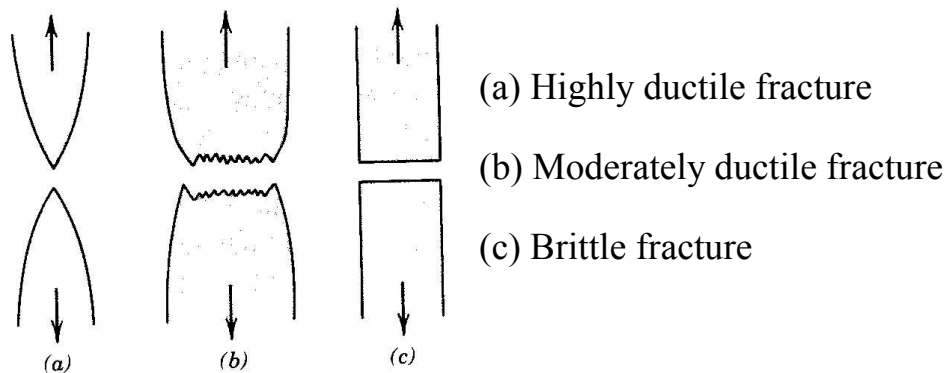


Fracture

Objectives :

- *identify* design parameters limiting fracture and fatigue
- *distinguish* between catastrophic failure vs slow (!) fracture - *leak before break*
- *predict* life of structures based on fatigue and creep phenomena
- *identify* failure mechanisms and parameters controlling them

Ductile vs Brittle \Leftrightarrow Fig.8.1 - 8.3



Fracture involves (i) crack initiation and (ii) crack propagation

stable vs unstable
(brittle)

Ductile

vs

Brittle

extensive plastic deformation

little or no plastic deformation

high e_t or RA

very low e_t or RA

dull fracture surface

bright/shiny

stable crack propagation

unstable

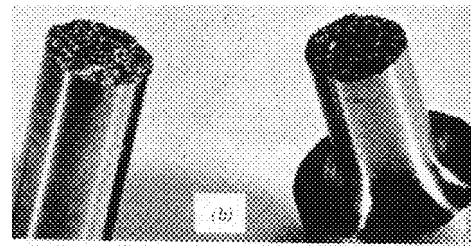
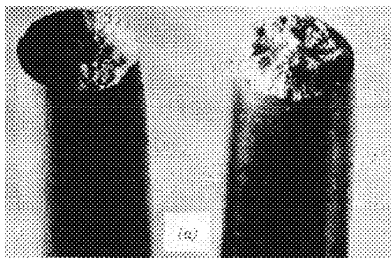
(no further crack propagation when $\sigma \rightarrow 0$)

(once cracks start propagating, they continue till fracture)

leads to catastrophic crack propagation & failure

cup-and-cone type fracture

grainy-faceted fracture surfaces



dimpled fracture (Fig.8.4)

cleavage / transgranular (Fig.8.6a)
or intergranular (Fig. 8.6b)
v-shaped *chevron* markings (Fig.8.5)

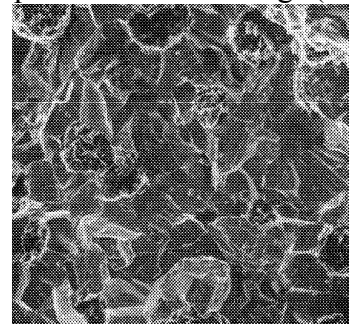
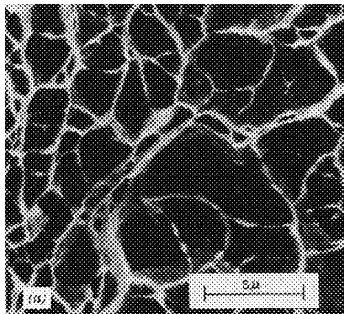


Fig. 8.6a

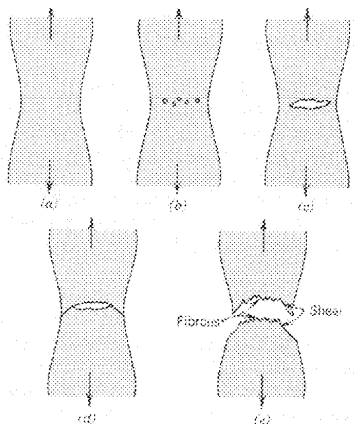


Fig. 8.2

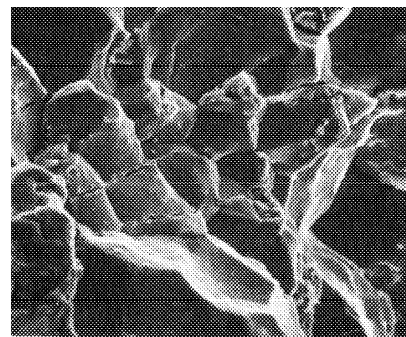
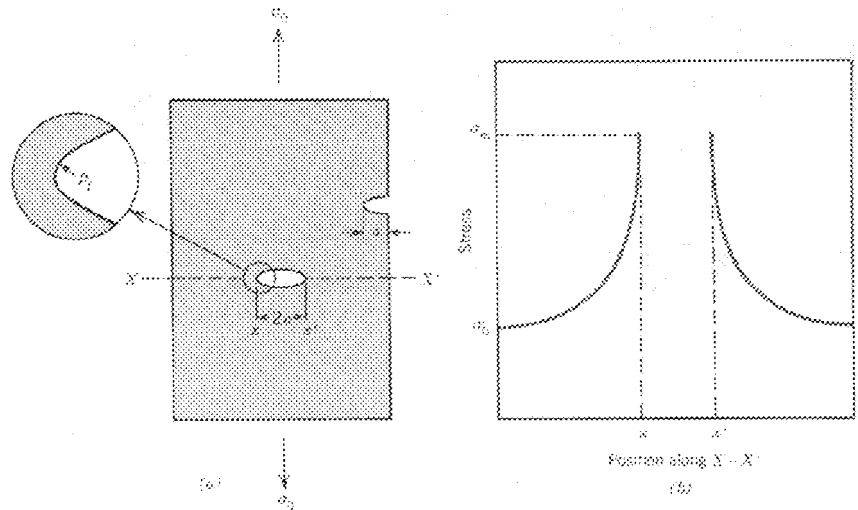


Fig. 8.6b

brittle fracture : crack motion is nearly \perp to the tensile stress axis
- yields a relatively flat fracture surface

Fracture Mechanics

Stress Concentration at crack tips (Fig. 8.7)



$$\sigma_{max}^{crack-tip} = 2 \sigma_0 \sqrt{\frac{a}{\rho_t}}$$

σ_0 is net section stress (nominal applied stress)

$$\kappa = \frac{\sigma_{max}^{crack-tip}}{\sigma_0} = 2 \sqrt{\frac{a}{\rho_t}} \quad (\text{Eq. 8.2})$$

Griffith theory of brittle fracture :

- fracture occurs when the tensile stress at some crack tip exceeds theoretical cohesive strength of the material

(implies that when there are no cracks at all (!), fracture strength would be equal to the theoretical cohesive strength)

With cracks (real situation) \Rightarrow elastic strain energy released during crack propagation equals the surface energy increase due to the creation of 2 new surfaces \Rightarrow

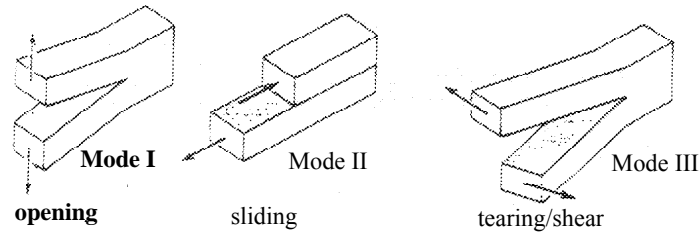
Eq. 8.3 : $\sigma_c = \sqrt{\frac{2E\gamma_s}{\pi a}}$ defines the critical stress needed for crack propagation

If there is some plastic deformation (true in majority of cases), add plastic strain

energy in Eq. 8.3 (Eq. 8.4) : $\sigma_c = \sqrt{\frac{2E(\gamma_s + \gamma_p)}{\pi a}}$

Fracture Toughness :

Modes I, II and III



Stress fields around cracks and stress intensity factor (K) : Eqs.8.5 $\sigma_{ij} = \frac{K}{\sqrt{2\pi r}} f_{ij}(\theta)$

r is distance from the crack tip & $i, j = x, y$; K specifies stress distribution at crack tip

Just like when σ_c is approached, crack propagation can occur ;

define a **critical fracture toughness** $K_{Ic} = Y \sigma \sqrt{\pi a}$ (Eq. 8.6) , $Y \approx 1$

K_{Ic} depends on the specimen geometry (specifically thickness) and decreases as size increases (Fig. 8.12) and it reaches a minimum value for thick specimens known as **plane strain fracture toughness** K_{Ic}

which is a material parameter $\{f(T, \dot{\epsilon}, \text{microstructure})$; $K_{Ic} \downarrow$ as grain-size \uparrow }

$$\left\{ \text{condition for plane strain : } B \geq 2.5 \left(\frac{K_{Ic}}{\sigma_y} \right)^2 \right\}$$

i.e. when the applied fracture toughness, $K_I = Y \sigma \sqrt{\pi a}$ reaches K_{Ic} ,
fracture occurs or crack propagates

[analogous to applied stress vs yield strength]

(units of K_I) \Leftrightarrow large for ductile and low for brittle

Design using Fracture Mechanics

Eqs. 8.9 & 8.10 \Rightarrow 3 variables : $\left\{ \begin{array}{l} K_{Ic} \text{ (material parameter)} \\ K_I \text{ (material parameter)} \\ \text{applied or imposed stress } (\sigma) \\ \text{flaw size } (a) \end{array} \right.$

case (i) : if K_{Ic} and a are specified \Rightarrow design stress $\sigma_c \leq \frac{K_{Ic}}{Y\sqrt{\pi a}}$

case (ii): if K_{Ic} and σ are specified \Rightarrow maximum allowable flaw size $a_c = \frac{1}{\pi} \left(\frac{K_{Ic}}{\sigma Y} \right)^2$

“a” is measured using various NDT methods (UT, optical, radiography, etc.)

Fracture Testing : Cv etc.