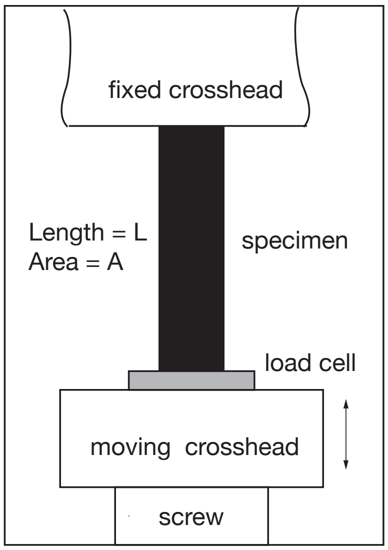
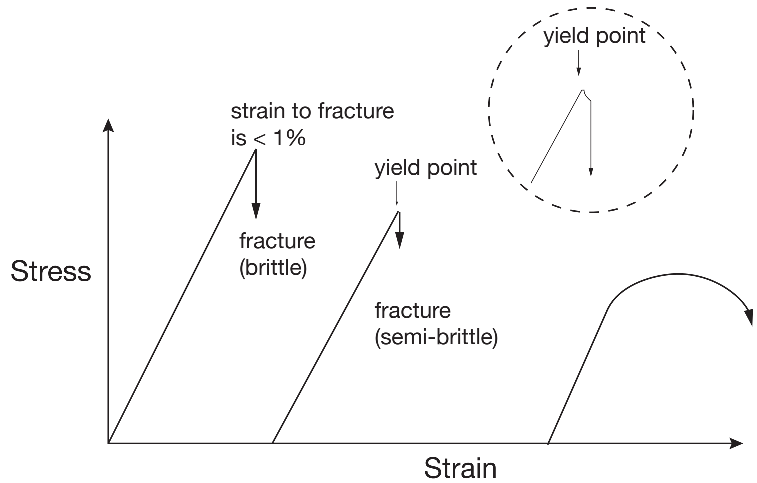
03A_Brittle, Semi-Brittle and Ductile Fracture

Stress-Strain Behavior





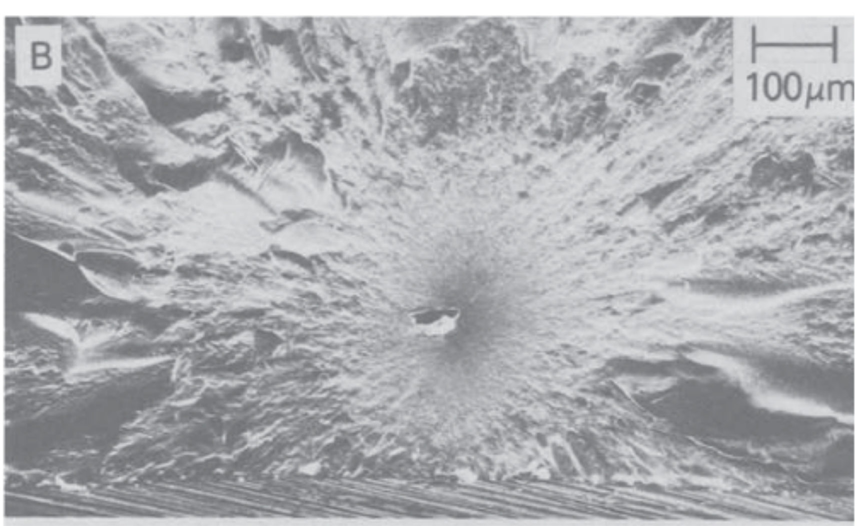
Notes:

•Brittle fracture is commonly seen in glass (nearly always) and often in ceramics. The stress-strain curve is linear representing elastic deformation until fracture.

•In Semi-Brittle Fracture the specimen deforms elastically except near the crack-tip where there is plastic deformation. The load to fracture is usually lower than in brittle fracture. Sometimes there is a hint of yielding at the crack tip in the stress-strain curve.

•In ductile fracture, nearly always in metals, much plastic deformation precedes fracture. Its onset is signaled by localization of strain in a tensile test, called "necking". Damage in the form of voids develops within this zone, which eventually leads to fracture by plastic tearing.

Brittle Fracture



Notes:

•Fracture surface from brittle fracture in glass.

•The fracture originates from a "flaw" about the size of 25 µm = 0.001 inch (the diameter of human hair)

•Fracture propagation is very dynamic... almost like a shock wave.

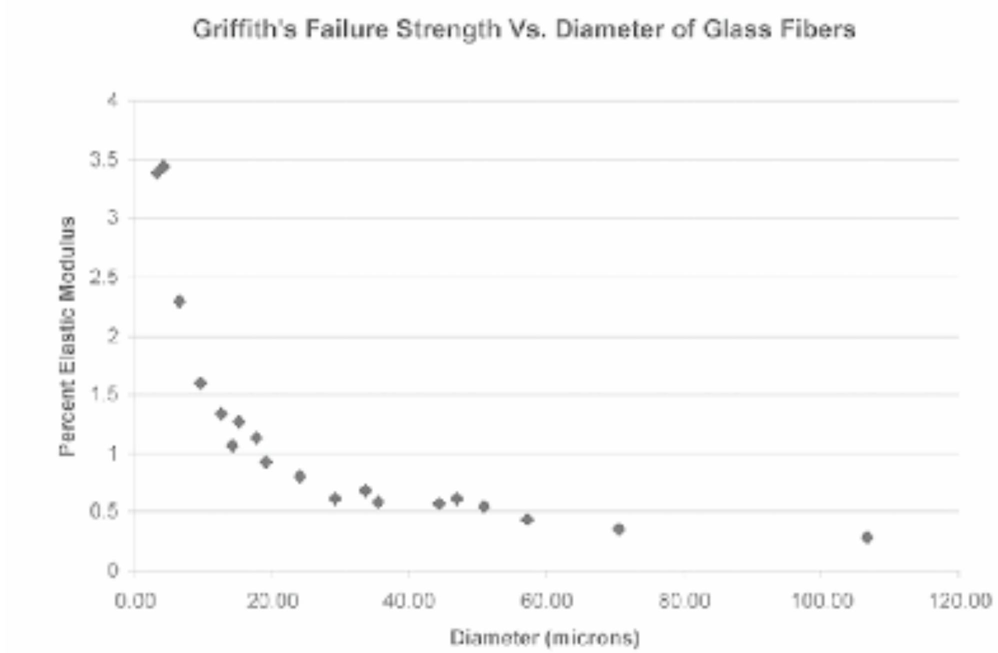
The physics:

•The propagation is an endothermic process, that is, energy is absorbed in order to provide the work of fracture

•Work is done to create new surface. Can be expressed as energy per unit area, called the work of fracture, and written as γ_F with units of J m^{-2}.

•At the crack tip bonds must be broken to advance the crack. Bond-breaking creates new surfaces, therefore the work required to break bonds divided by the area per bond (the footprint of the bond) should be equal to $2\gamma_F$ (the factor of two accounts for the two surfaces that are created when a bond breaks.

Relationship between Flaw Size and Physical Dimensions, e. g. the diameter of glass fibers:



Fracture stress is determined by the size of the flaw. It is often expressed as a percentage of the Youngs Modulus, since the theoretical fracture stress (also called the ideal fracture stress) is related to the strength of the bonds, which is related to the bond-stiffness. The elastic modulus depends on the bond stiffness. In the above curve the fracture stress of glass fibers rises to 3.5% of the elastic modulus.

It is intuitively obvious that the flaw-size will be related to the physical size of the specimen. Thus the increase in the fracture strength of the glass fibers can be ascribed to smaller flaw size in fibers with a smaller diameter.

The upper bound for the fracture stress is when the bonds across the entire cross section of the fiber break at once when the applied stress approached the rupture strength of the bonds. This upper bound fracture stress is 15% to 25% of the elastic modulus. Indeed highly polished glass fibers about 1 µm in diameter approach this ideal fracture strength.

Semi-Brittle Fracture

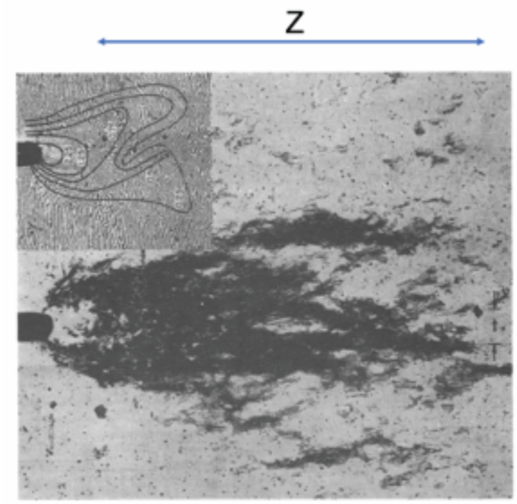


Fig. 7. Interference pattern with isostrain contours (top left corner) and the corresponding plastic zone revealed by etching, both for Sample S-56 (t = 0.017 in., T/Y = 0.81). ×17.5.

The above picture shows intense plastic deformation at the crack tip while, overall, the specimen deforms elastically. The local deformation eventually leads to plastic tearing, which advances the crack.

The physics:

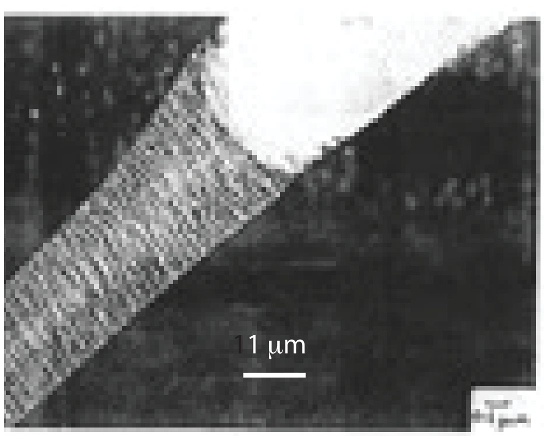
Fracture occurs by the propagation of the crack when the "damage" in front of the crack tip reaches a critical value.

The growth of damage is driven by opening of the mouth of the crack, which is called the Crack Tip Opening Displacement (CTOD).

Therefore, the fracture criterion can be given in terms of a critical value of CTOD.

The magnitude of the CTOD is related to the applied stress and the size of the microcrack, as is the case in brittle fracture, even to though the mechanism of fracture at the crack tip is quite different.

Fracture in polymers



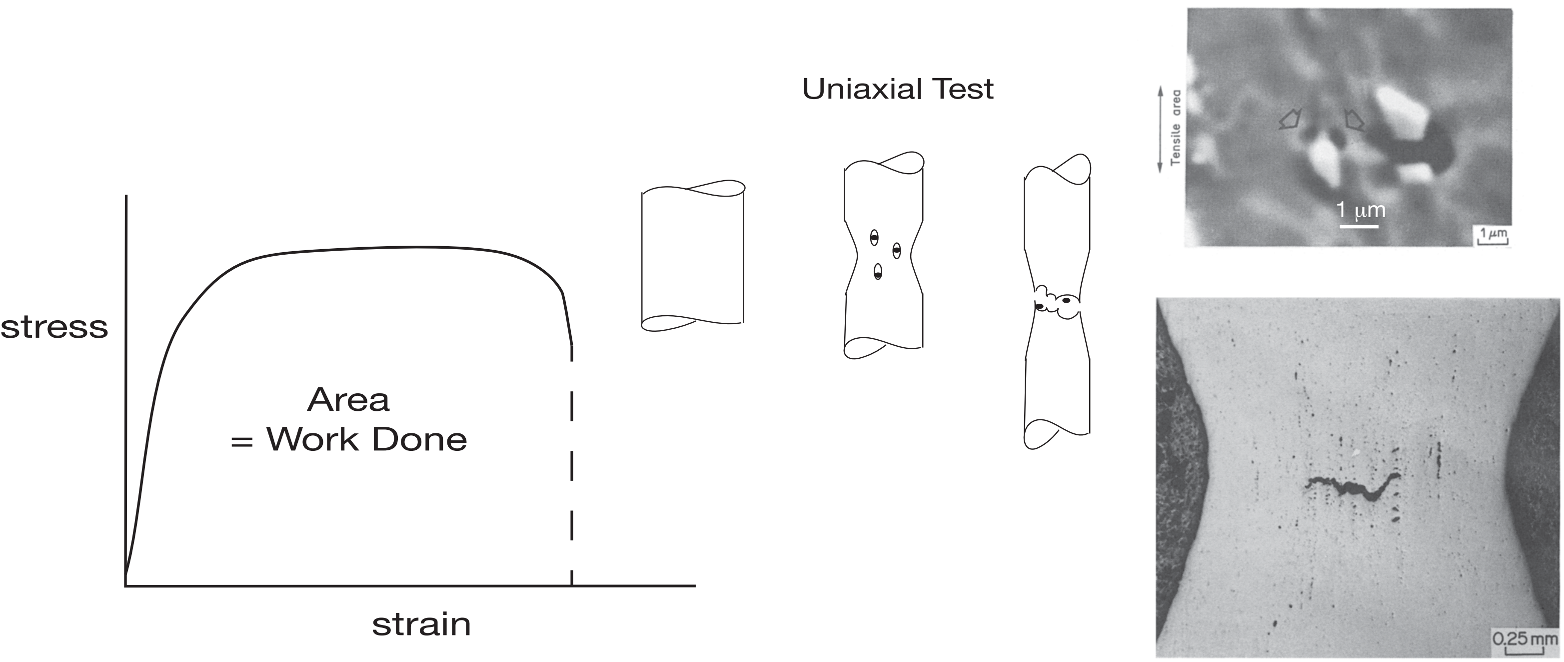
The above transmission electron micrograph shows the stretched fibrils in the polymer at the crack tip, at the breaking point.

The Physics

Polymers are a tangle of chains of organic molecules. Near the crack tip these chains stretch and straighten out, and then eventually rupture.

The crack tip advances by such local stretching and rupture of the polymer chains, which is accommodated by the opening of the crack tip. Therefore, the local criterion for fracture can be expressed in terms of a critical value of the CTOD.

Ductile Fracture



Ductile fracture in a uniaxial tensile is described above. The sample deforms to large tensile strains (ranging from a few percent to several tens of percent).

The onset of fracture is signaled by localization of strain what is called the formation of a "neck". The strain continues to localize within this region. Voids form at hard second phase particles, which grow and coalesce to cause fracture by plastic tearing.

Metals which fracture at small tensile strains are prone to semi-brittle behavior as described above. In these cases such uniaxial tensile stress can provide insights and predictions of semi-brittle behavior.