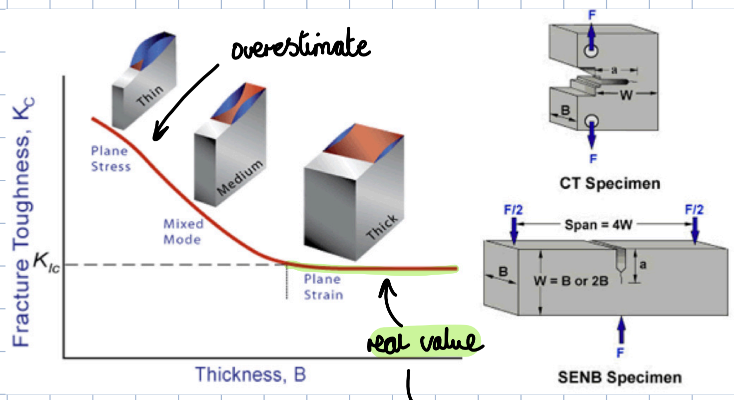
- Fracture toughness meant to be a linear material property but important to understand role of material thickness & application of loading direction when establishing fracture toughness.
  - ↳ Must understand:
    - Plane strain & stress
    - Crack tip state of tension
    - Isotropic vs. anisotropic toughness

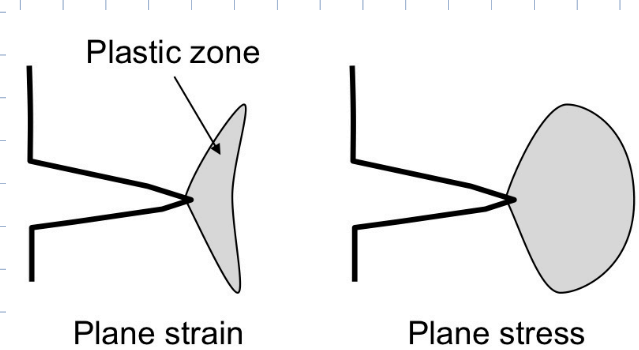


↳ Plane strain K_c, K_{Ic}

↳ ↓ thickness = ↑ in plane plastic def ∴ ↑ K_c

Plastic zone / fracture process zone depends on nature of stress ahead of crack:

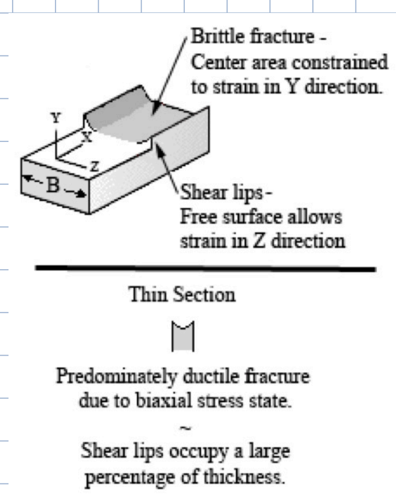
→ Plane stress $r_p \approx 3 \times$ Plane strain r_p



Plane Stress: $\sigma_{zz} = 0$, $\varepsilon_{zz} \neq 0$ ∴ biaxial stress state

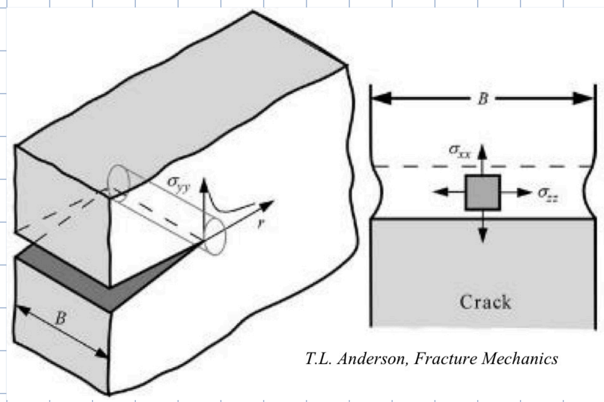
↳ results in fracture in characteristic ductile manner, with a 45° shear lip formed at each free surface

Plastic zone radius can be approximated by: $r_p = \frac{1}{2\pi}\left(\frac{K_c}{\sigma_y}\right)^2$



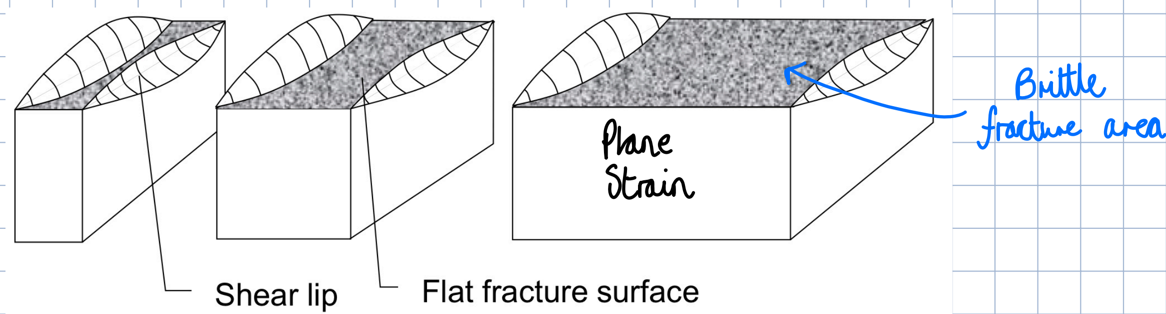
Plane Strain : $\sigma_{zz} >> 0$ ∴ triaxial stress state , $\varepsilon_{zz} = 0$

$$r_p = \frac{1}{6\pi}\left(\frac{K_{IC}}{\sigma_y}\right)^2$$



Shear Lips :

- Form as crack approaches surface
- For small samples, shear lips are dominant failure mechanism.
- For very thick samples, contribution of shear lips is trivial ∴ valid measure of K_c.



Mode 1 Fracture Toughness ASTM Standard :

- Must ensure plane strain ∴ thick specemins :

$$K_{IC} = \frac{P_c}{B\sqrt{W}} f\left(\frac{a}{W}\right)$$

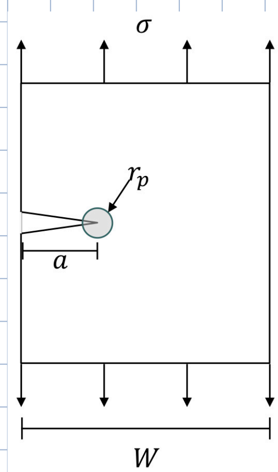
$f\left(\frac{a}{W}\right)$ = Slide 12

LEFM Validity :

- For LEFM equations to be valid, ~ plastic zone ahead of crack must be $r_p < \frac{a}{50}$

  and $r_p < (W-a)/50$

- Additionally for plane strain, $r_p < B/50$
  - B → thickness



$$\sigma_S = \frac{K_{IC}}{\beta\sqrt{\pi a}}$$

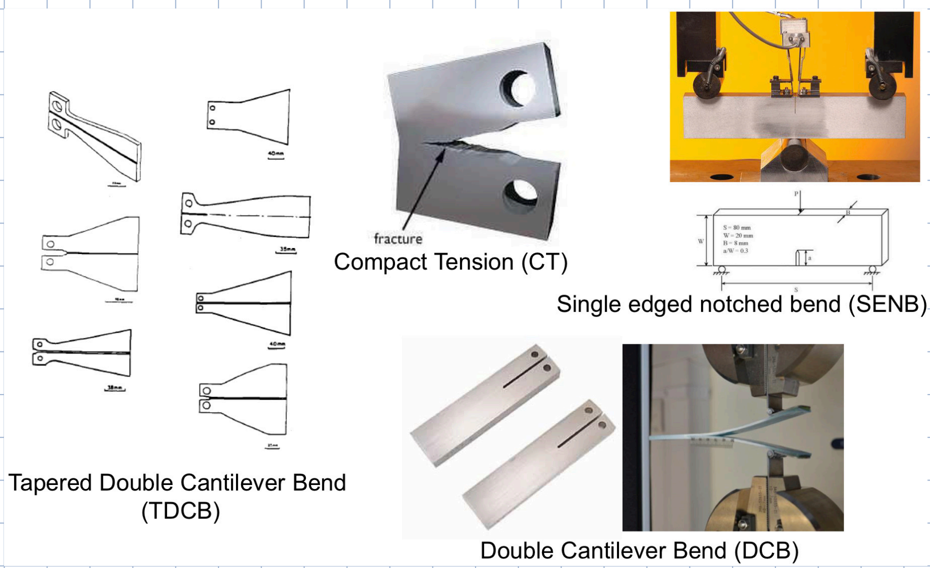
Strain Energy, Compliance & Crack Growth:

$$G = \frac{P^2}{2B}\frac{dC}{da}$$

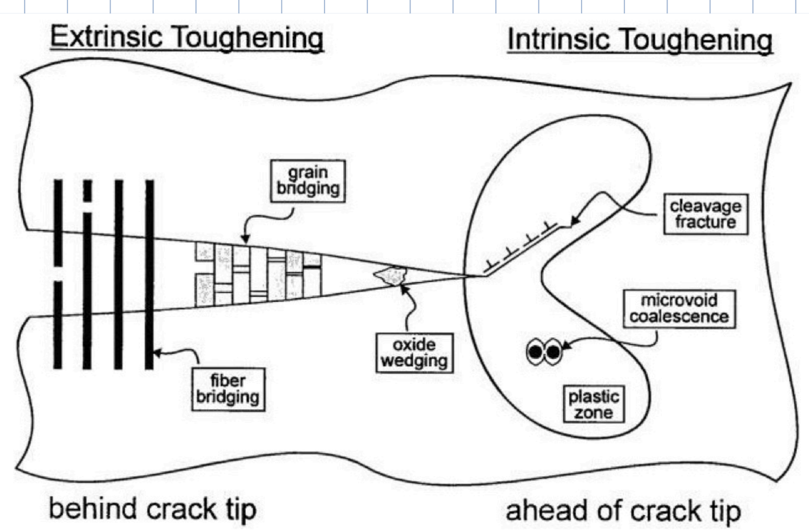
derivation in slides

→ Compliance, C, is the inverse of stiffness : ↑C = ↑ deformation

Test Configurations:



Factors that Influence Fracture Toughness:



Elastic Plastic Fracture Mechanics:

- Need to characterise a ductile or highly tough material

→ to do this, a procedure developed called crack tip opening displacement

→ Crack tip plasticity makes crack behave as if it were longer, $a + r_p$

→ this method calculates displacement at physical crack tip.

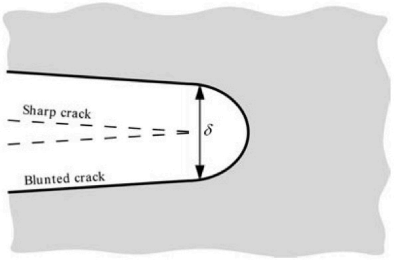


FIGURE 3.1 Crack-tip-opening displacement (CTOD). An initially sharp crack blunts with plastic deformation, resulting in a finite displacement (δ) at the crack tip.

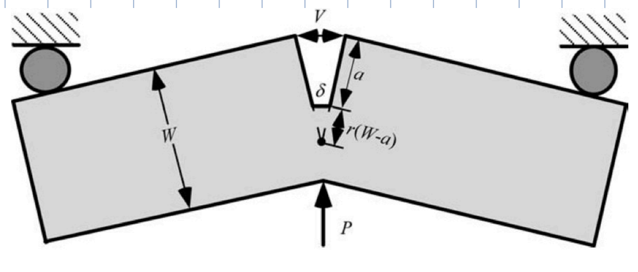


FIGURE 3.5 The hinge model for estimating CTOD from three-point bend specimens.

→ Seperating elastic & plastic components of the CTOD:

$$\delta = \delta_{el} + \delta_{p} = \frac{K_I^2}{m\sigma_{ys}E'} + \frac{r_p(W-a)V_p}{r_p(W-a)+a}$$

r_p → rotational factor 0.44

m → dimensionless constant:
~1 for plane strain
~2 for plane stress

E' → effective modulus:
$E = E'$ for plane stress

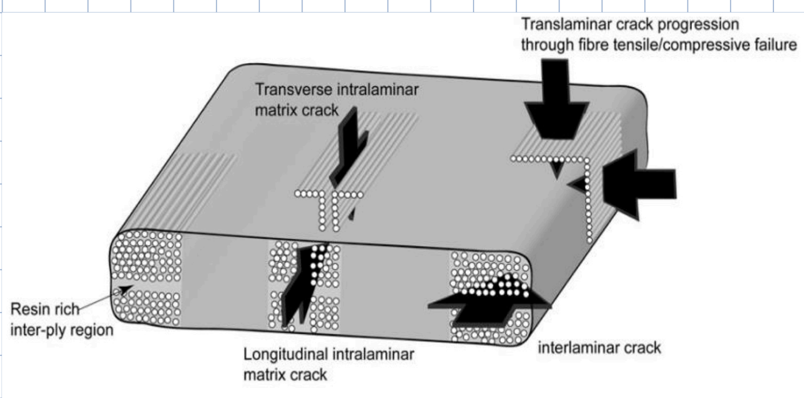
$E = \frac{E}{1-\nu^2}$ for plane strain

Isotropic vs Anisotropic Materials:

Isotropic → Same E, ν all directions

Anisotropic → different "

Failure of Composite Laminates:



Overview of ply-level failure