#15: Fracture Overview

Ductile and Brittle Fracture (phenomenology)

Micrographs

•Ductile Fracture (mostly in metals)

•Brittle Fracture (mostly in ceramics)

•Semi-brittle Fracture (hard steels for example)

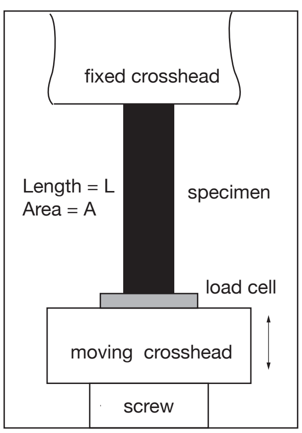
Engineering Descriptions of Fracture by Crack Propagation

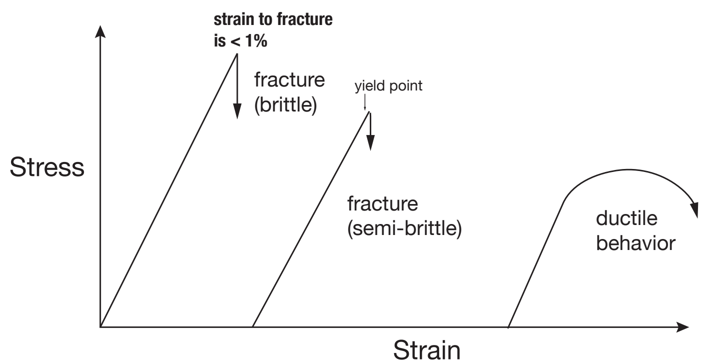
•The significance of flaw size "c"

•Fracture strength depends on the flaw size

•Fracture toughness, K_{IC}, combines fracture strength and the flaw size into one "material" parameter called the fracture toughness.

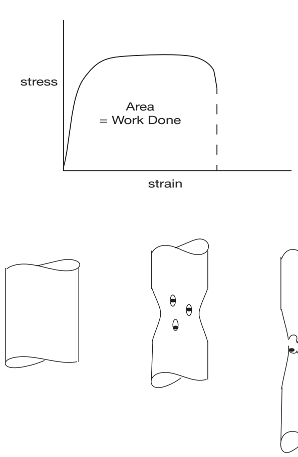
Micrographs

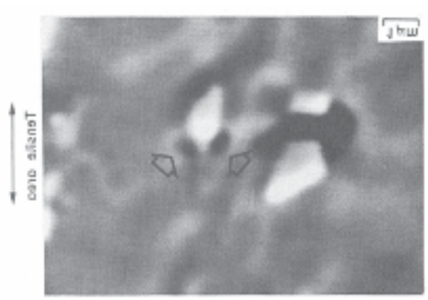


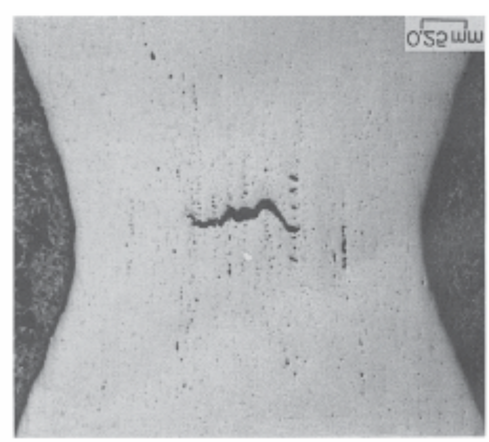


Ductile Fracture

Uniaxial Test of a Metal







Semi-Brittle Fracture

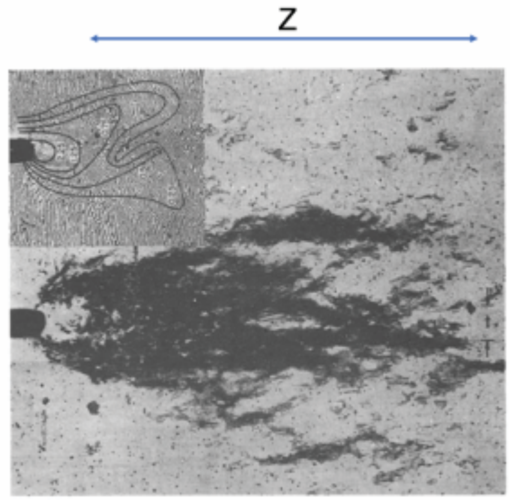


FIG. 7. Interference pattern with isostrain contours (top left corner) and the corresponding plastic zone revealed by etching, both for Sample S-56 (t = 0.017 in., T/Y = 0.81). ×17.5.

$$2\gamma_F = CTOD * Y$$

$$2\gamma_F = \frac{K_{IC}^2}{E} = CTOD * Y$$

$$CTOD = \frac{K_{IC}^2}{YE}$$

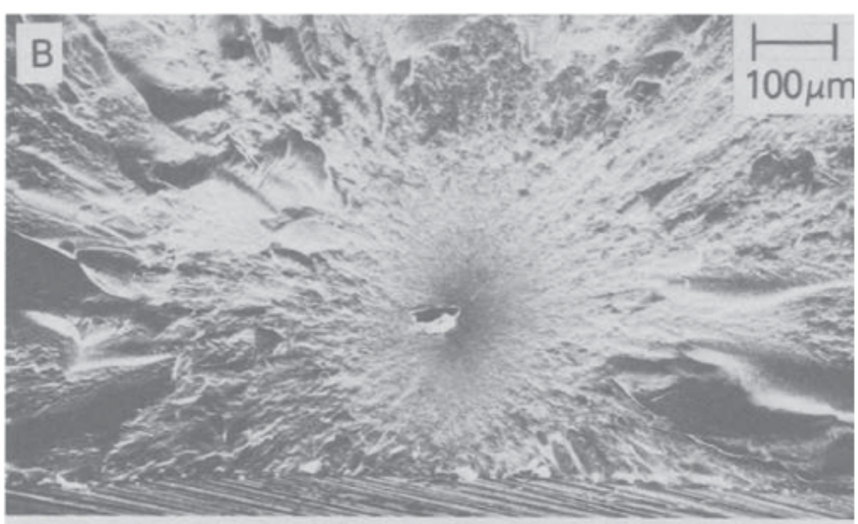
Fracture occurs by the propagation of the crack when the "damage" in front of the crack tip reaches a critical values. This local damage supersedes the general damage as in ductile fracture leading to a transition from ductile to crack propagation mode of fracture.

Fracture in polymers also occurs in a semi-brittle manner

The transmission electron micrograph on the left shows the deformation of "fibrils" which are stretched to the point of breaking at the crack tip, thereby advancing the crack forward.

Clearly the local criterion for fracture would be (a) that the local stress much be large enough - the local yield stress - to stretch the fibril from its bundle, and a second criterion is the (b) the crack tip opening displacement - CTOD - must reach a critical value. Usually CTOD is limiting.

Brittle Fracture



The above micrograph shows the "mirror-like" fracture surface of brittle fracture in glass. Clearly the size of the flaw must play a role in the "fracture strength".

In metals the yield (0.2% offset yield) stress is a material parameter. In elastic the Youngs modulus and the bulk modulus and the Poisson's ratio are material parameters.

The question is can there be a material parameter that quantitatively describes the onset of brittle fracture. The answer is YES.. and it turns out the answer is simple.

The Approach to the Physics, Thermodynamics (the Energetics) of the Fracture Process

•To begin with we consider fracture (crack) propagation as an "energy consuming" process. A specific amount of work is done to propagate the crack, and this work is related to the extent that the crack moves forward. This concept leads to the articulation of a work of fracture, which is the work done to propagate the crack so that its surface area increases by one unit.

$2\gamma_F$ is the work done per unit area of to advance the crack. Consider the edge of the crack tip (which is a line) to have a length L, and let us advance the crack by a distance Δx, the work done to advance the crack is given by

$$2\gamma_F L\Delta x \qquad (1)$$

The above a physical work done to advance the crack. This work is provided by the "surroundings to the system".

The analysis for relating the work done from the outside to work required within the sample to propagatet the crack is given by Eq. (1), is the basis for fracture mechanics.

Therefore, $2\gamma_F$ becomes a materials parameter.

The Fracture Toughness

$$2\gamma_F = \frac{K_{IC}^2}{E} \qquad (2)$$

Thus, K_{IC}, called the fracture toughness is the engineering parameter, for describing fracture by the propagation of a crack. It has units of MPa $m^{0.5}$.

The fracture toughness equation has the following form

$$K_{IC} = \text{(shape parameter) } \sigma\sqrt{c} \qquad (3)$$

where σ is the applied stress (normal to the plane of the crack), and c is the "flaw size" (it is evident in the middle of the picture showing the fracture surface of brittle fracture in glass).

Handbook of Stress Intensity Factors

Cracks of different shapes and orientations are accommodated with an adjustment parameter. There is a handbook that describes a variety of crack shapes and orientations. The reference is given below:

Tada H, Paris P, Irwin G. The analysis of cracks handbook. New York: ASME Press. 2000;2:1.

Significance of the Stress Intensity Factor

We have switched rather quickly from fracture toughness, K_{IC}, to stress intensity factor, K_I.

The stress intensity factor represents the "loading of the crack tip", analogous to the applied stress in a uniaxial tensile stress applied to a cylindrical sample, which then determines the yield stress for the onset of plastic deformation.

In a similar way K_I is the loading of the crack tip. Fracture occurs when this loading exceeds the critical value, K_{IC}.

Note how the stress intensity factor simplifies the study of fracture by combining the applied stress and the flaw size into a single parameter.

By the same token, K_{IC} becomes a material parameter which can be read in handbooks, and can be used for engineering design, in the same way as the elastic modulus is used in the design of aircraft wings, bridges etc.