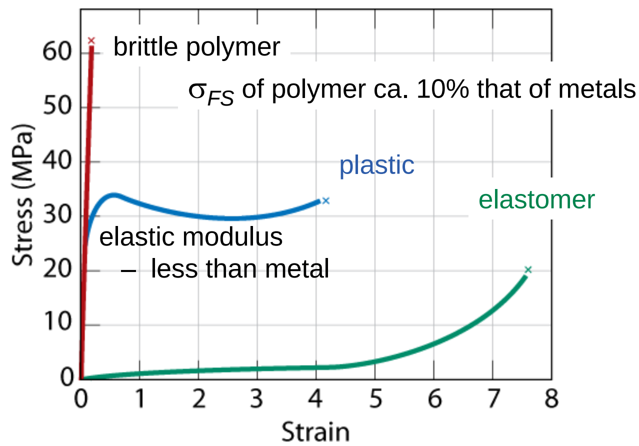
Chapter 5 Polymer properties and applications

- Mechanical characteristics of polymers
- Stress-strain behavior
- Deformation of polymers
- Factors that influence the mechanical properties of polymers
- Polymer applications

Mechanical characteristics of polymers

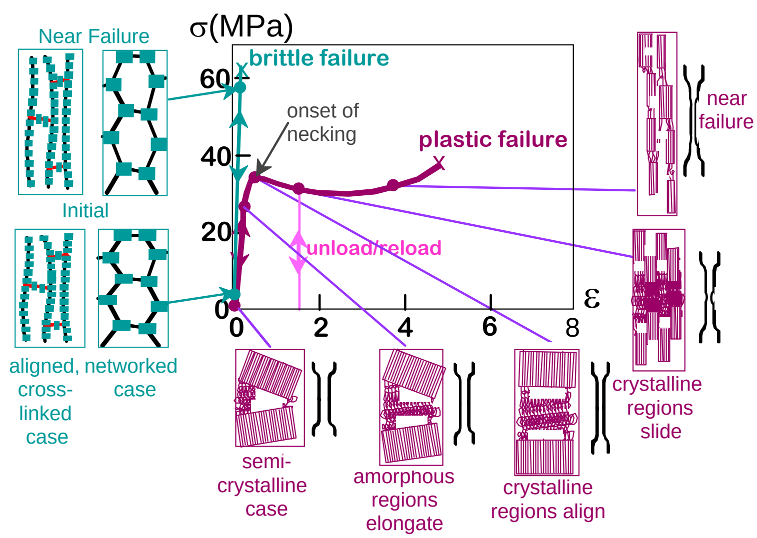
- Polymers
  - lower elastic modulus with a wide range (7MPa-4 GPa)
  - lower tensile strength (order of 100MPa)
  - larger plastic deformation (possibly as high as 1000%)
  - mechanical behavior are more sensitive to environmental changes
- Metals
  - Larger elastic modulus (48-410 GPa)
  - Higher tensile strength (up to 4100GPa)
  - Smaller plastic deformation(less than 100%)
  - less sensitive to environment

Stress-strain behavior of polymers



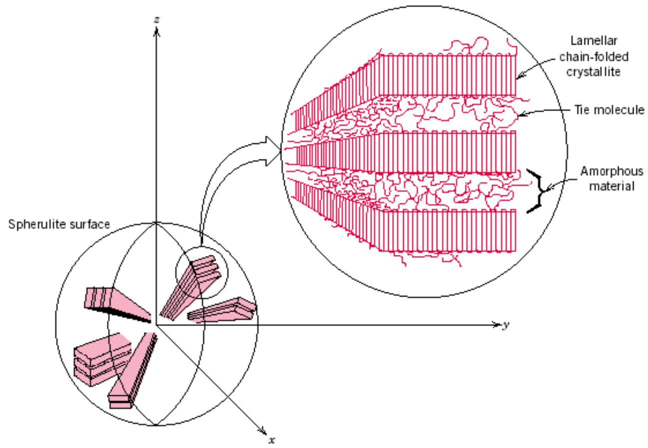
Strains – deformations > 1000% possible
(for metals, maximum strain ca. 10% or less)

Deformation of brittle and semicrystalline polymers

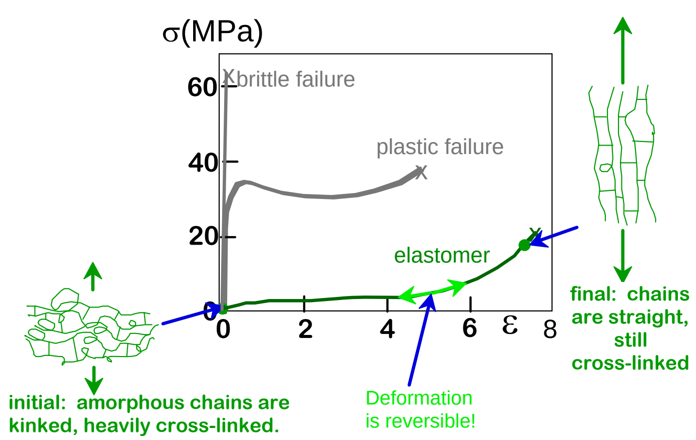


Structure of semicrystalline polymers (review)

- Detailed structure of a spherulite



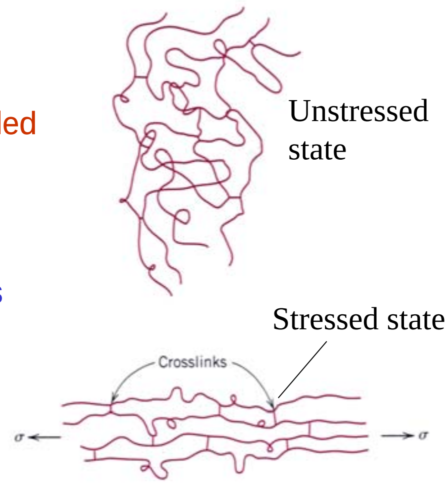
Deformation of elastomer



- **Compare to responses of other polymers:**
  - **brittle response (aligned, cross linked & networked case)**
  - **plastic response (semi-crystalline case)**

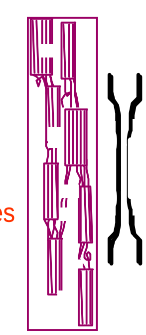
Deformation of elastomers (*cont*.)

- Polymeric structures
  - amorphous, highly twisted, kinked and coiled
  - free rotation of chain bonds
- Deformation of elastomers
  - rubberlike elasticity
  - driving force for elastic deformation: entropy



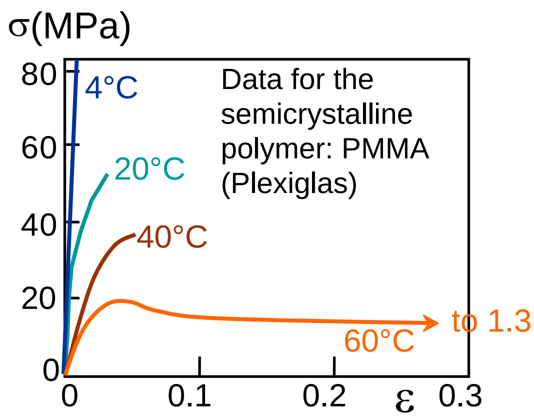
Factors that influence the mechanical properties of polymers

- Molecular weight
  - σ_{TS} often increase with Mw
  - Longer chains are entangled or anchored better
- %crystallinity: % of material that is crystalline
  - σ_{TS} and E increase with %crystallinity
  - Annealing increases with %crsystallinity
- Drawing: aligns polymer chains to the stretching direction
  - E and TS increases in the direction of tension and reduces in other directions
  - Ductility is reduced



Effect of T and strain rate

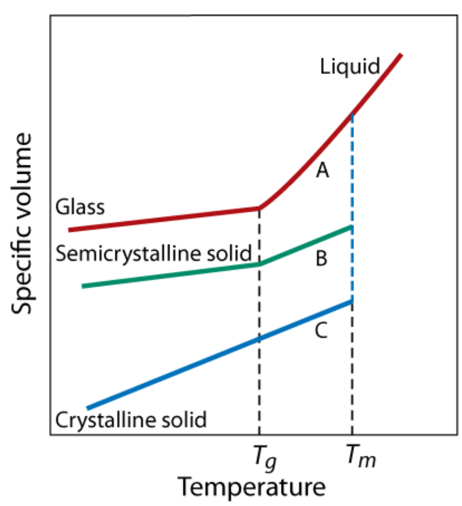
- Decrease T
  - increase E
  - increase TS
  - decrease ductility
- Increase strain rate
  - same effect as decreasing T



Melting vs. glass transition temp.

What factors affect T_m and T_g?

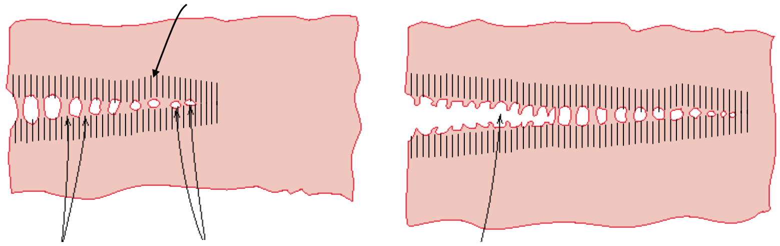
- Both T_m *and* T_g increase with increasing chain stiffness
- Chain stiffness increased by
  1. Bulky sidegroups
  2. Polar groups or sidegroups
  3. Double bonds or aromatic chain groups
- Regularity – effects T_m only



Polymer fracture

- ☐ Crazing ≅ Griffith cracks in metals

-- spherulites plastically deform to fibrillar structure
-- microvoids and fibrillar bridges form

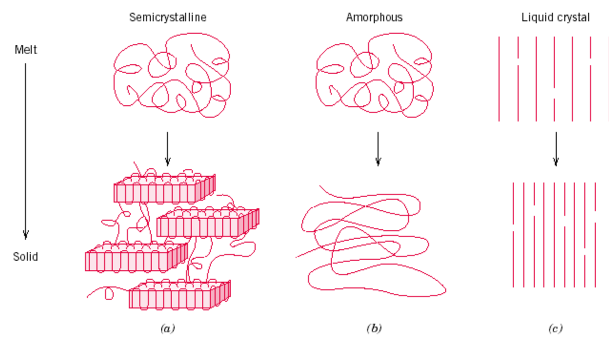


Polymer applications

- ☐ Plastics, elastomers, fibers, coatings,
- ☐ Polymer additives
  - fillers
  - plasticizers
  - stabilizers
  - colorants
  - flame retardants

Polymer applications

- Advanced polymers
  - ultrahigh molecular weight polyethylene
  - liquid crystal polymers



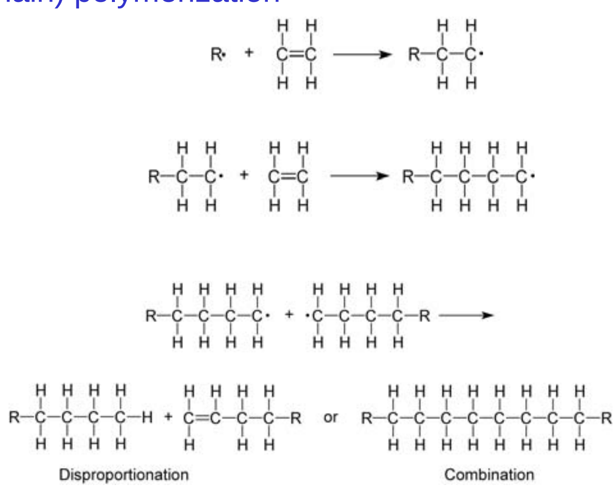
Polymer synthesis and processing

- Addition (chain) polymerization

Initiation

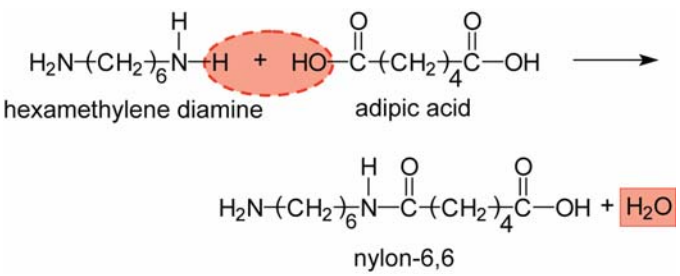
Propagation

Termination



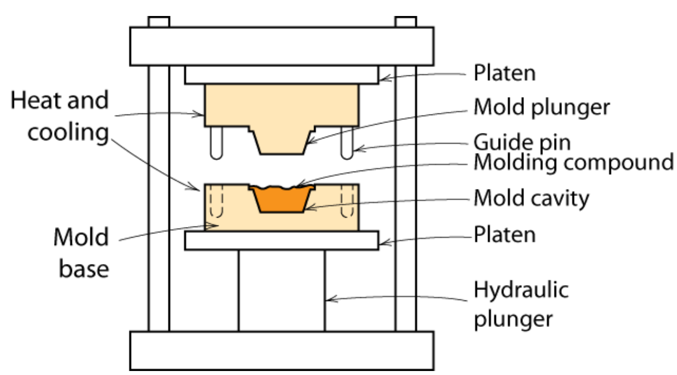
Polymer synthesis and processing (cont.)

- Condensation (step) polymerization



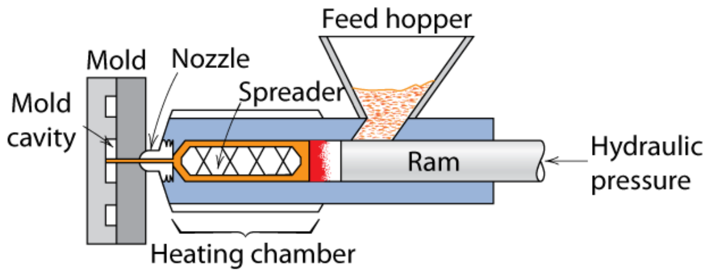
Processing plastics - molding

- Compression and transfer molding
  - thermoplastic or thermoset

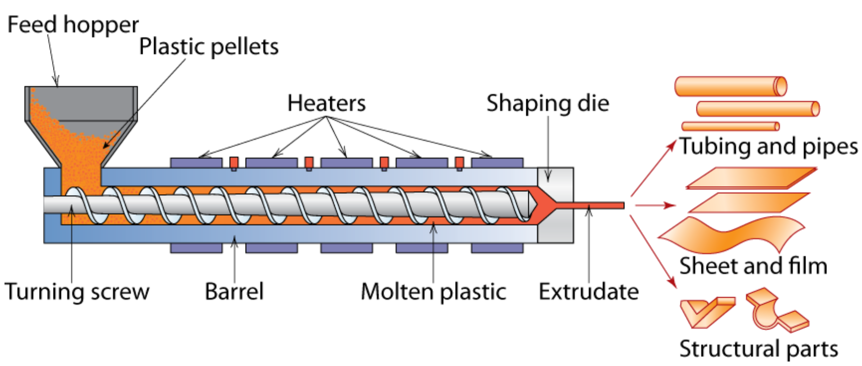


Processing plastics - molding

- Injection molding
  - thermoplastic & some thermosets



Processing plastics – extrusion



Summary

- General drawbacks to polymers
  - E, $\sigma_{y,}$ Kc, $T_{application}$ are small
  - T-dependent deformation
  - Result: polymers benefit from composite reinforcement
- Thermoplastics (PE, PS, PP, PC)
  - smaller E, $\sigma_{y,}$ $T_{application}$
  - larger Kc
  - easier to form and recycle
- Elastomers (rubber)
  - large reversible strains
- Thermosets (epoxies, polyesters)
  - larger E, $\sigma_{y,}$ $T_{application}$
  - smaller Kc