture criterion

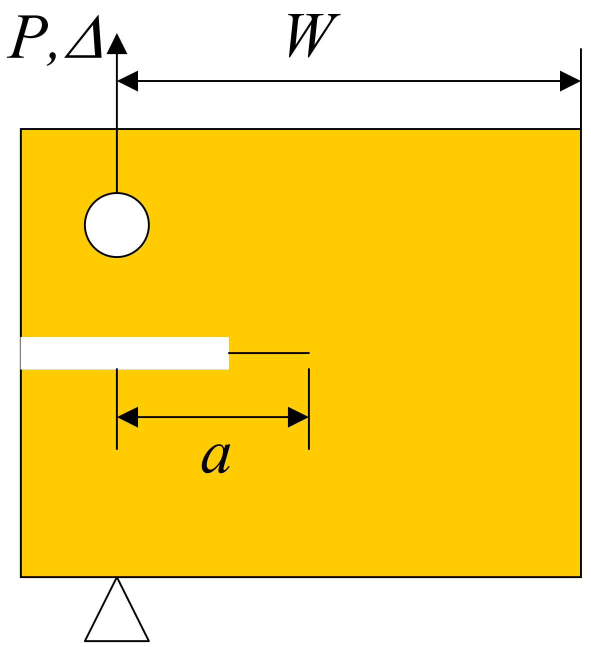
$$K(a, P, \ldots) = K_c$$

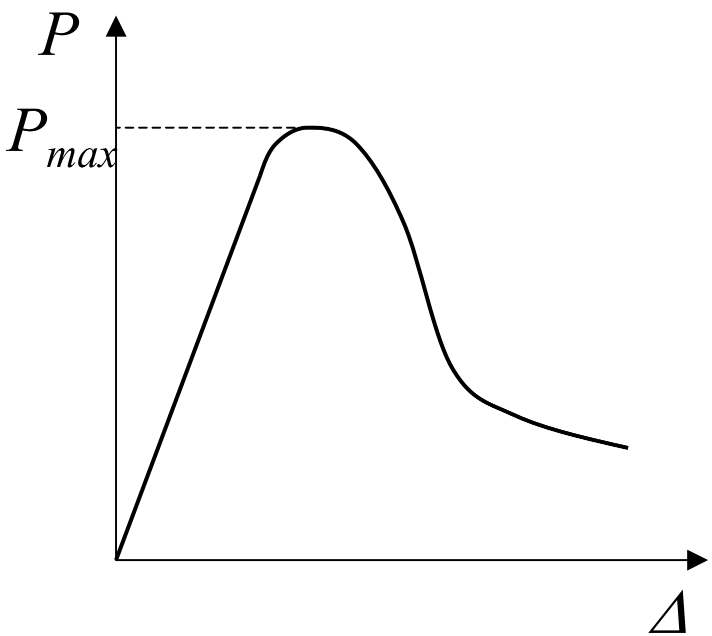
- For a fixed crack size, predict the critical load for the onset of fast fracture.
- For a fixed load, predict critical crack size.

- Measuring fracture toughness: introduce a crack of certain size and determine the critical load to cause fast fracture.

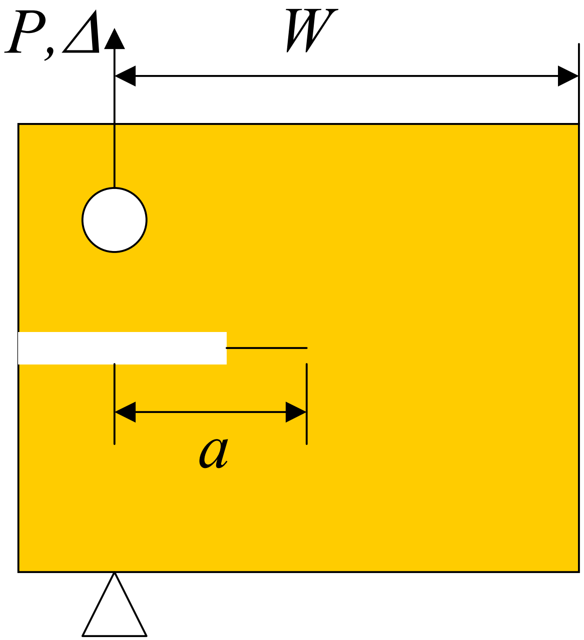
# Fracture toughness testing

- Compact tension specimen, with initial crack produced by fatigue.
- Ramp displacement loading, and measure the maximum load to determine the toughness.



# Compact tension specimen




Stress intensity factor:

$$K = \frac{P}{b\sqrt{W}} f\left(\frac{a}{W}\right)$$

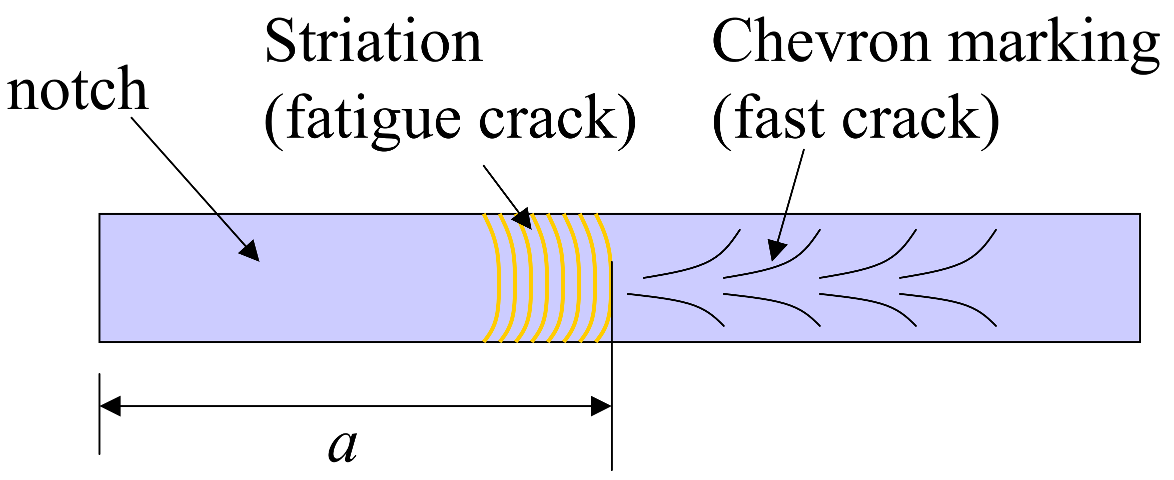
Fracture toughness:

$$K_c = \frac{P_{\max}}{b\sqrt{W}} f\left(\frac{a}{W}\right)$$

What would happen when *a* or *b* varies?

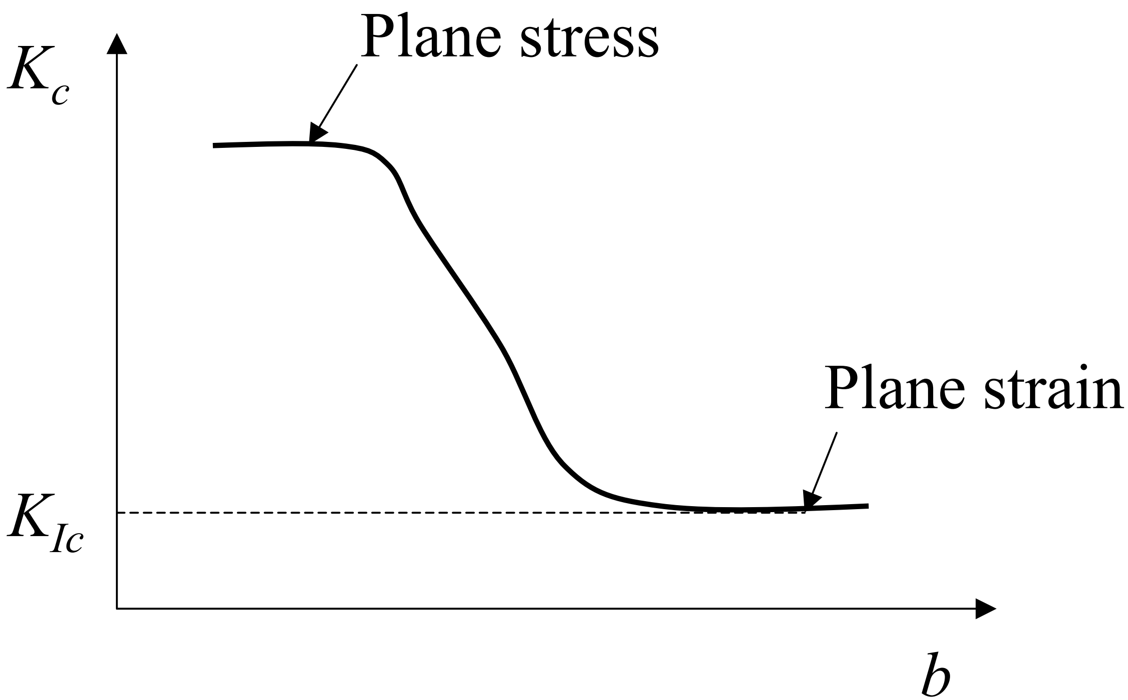
# Initial crack length

- Fatigue produces a sharp, natural crack.
- After fast fracture, the boundary between the striation and chevron markings indicates the location of the initial crack tip.

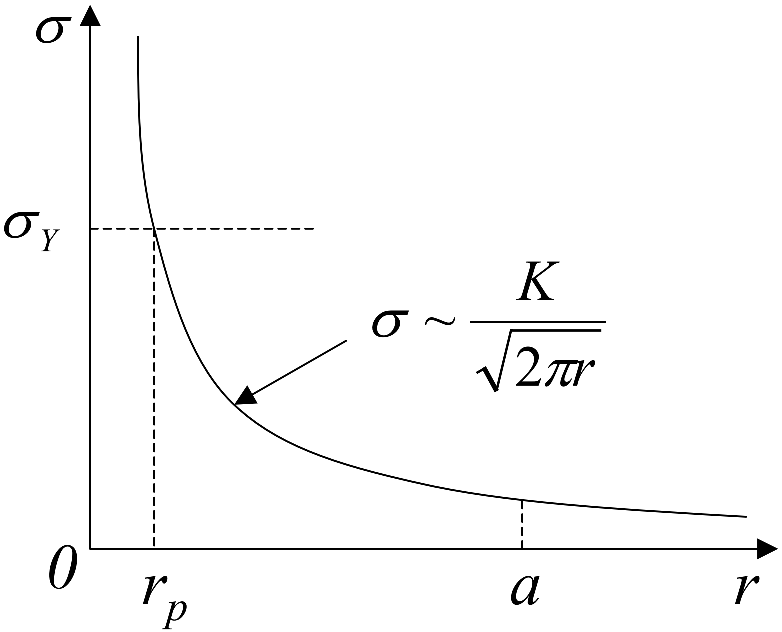


# Effect of specimen thickness

- Measured fracture toughness depends on specimen thickness.
- Thin specimen: plane stress, slant fracture, high toughness.
- Thick specimen: plane strain, flat fracture, low toughness.



# Plastic zone size




$$\frac{K}{\sqrt{2\pi r_p}} = \sigma_Y \longrightarrow r_p \sim \frac{1}{2\pi}\left(\frac{K}{\sigma_Y}\right)^2$$

Plastic zone size increases as the load (K) increases.

Maximum plastic zone size: $$r_p^c \sim \frac{1}{2\pi}\left(\frac{K_c}{\sigma_Y}\right)^2$$

# Small scale yielding condition

- Linear fracture mechanics is only useful when the plastic zone size is much smaller than the crack size.

$$\left(\frac{K_c}{\sigma_Y}\right)^2 << a$$

For glass: $$\left(\frac{K_c}{\sigma_Y}\right)^2 \sim 10\text{nm}$$

For steels: $$\left(\frac{K_c}{\sigma_Y}\right)^2 \sim 2-200\text{mm}$$

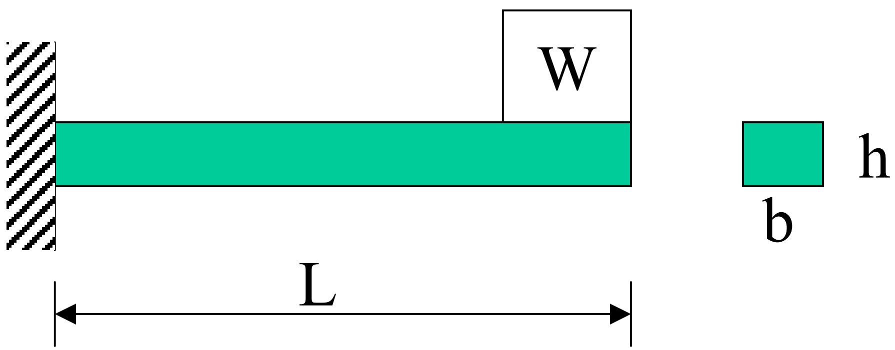
# Plane strain toughness

- Plane stress: biaxial stress, larger plastic zone ($r_p$).
- Plane strain: $b >> r_p$, small scale yielding
- ASME specification for plane strain toughness ($K_{Ic}$):

$$a, b \geq 2.5\left(\frac{K_c}{\sigma_y}\right)^2$$

Use the plane strain toughness $K_{Ic}$ for conservative design.

# Case study



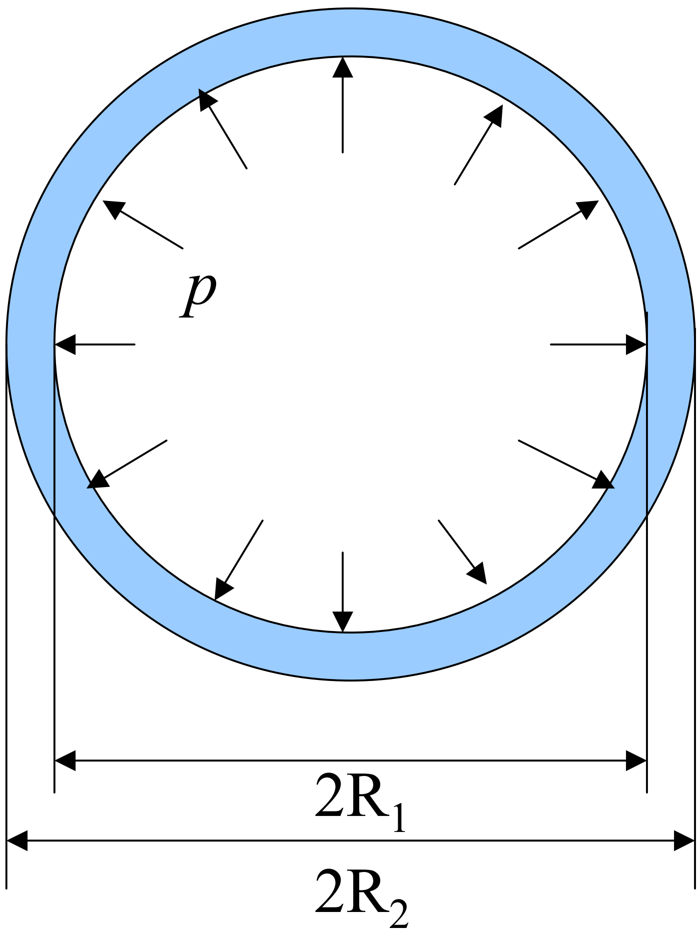

Maximum stress at the root: $\sigma_{\max} = \dfrac{6WL}{bh^2}$

Design against plastic yielding: $\sigma_{\max} < \sigma_Y$

Design against fracture: $K < K_c$

$$K \approx 1.12\sigma_{\max}\sqrt{\pi a} \longrightarrow \sigma_{\max} < \frac{K_c}{1.12\sqrt{\pi a}}$$

# Fracture of a pressure vessel



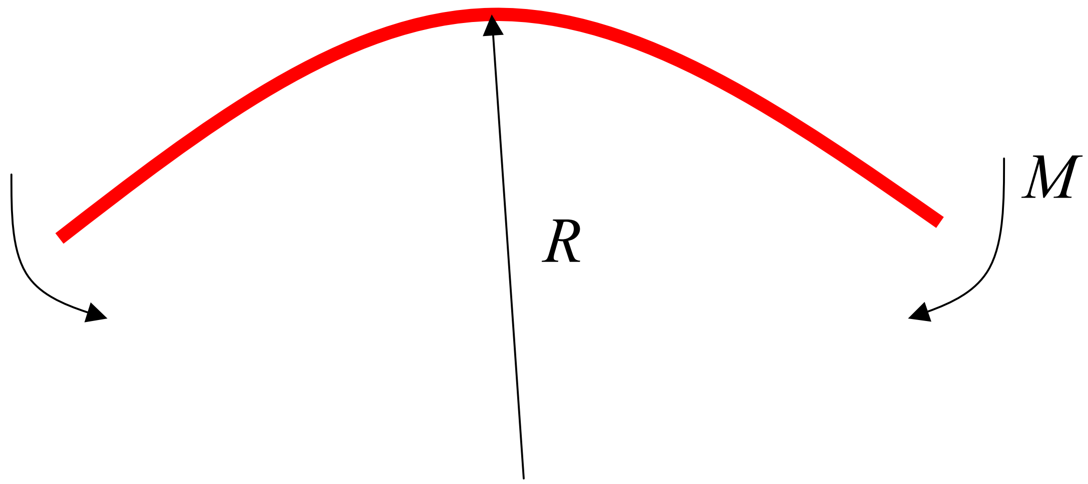

$R_1 = 20$ mm

$R_2 = 40$ mm

$\sigma_y = 2$ GPa

$K_c = 10$ MPa-m$^{1/2}$

# Bending of a glass rod




d = 10 mm

E = 100 GPa

$K_c$ = 1 MPa-$m^{1/2}$

# Summary

- Fracture criterion
- Fracture toughness testing using compact tension specimens
- Plane strain toughness and plane stress toughness
- Plastic zone size and small scale yielding