# Chapter 15: Characteristics, Applications & Processing of Polymers

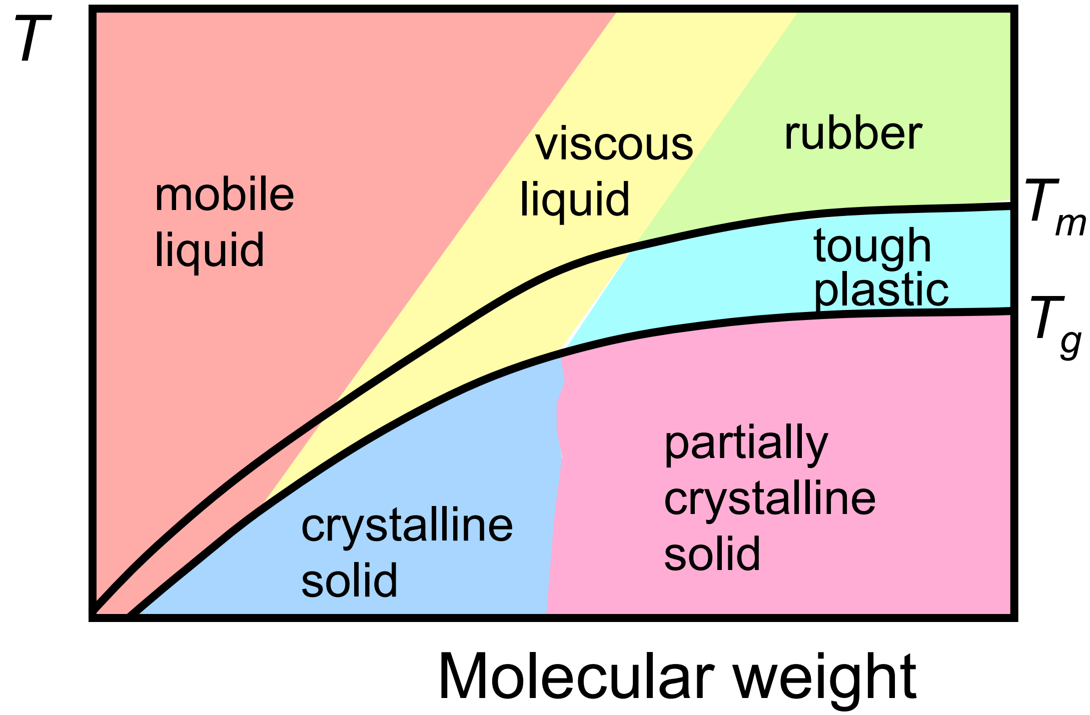
- What are the tensile properties of polymers and how are they affected by basic microstructural features?
- Hardening, anisotropy, and annealing in polymers.
- How does the elevated temperature mechanical response of polymers compare to ceramics and metals?

# Processing of Plastics

- Thermoplastic –
  - can be reversibly cooled & reheated, i.e. recycled
  - heat till soft, shape as desired, then cool
  - ex: polyethylene, polypropylene, polystyrene, etc.
- Thermoset
  - when heated forms a network
  - degrades (not melts) when heated
  - mold the prepolymer then allow further reaction
  - ex: urethane, epoxy, bakelyte

# Thermoplastics vs. Thermosets

- Thermoplastics:
  -- little crosslinking
  -- ductile
  -- soften w/heating
  -- polyethylene
  polypropylene
  polycarbonate
  polystyrene



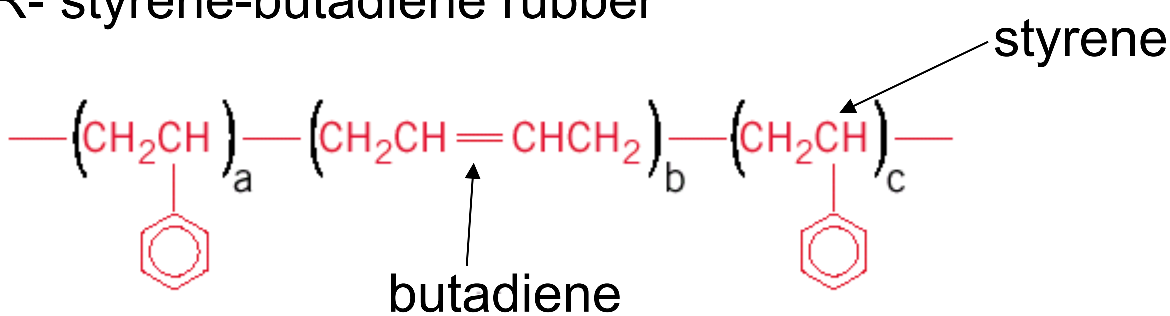

Adapted from Fig. 15.19, *Callister 7e*. (Fig. 15.19 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley and Sons, Inc., 1984.)

- Thermosets:
  -- large crosslinking
  (10 to 50% of mers)
  -- hard and brittle
  -- do NOT soften w/heating
  -- vulcanized rubber, epoxies,
  polyester resin, phenolic resin

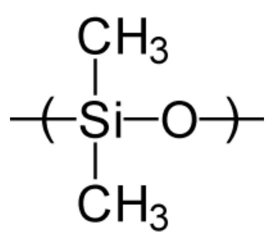
# Polymer Types: Elastomers

Elastomers – rubber

- Crosslinked materials
  - Natural rubber
  - Synthetic rubber and thermoplastic elastomers
    - SBR- styrene-butadiene rubber




  - Silicone rubber



# Polymer Types: Fibers

Fibers - length/diameter >100

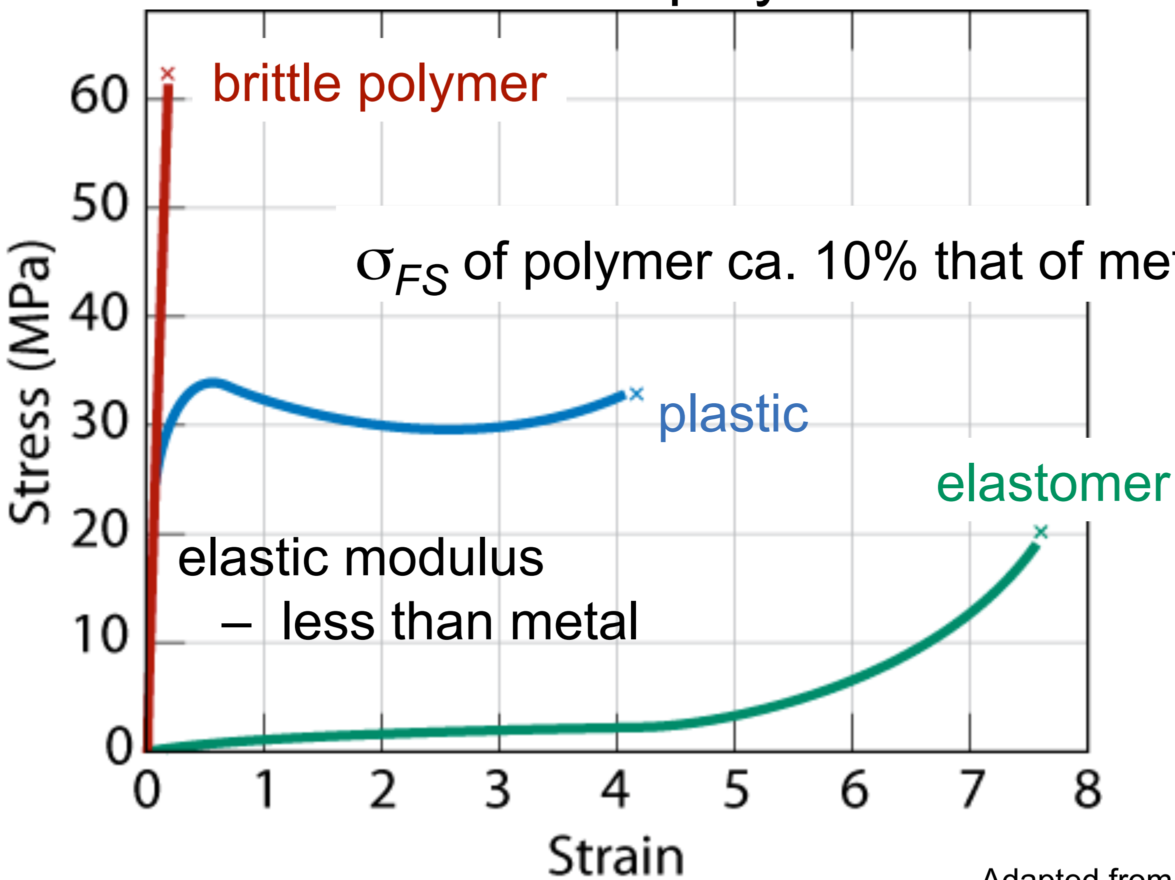
- Textiles are main use
  - Must have high tensile strength
  - Usually highly crystalline & highly polar
- Formed by spinning
  - ex: extrude polymer through a spinnerette
    - Pt plate with 1000's of holes for nylon
    - ex: rayon – dissolved in solvent then pumped through die head to make fibers
  - the fibers are drawn
  - leads to highly aligned chains- fibrillar structure

# Polymer Types

- Coatings – thin film on surface – i.e. paint, varnish
  - To protect item
  - Improve appearance
  - Electrical insulation
- Adhesives – produce bond between two adherands
  - Usually bonded by:
    1. Secondary bonds
    2. Mechanical bonding
- Films – blown film extrusion
- Foams – gas bubbles in plastic

# Mechanical Properties

- i.e. stress-strain behavior of polymers



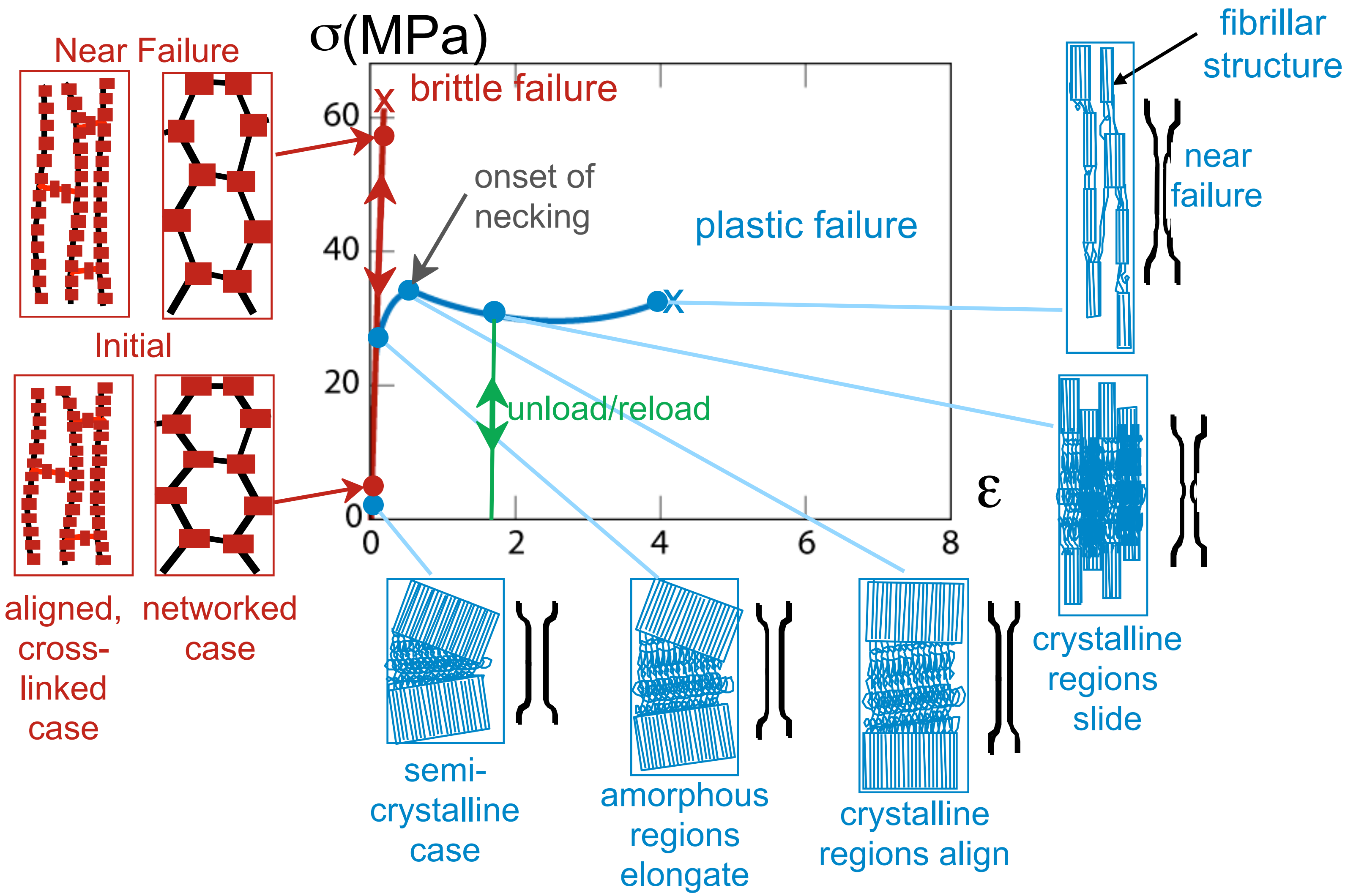

$\sigma_{FS}$ of polymer ca. 10% that of metals

elastic modulus
– less than metal

Adapted from Fig. 15.1, *Callister 7e*.

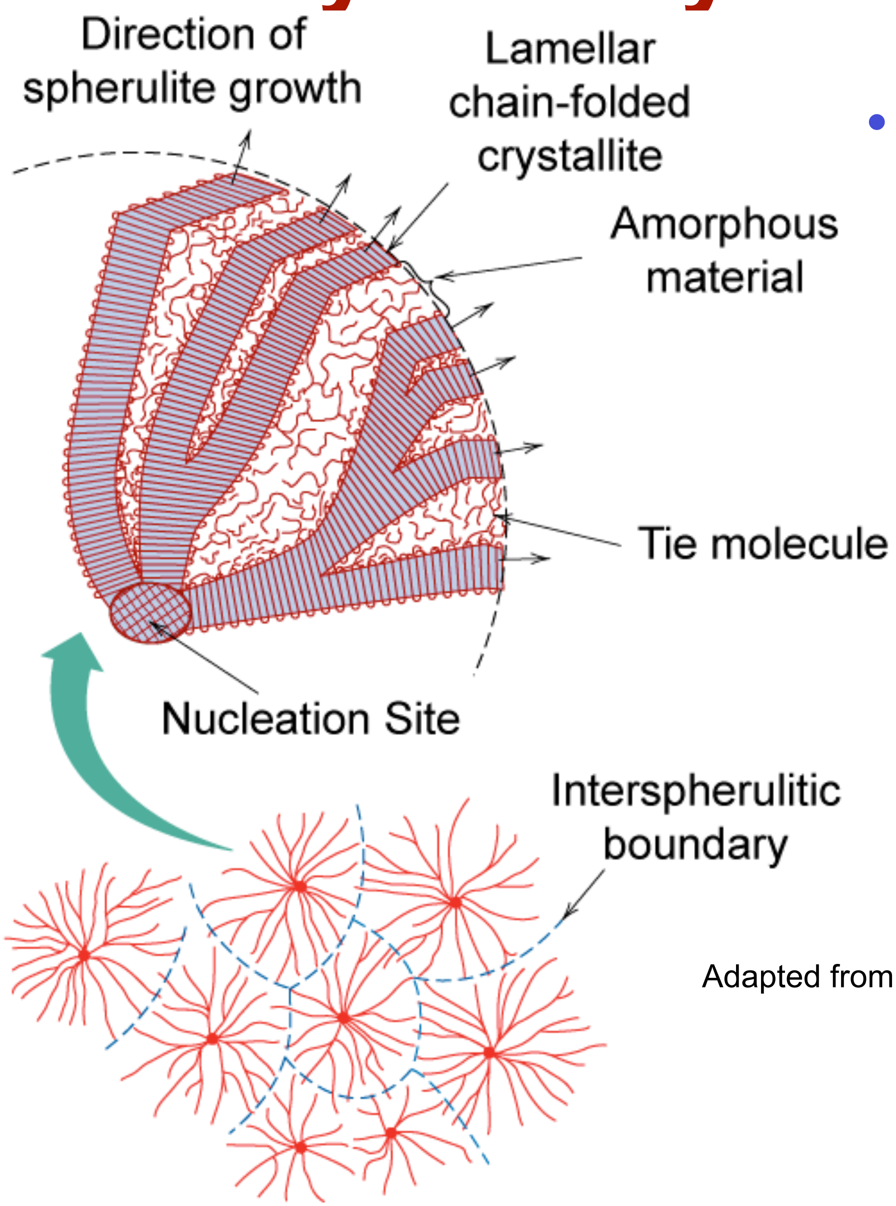
Strains – deformations > 1000% possible
(for metals, maximum strain ca. 10% or less)

# Tensile Response: Brittle & Plastic




Stress-strain curves adapted from Fig. 15.1, *Callister 7e.* Inset figures along plastic response curve adapted from Figs. 15.12 & 15.13, *Callister 7e*. (Figs. 15.12 & 15.13 are from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)

# Polymer Crystal Forms

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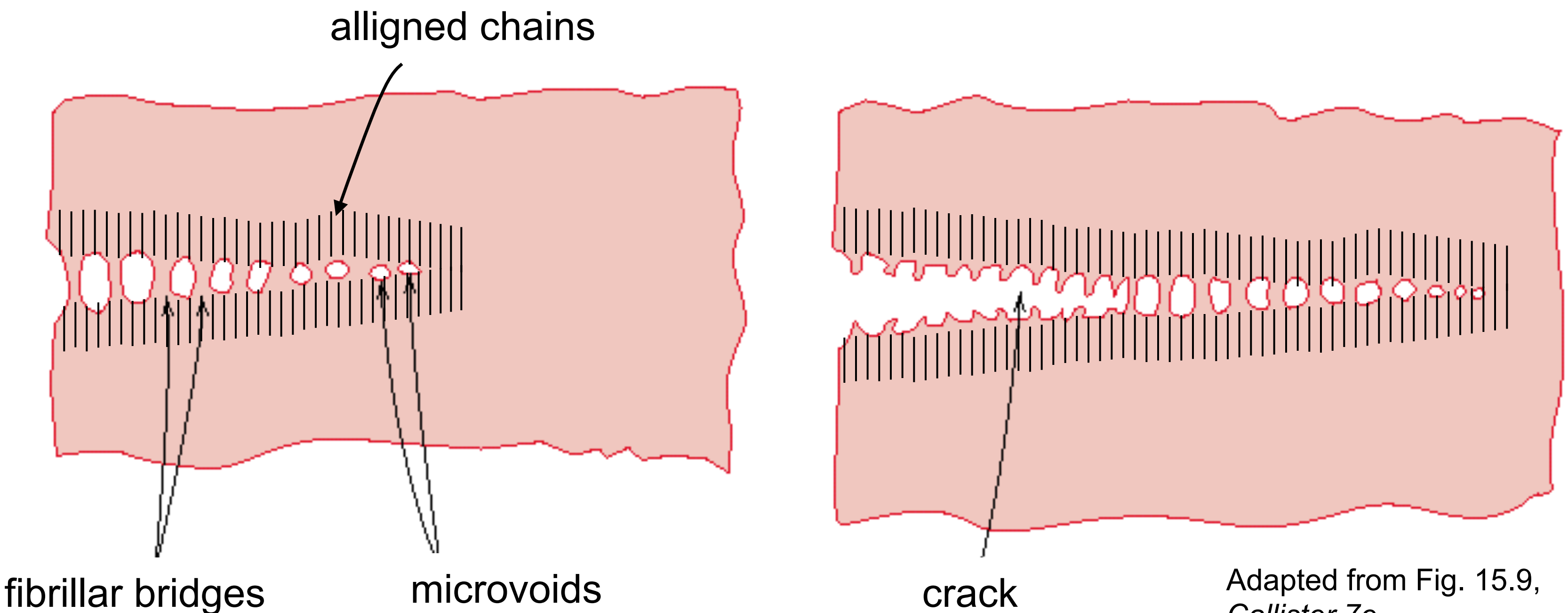
- Spherulites – fast growth – forms lamellar (layered) structures

Adapted from Fig. 14.13, *Callister 7e.*

# Polymer Fracture

Crazing ≅ Griffith cracks in metals

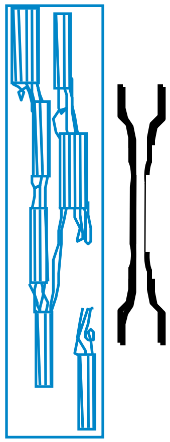
– spherulites plastically deform to fibrillar structure
– microvoids and fibrillar bridges form




Adapted from Fig. 15.9, *Callister 7e*.

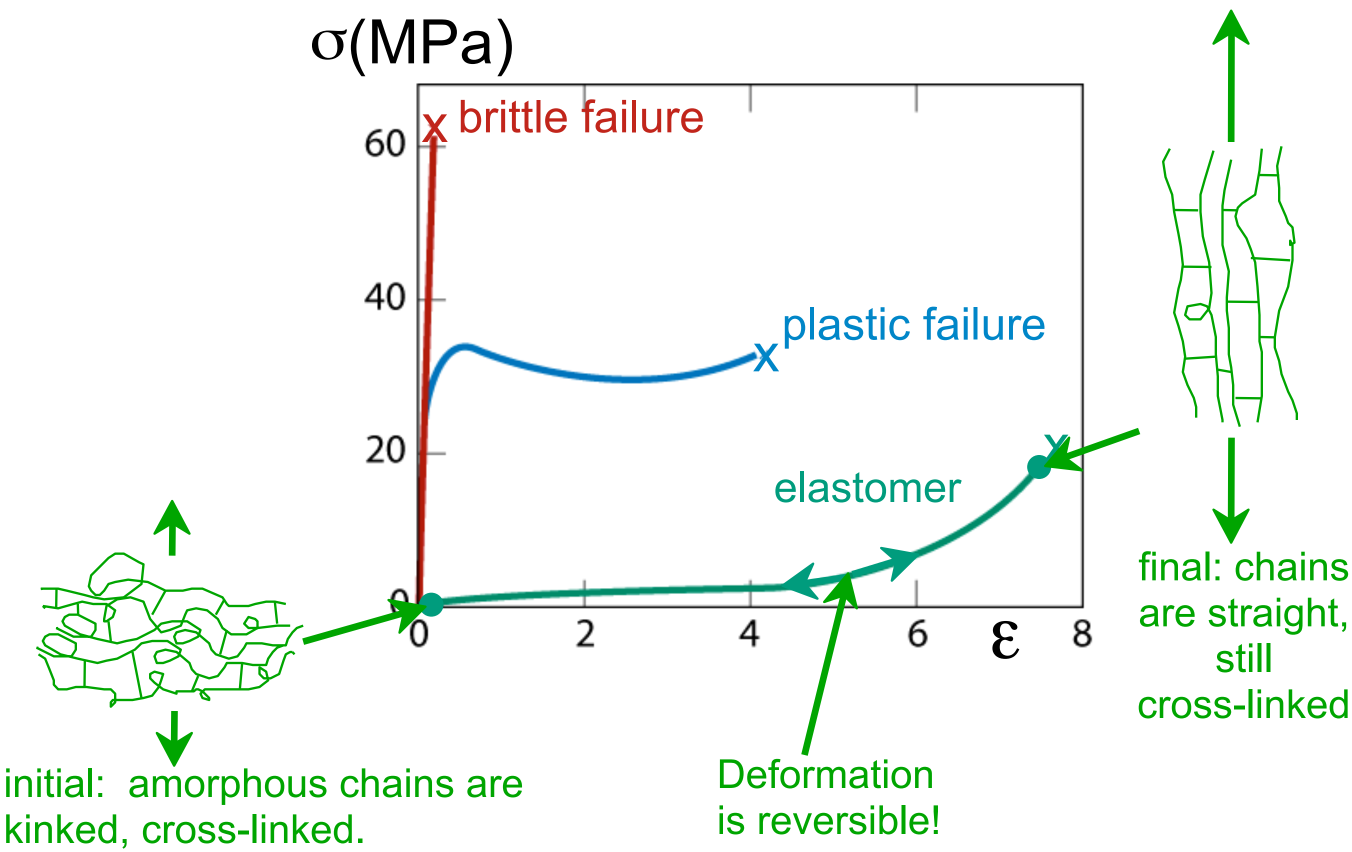
# Predeformation by Drawing

- Drawing…(ex: monofilament fishline)
  -- stretches the polymer prior to use
  -- aligns chains in the stretching direction
- Results of drawing:
  -- increases the elastic modulus (*E*) in the stretching direction
  -- increases the tensile strength (*TS*) in the stretching direction
  -- decreases ductility (%*EL*)
- Annealing after drawing...
  -- decreases alignment
  -- reverses effects of drawing.
- Compare to cold working in metals!



Adapted from Fig. 15.13, *Callister 7e*. (Fig. 15.13 is from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)

# Tensile Response:  Elastomer Case



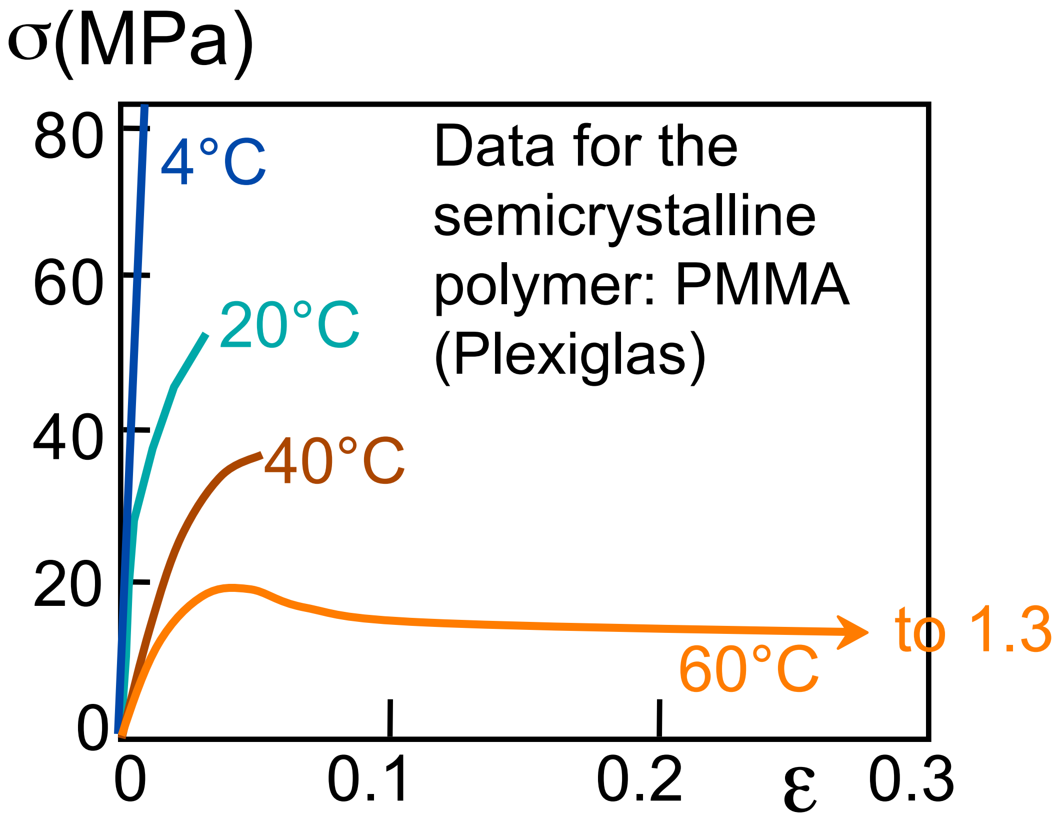

Stress-strain curves adapted from Fig. 15.1, *Callister 7e.* Inset figures along elastomer curve (green) adapted from Fig. 15.15, *Callister 7e.* (Fig. 15.15 is from Z.D. Jastrzebski, *The Nature and Properties of Engineering Materials*, 3rd ed., John Wiley and Sons, 1987.)

- Compare to responses of other polymers:
  - -- brittle response (aligned, crosslinked & networked polymer)
  - -- plastic response (semi-crystalline polymers)

# *T* and Strain Rate: Thermoplastics

- Decreasing *T*...
  - -- increases *E*
  - -- increases *TS*
  - -- decreases *%EL*

- Increasing strain rate...
  - -- same effects as decreasing *T*.



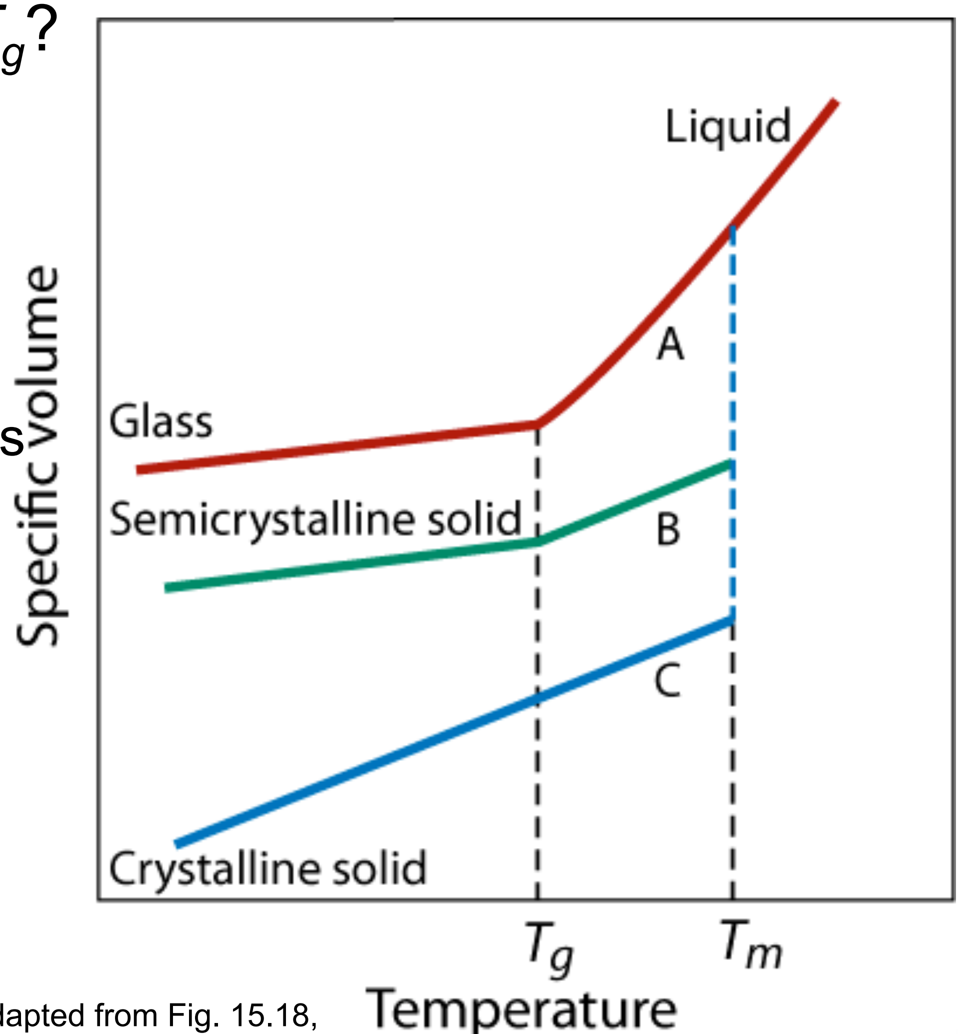

Adapted from Fig. 15.3, *Callister 7e*. (Fig. 15.3 is from T.S. Carswell and J.K. Nason, 'Effect of Environmental Conditions on the Mechanical Properties of Organic Plastics", *Symposium on Plastics*, American Society for Testing and Materials, Philadelphia, PA, 1944.)

# 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



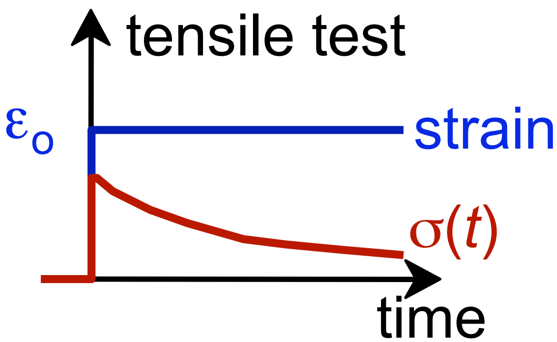

Adapted from Fig. 15.18, *Callister 7e*.

# Time Dependent Deformation

- Stress relaxation test:

  -- strain to $\varepsilon_o$ and hold.

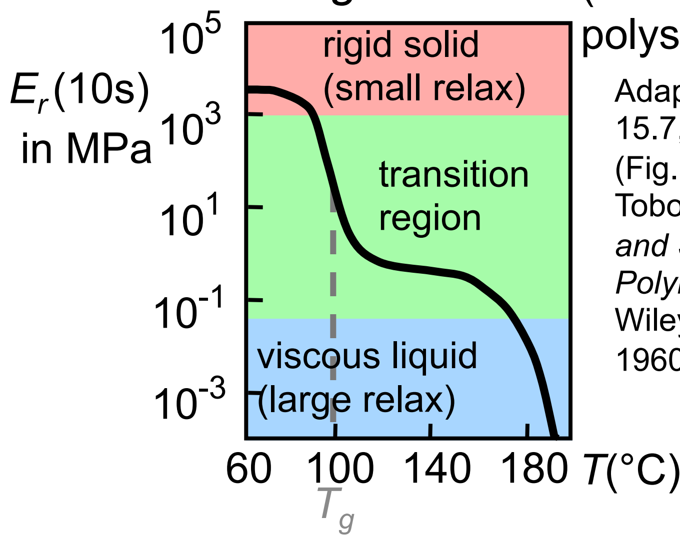
  -- observe decrease in stress with time.




- Relaxation modulus:

$$E_r(t) = \frac{\sigma(t)}{\varepsilon_o}$$

- Data: Large drop in $E_r$ for $T > T_g$. (amorphous polystyrene)




Adapted from Fig. 15.7, *Callister 7e*. (Fig. 15.7 is from A.V. Tobolsky, *Properties and Structures of Polymers*, John Wiley and Sons, Inc., 1960.)

- Sample $T_g$(°C) values:

| | |
|---|---|
| PE (low density) | - 110 |
| PE (high density) | - 90 |
| PVC | + 87 |
| PS | +100 |
| PC | +150 |

Selected values from Table 15.2, *Callister 7e*.

# Summary

- General drawbacks to polymers:
  -- $E$, $\sigma_y$, $K_c$, $T_{application}$ are generally small.
  -- Deformation is often $T$ and time dependent.
  -- Result: polymers benefit from composite reinforcement.
- Thermoplastics (PE, PS, PP, PC):
  -- Smaller $E$, $\sigma_y$, $T_{application}$
  -- Larger $K_c$
  -- Easier to form and recycle
- Elastomers (rubber):
  -- Large reversible strains!
- Thermosets (epoxies, polyesters):
  -- Larger $E$, $\sigma_y$, $T_{application}$
  -- Smaller $K_c$

Table 15.3 *Callister 7e*:

Good overview of applications and trade names of polymers.