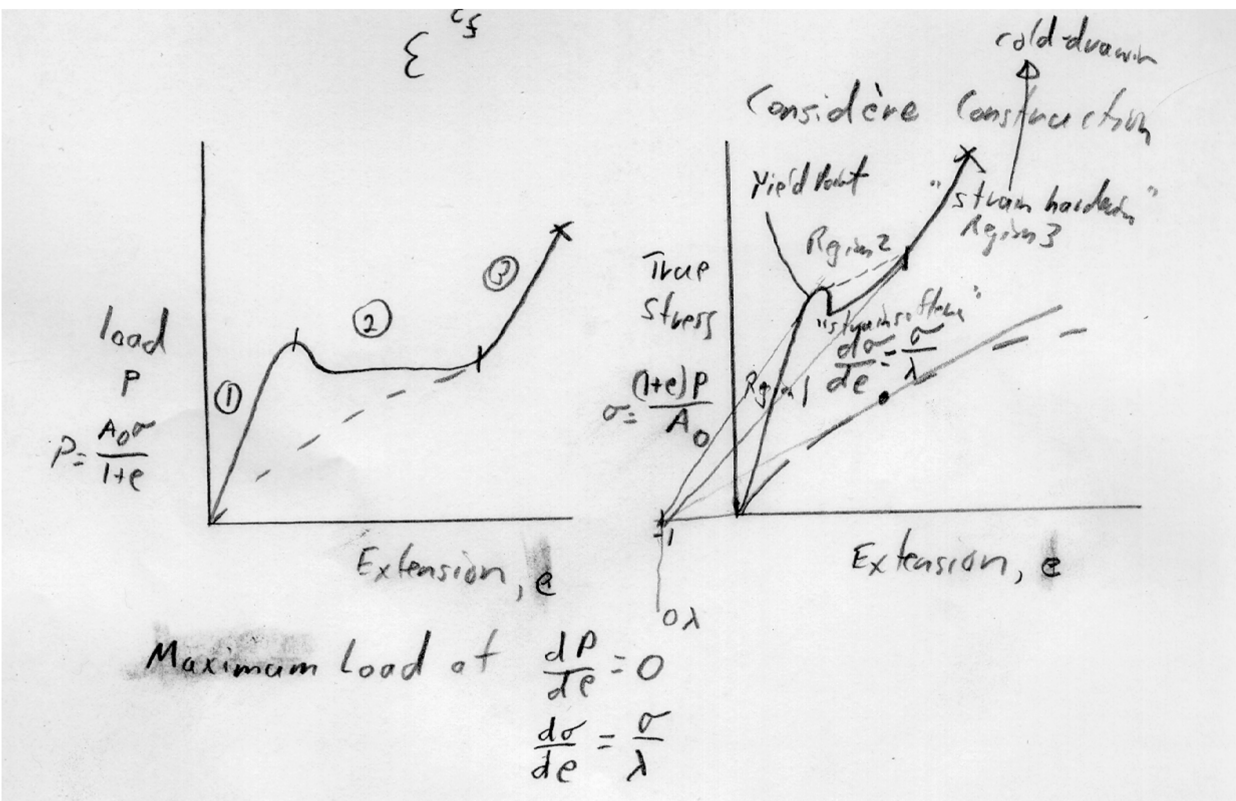
Polymer Yielding:
(Based on I. M. Ward's "Mechanical Properties of Polymers")

Yielding in polymers is strongly temperature and strain-rate dependent. By choosing a standard test rate it is possible to adopt yield and failure functions such as the Von Mises Criterion for yielding and the Griffith Criterion for failure. In this context we can consider a phenomenological approach to yielding in polymers. In general, polymers show three types of yield, 1) homogeneous deformation to rupture, rubbery behavior; 2) Brittle failure, often accompanied by crazing; 3) necking and cold drawing, often accompanied by shear banding. All three of these behaviors can be seen in the same sample depending on rate and temperature. Additionally, localized heating on deformation of polymers is important to the mechanical behavior due to the rate, temperature dependence of mechanical response and the low thermal conductivity of most polymers.

Additionally, polymers are generally anisotropic in mechanical response due to high degrees of molecular and structural orientation in processing. Unless special precautions are made to ensure an isotropic sample it can usually be assumed that a polymer sample is mechanically anisotropic.



Yielding is often described in terms of the Considere Construction shown above.

Polymer yield behavior can be described using the Von Misses criterion if the criterion is modified to include a hydrostatic pressure dependence of yielding. This can be accomplished by making the yield point, k, a function of the normal stresses,

$$F\left(\sigma_{xx}-\sigma_{zz}\right)^2+G\left(\sigma_{zz}-\sigma_{xx}\right)^2+H\left(\sigma_{xx}-\sigma_{yy}\right)^2$$
$$+2L\sigma_{yz}^2+2M\sigma_{zx}^2+2N\sigma_{xy}^2=1$$

The Tresca criterion, modified for the normal pressure applied to the shear plane, is called the Coulomb Criterion and is used to describe polymer yielding (originally derived for soil yielding),

$$\tau=\tau_c-\mu\sigma_N$$
$$\mu=\tan\varphi=\tan\left(2\left[\frac{\pi}{4}-\theta\right]\right)$$

θ is the angle between the normal to the shear plane and the direction tensile stress is applied.

Necking:
Adiabatic heating
strain softening (strain hardening can't keep up with loss of area)
Yield stress increases with hydrostatic pressure

Yielding of oriented polymers:
kink band versus slip band
kink band is diffuse with a larger angle to draw direction
slip band parallel to draw direction, sharp

Bauschinger Effect: Tensile and compressive yield stresses differ (at odds with atomic model in metals)

"It is more difficult to extend an already oriented structure than to contract it"

Rate Dependence:

Higher yield stress and more brittle behavior at higher strain rates
Lower yield stress and more ductile behavior at higher temperatures.
Activated rate process
This can include a pressure term also.

$$\tau=\frac{RT}{v}\left\{\frac{\Delta H}{RT}+\ln\frac{2e'}{e'_0}\right\}$$
$$e'=\frac{e'_0}{2}\exp\left\{-\left(\frac{\Delta H-v\tau+\left(P\Omega\right)}{RT}\right)\right\}$$

Brittle versus Ductile:

Max Stress is Failure stress = brittle (and at low strain)
Energy for an impact test is low (brittle)
Fracture surface