R-Curve

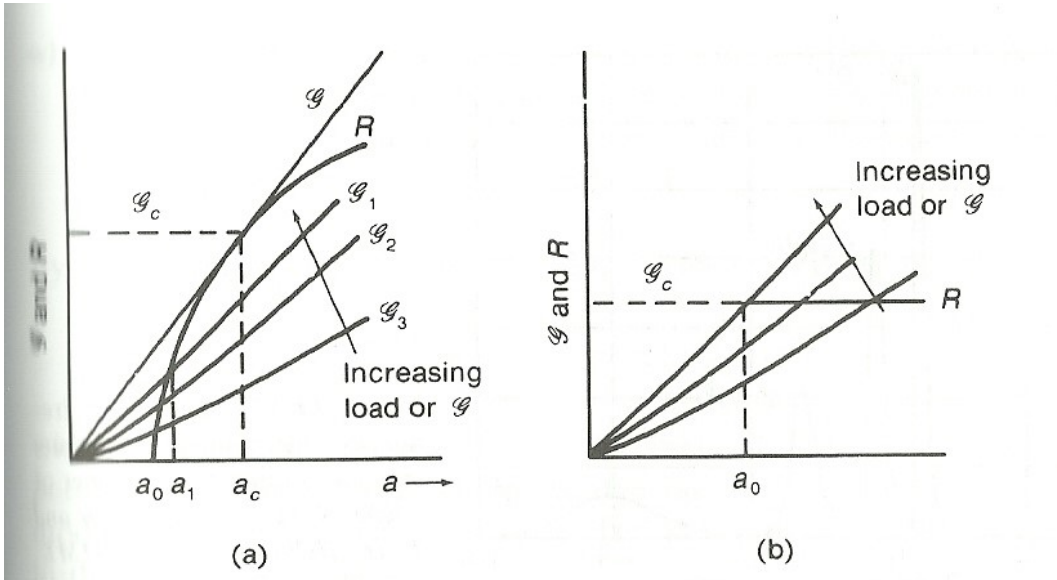


Figure 11-16 (*a*) *R* curve for a ductile material; (*b*) *R* curve for a brittle material.

Irwin suggested that instability or failure will occur when the rate of change in the elastic energy-release rate ∂G/ ∂a equals to the rate of change in material resistance to crack growth ∂R/ ∂a.

Materials resistance to fracture R is expected to increase with increasing plastic-zone development and strain hardening

Crack extension occurs when G > R for material with some ductility

- A compact tension specimen is loaded incrementally and measuring load P and crack length a. at each step K_R (equivalent to R) is calculated

$$K_R = P / B\sqrt{W} \times f(a/W)$$

where

$$f(a/W) = [(2 + a/W)/(1 - a/W)^{3/2}][0.866 + 4.64(a/W) - 13.32(a/W)^2 + 14.72(a/W)^3 - 5.6(a/W)^4]$$

The crack length used in the above equ is effective crack length

$$a_{eff} = a_o + \Delta a + r_p$$

Fracture-mode transition: plane stress vs. plane strain

- Plane-stress fracture toughness K_c is dependent on both metallurgical and specimen geometry
- Plane-strain fracture toughness K_{IC} depends only on metallurgical factors.
- When $r_y/t \geq 1$, plane-stress conditions exists and toughness is high
- When $r_y/t < 1/10$ plane-strain condition will exist
- The necessary thickness to develop a plane-stress or plane-strain condition will depend on the yield stress of the material

- If the yield strength is increased by a factor of 2, the thickness necessary to achieve plane-strain condition for a given stress intensity level will be reduced by a factor of four.

$$r_y \propto \frac{1}{\sigma_o^{\,2}}$$

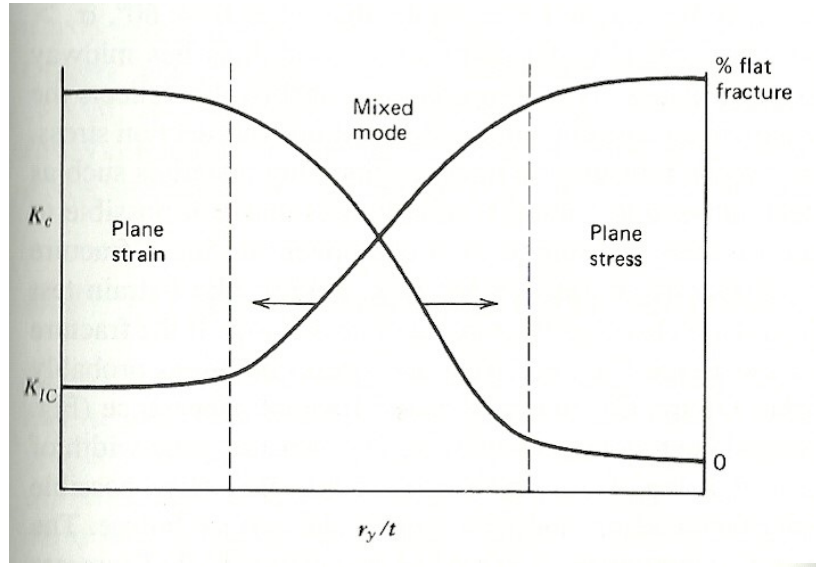
- Hence, very thin specimen with high yield strength material can experience plane-strain condition, whereas very large sections of low-yield strength may never experience plane-strain condition.

Fracture mode transition

The relative degree of flat and slant fracture depends on the crack tip stress state.

Plane-stress condition, ry ≥ t, the fracture often happens at a +/-45° orientation wrt the load axis

In plane-strain, where $\sigma_z = \nu\,(\sigma_y + \sigma_x)$ and $r_y << t$, the plane of maximum shear is found in the XY plane.



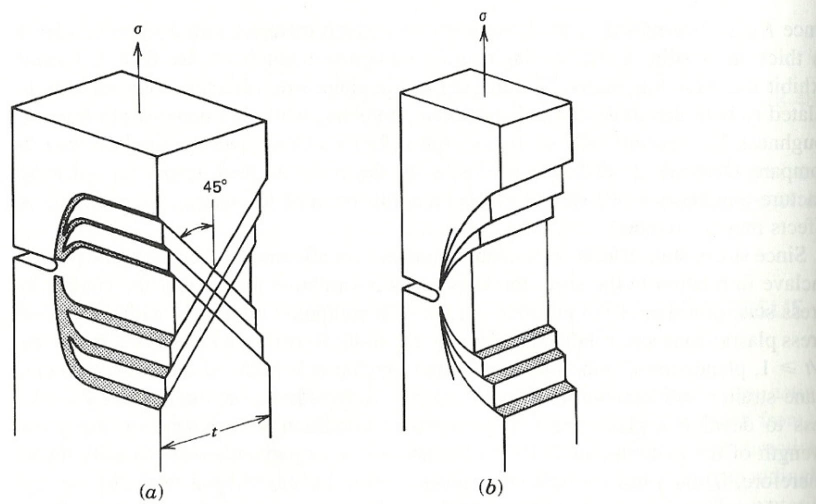


FIGURE 8.16 Crack-tip deformation patterns in (*a*) plane stress, and (*b*) plane strain. (After Hahn and Rosenfield;[19] reprinted with permission of Hahn, *Acta Metall.* 13 (1965), Pergamon Publishing Company.)

Fracture toughness of engineering alloys

- For a given metallurgical structure K_{IC} increases with increasing temp and decreases with increasing strain rate.
- Increasing the strength of materials results in a decrease in K_{IC}
- The best microstructures for combining toughness with strength are strengthened with fine particles (100 μm or less).

- Inclusions are detrimental to the fracture toughness in strong metals
- Inclusions can be removed by vacuum melting of steel and using high purity melt stock of Al alloy
- Fine grain size improves K_{IC}.

Example

- Identical compact tension specimens have been prepared to determine the fracture toughness of the 7178 Al alloy, subjected to two different heat treatments. The crack length and thickness of the samples are 4 cm and 1 cm, respectively. Would the specimen dimensions described above provide valid plane-strain fracture toughness conditions?

Conditions	K_{IC} (Mpa $m^{1/2}$)	σ_{ys} (MPA)
7178-T651	23.1	570
7178-T7651	33	490