Example on fracture toughness

The stress intensity for a partial-through thickness flaw is given by $K = \sigma\sqrt{\pi a}\sqrt{\sec \pi a / 2t}$, where *a* is the depth of penetration of the flaw through a wall thickness *t*. If the flaw is 5 mm deep in a wall 12 mm thick, determine whether the wall will support a stress of 172 MPa. It is made from 7075-T6 Al alloy. Given K_{IC} = 24 MPa $m^{1/2}$

K_{IC} Plane-strain toughness testing

- The methods of fracture toughness analysis is based on linear elastic fracture mechanics.
- These testing procedures are restricted to materials with limited ductility, e.g., high-strength steel, Ti and Al alloy
- The elastic stress field near a crack tip is described by the stress intensity factor, K.
- The magnitude of the K depends on
    - Geometry of the solid containing the crack
    - The size and location of the crack
    - The magnitude and distribution of the loads imposed on the solid

- A critical value of K is used to define the conditions for brittle fracture.
- As the usual test involves the opening mode of loading (Mode I) the critical value of K is called K_{IC}, the plane strain fracture toughness.
- K_{IC} is a material property which defines the inherent *resistance of the material in the presence of a crack-like defect*.
- For a type of loading and geometry the relation is:

$$K_{IC} = \alpha\sigma\sqrt{\pi a_c}$$

Where α is parameter which depends on specimen and crack geometry and a_c is critical crack length

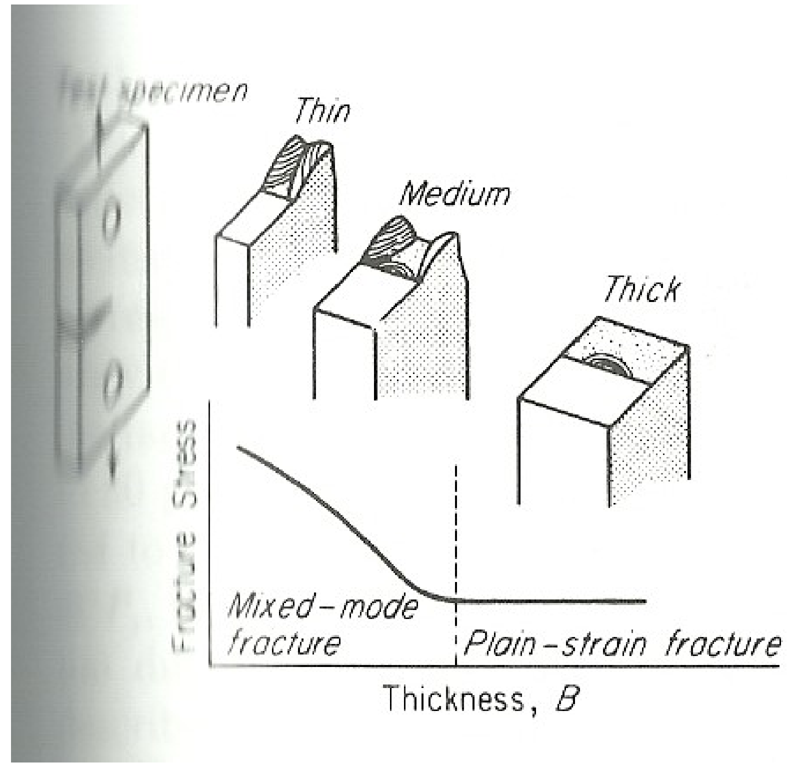
- K_{IC} is a basic material property
- K_{IC} changes with temperature and strain rate
- For a material with a strong temp and strain-rate dependence, K_{IC} decreases with decreased temp and increased strain rate.
- For a given alloy, K_{IC} depends on metallurgical variables, such as heat treatment, texture, melting practice, impurities and inclusions etc.

Plane-strain fracture toughness

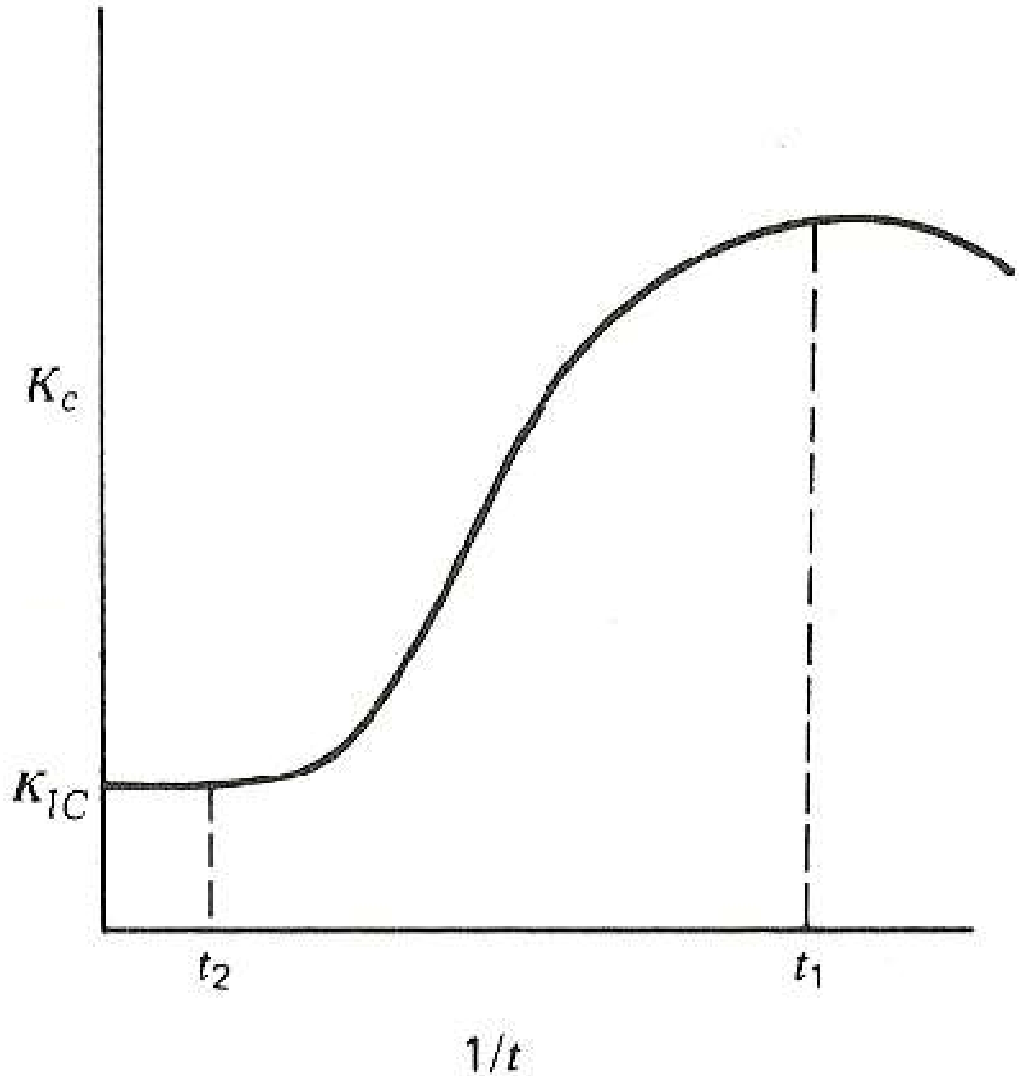
- We saw that a notch in a thick plate is more damaging than in a thin plate because it leads to a plane-strain state of a stress with a high degree of triaxiality.
- A mixed-mode, ductile-brittle fracture with 45° shear lips is obtained for the thin specimens.
- Once the specimen has the critical thickness, the surface is flat and the fracture stress will not change with specimen thickness further.
- The minimum thickness to achieve plane-strain conditions and valid K_{IC} is:

$$B = 2.5\left(\frac{K_{IC}}{\sigma_o}\right)^2$$

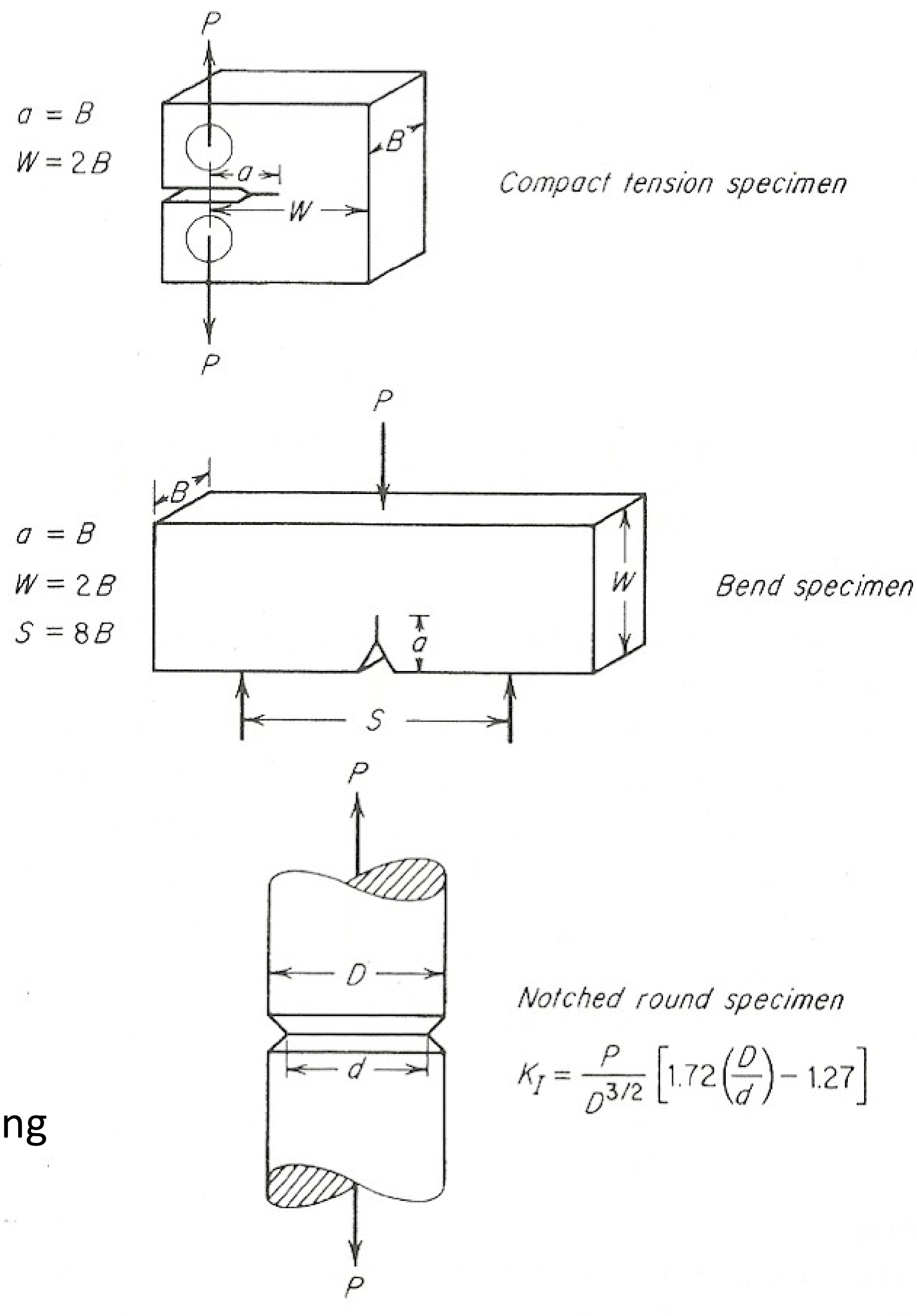
Where σ_o is the 0.2 % offset yield strength



Effect of specimen thickness on stress and mode of fracture

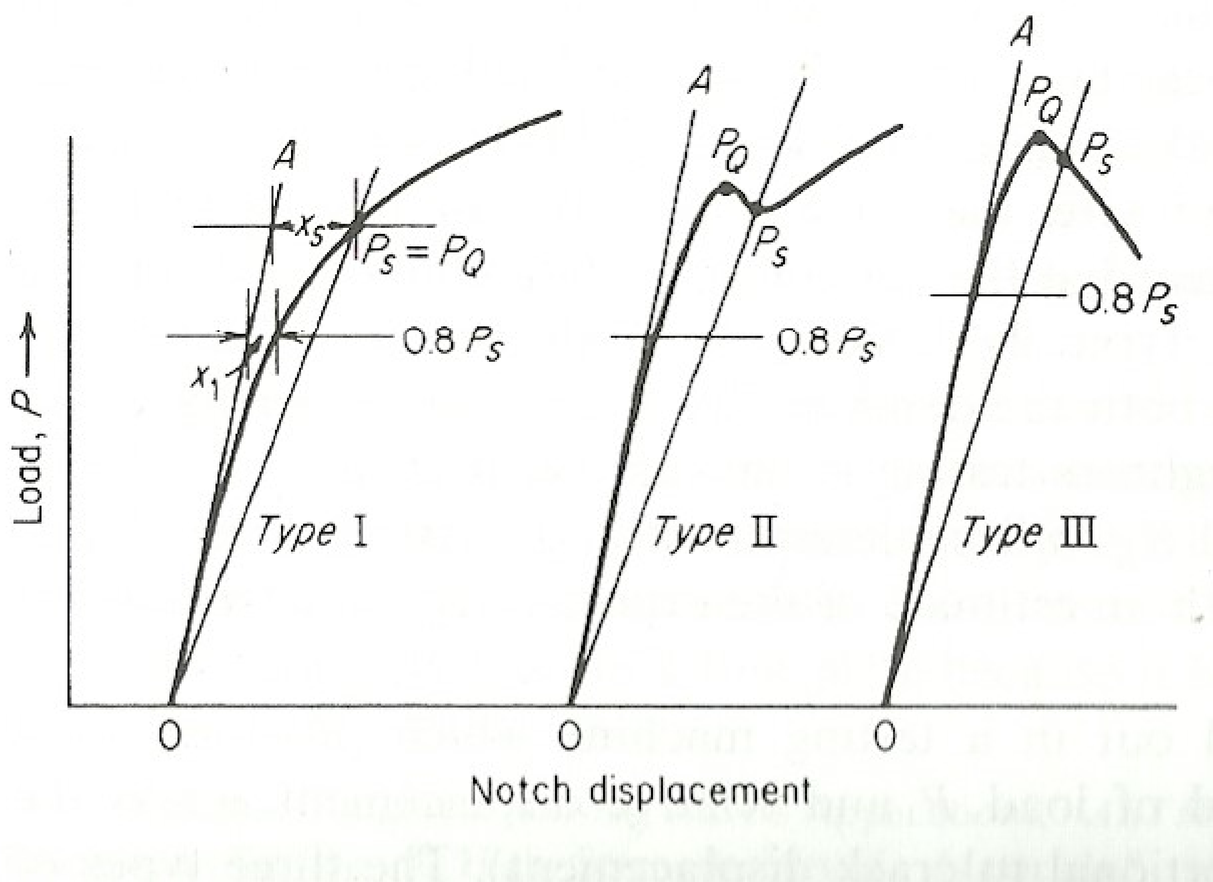


K_C dependence on thickness of the specimen



Common specimens for K_{IC} testing

Load-displacement curves



- For compact tension specimen

$$K_Q = \frac{P_Q}{BW^{1/2}}\left[29.6\left(\frac{a}{W}\right)^{1/2} - 185.5\left(\frac{a}{W}\right)^{3/2} + 655.6\left(\frac{a}{W}\right)^{5/2} - 1017.0\left(\frac{a}{W}\right)^{7/2} + 638.9\left(\frac{a}{W}\right)^{9/2}\right]$$

- For bend specimen

$$K_Q = \frac{P_Q S}{BW^{3/2}}\left[2.9\left(\frac{a}{W}\right)^{1/2} - 4.6\left(\frac{a}{W}\right)^{3/2} + 21.8\left(\frac{a}{W}\right)^{5/2} - 37.6\left(\frac{a}{W}\right)^{7/2} + 38.7\left(\frac{a}{W}\right)^{9/2}\right]$$

Examples

1. A material possessing a plane-strain fracture toughness value of 50 MPa.m$^{1/2}$ and a yield strength of 1000 MPa is to be made into a large panel.

(a) If the panel is stressed to a level of 250 MPa, what is the maximum size flaw that can be tolerated before catastrophic failure occurs? (Assume a center notch configuration)

(b) If the panel were 2.5 cm thick, would this constitute a valid plane-strain condition?

(c) If the thickness were increased to 10 cm, would there be a change in the critical size of the flaw calculated in part (a)?

2. Is it possible to conduct a valid plane strain fracture toughness test for a CrMoV steel alloy under the following conditions: KIC = 53 MPa. M$^{1/2}$; yield strength = 620 MPa, W = 6 cm and plate thickness B = 2.5 cm?