5.6 Brittle fracture of polymer

Rectangular bar of width W under uniaxial tension (See Fig 5.17):

Brittle fracture

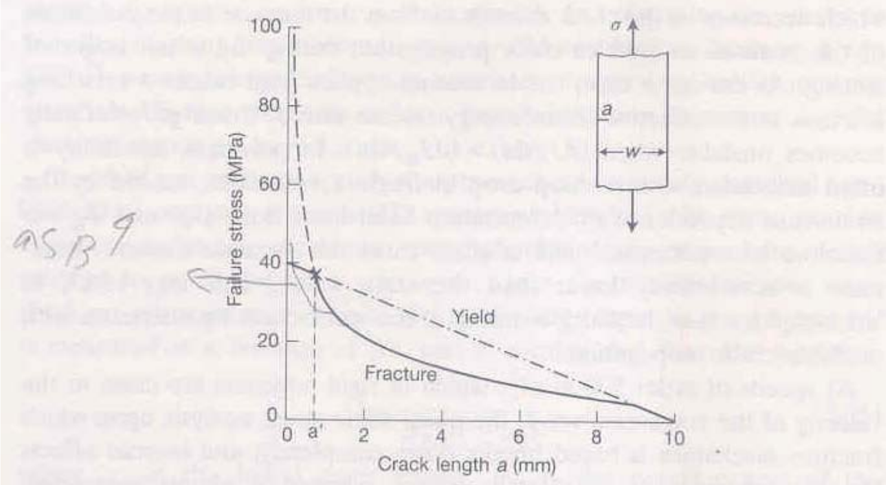
$$K_{IC} = Y\bar{\sigma}_F(\pi a)^{\frac{1}{2}} \qquad (5.30)$$

$$Y = \text{Geometry factor} \quad (\text{See } 5.31)$$

Ductile fracture (yield)

$$\sigma_{max} = \sigma_y(W - a)/W \qquad (5.36)$$

Fig 5.17 here (Pls replace)

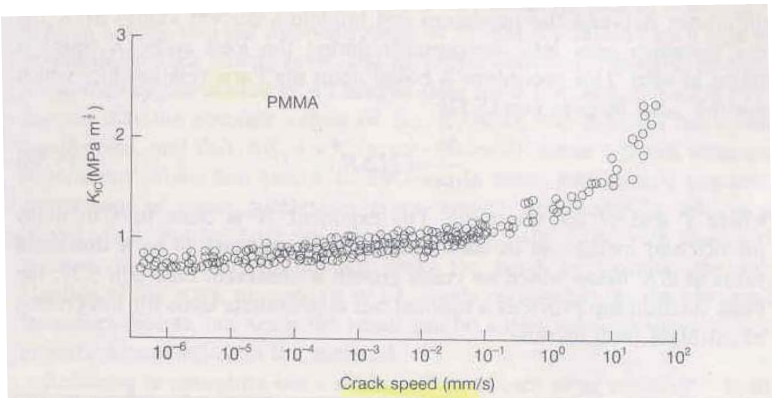


5.17 Relationship between crack length and type of failure in a bar of polymer of width $W = 10$ mm. The brittle fracture curve is calculated for a K_{IC} of 2.0 MPa $m^{0.5}$. Straight line shows ductile stress for $\sigma_y = 40$ MPa. Note that brittle fracture occurs before the material is able to yield, except at short crack lengths or very long crack lengths.

For $a < a' \Rightarrow$ Yield (ductile fracture) (See the caption in the figure)

$a > a' \Rightarrow$ Brittle fracture, a' : critical crack length (see Fig 5.17)

Fig 5.18 here



5.18 Relationship between K_{IC} and crack speed in PMMA. Data from many different authors (after W. Doell).

As crack speed ↑ $\Rightarrow K_{IC} \uparrow \Rightarrow a' \downarrow \Rightarrow$ Impact and other forms of rapid loading tend to cause brittle fracture. (The increase of K_{IC} is smaller than the increase in yield stress, so a' decreases)

Static fatique : Slow crack growth under long term steady loading→Threshold value for K_I below which no crack groes. Above this, a sub-critical crack growth is related to growth rate, da/dt as

$$\frac{da}{dt} = \beta {K_I}^m \qquad (5.37)$$

$\beta, m =$ constant

Time to failure can be calculated from (37) by integration or iteration. Final fracture occurs when $K_I \Rightarrow K_{IC}$

Dynamic fatique

$$\frac{da}{dn} = \zeta(\Delta K)^N \qquad (5.38)$$

$\zeta, N =$ const $\quad (N \approx 4$ for plastic)

$n =$ # of fatigue cycle

$\Delta K = K_{max} - K_{min}$ (Threshold ΔK for fracture)

For tension-compression, K (compression)=0

$K = Y\bar{\sigma}(\pi a)^{\frac{1}{2}}$

A threshold value exists for ΔK below which no crack growth is observed.

EX 5.11 here

Example 5.11

Rigid PVC is a polymer that conforms well to the Paris relationship.

Fatigue crack growth data at 20°C for PVC can be represented by the equation

$$\frac{da}{dn} = 0.035\Delta K^{2.4},$$

where da/dn is in μm per cycle and ΔK is in MPa m$^{0.5}$. A compact tension specimen has $B = 6$ mm, $W = 50$ mm, and $a = 20$ mm. Calculate da/dn when the specimen is cycled between $F_{max} = 100$ N and $F_{min} = 50$ N.

Solution

Using the expression for Y given in eqn 5.31, at $a/W = 0.4$,

$$Y = 16.70 - 41.88 + 59.18 - 36.72 + 9.23 = 6.51;$$

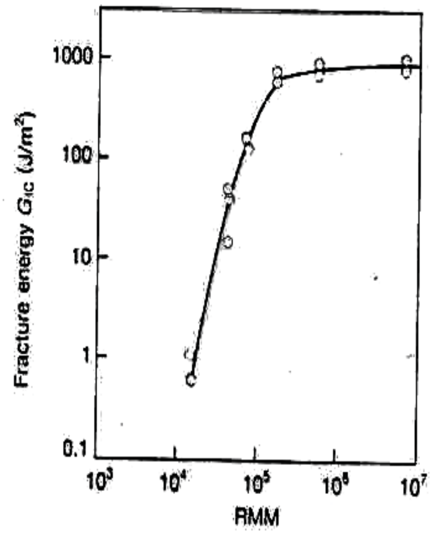
$$\Delta K = Y(\pi a)^{\frac{1}{2}}(\sigma_{max} - \sigma_{min}) = Y(\pi a)^{\frac{1}{2}} \frac{(F_{max} - F_{min})}{BW},$$

$$= 6.51 \times (\pi \times 0.02)^{\frac{1}{2}} \frac{(100 - 50)}{0.006 \times 0.05}$$

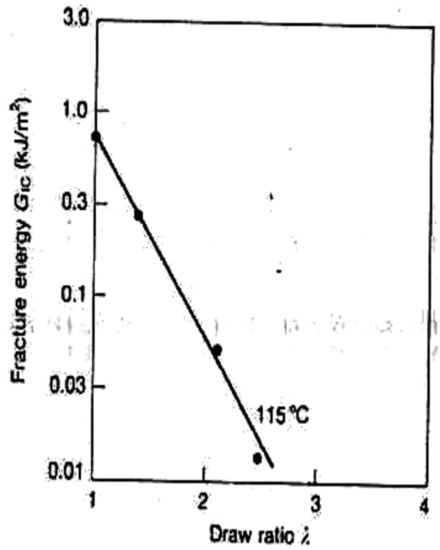
$$= 0.272 \text{ MPa m}^{0.5};$$

$$\frac{da}{dn} = 0.035\Delta K^{2.4}$$

$$= 1.54 \text{ nm per cycle}.$$



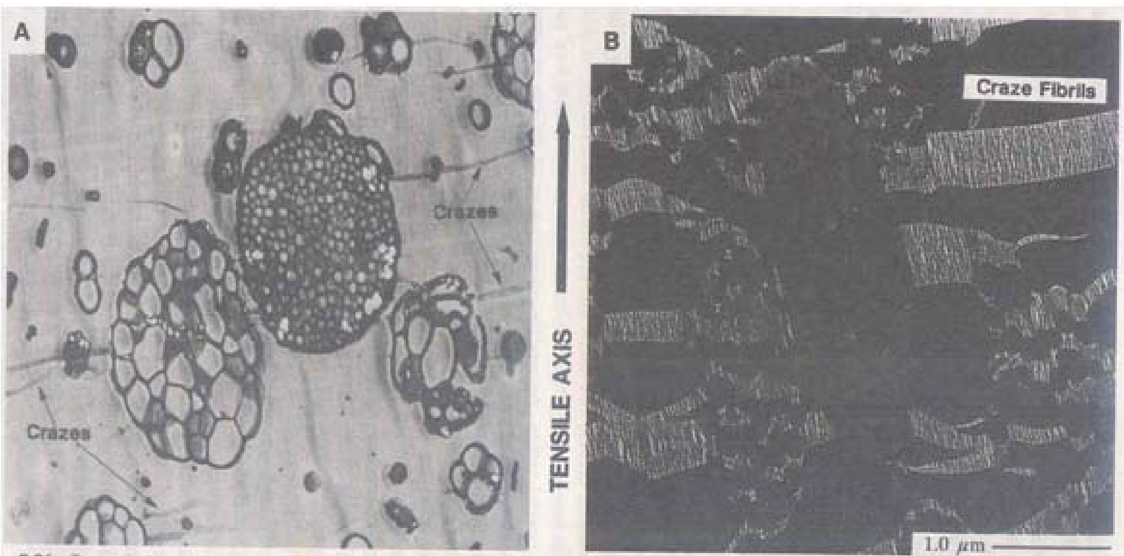
5.19 Relationship between G_{IC} and relative molar mass in PMMA (a
D. T. Turner).



5.20 Fracture energy of polystyrene at 23°C after drawing above the glass transition a
10^{-2} s^{-1}, showing effect of molecular orientation. The crack plane is parallel to the dra
direction (after L. J. Broutman and F. J. McGarry).

5.7 Rubber toughening

Fig 5.21 here



5.21 Transmission electron micrographs of HIPS: (A) osmium-stained thin section showing 'salami' structure, with polystyrene sub-inclusions embedded in (black) rubber phase, in a matrix of polystyrene; (B) unstained thicker section stretched on the microscope stage. The unloaded specimen (A) has largely recovered, and shows compressed crazes. The stressed sample (B) shows extended craze fibrils and fibrillated rubber. (Micrographs by courtesy of R. C. Cieslinski, Dow Chemical USA.)

Fig 5.22 here

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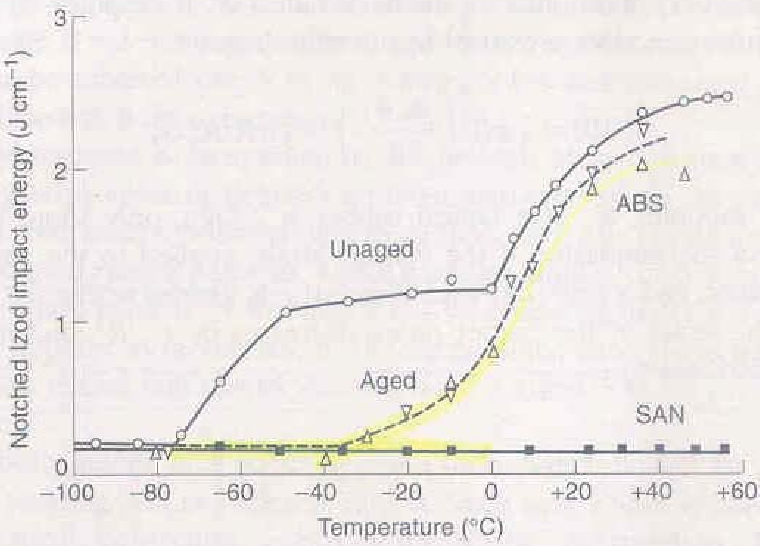

5.22 Notched Izod impact test results for SAN (0% rubber) and ABS (20% rubber), showing effects on ABS of 3 months' exposure to sunlight during the English summer.