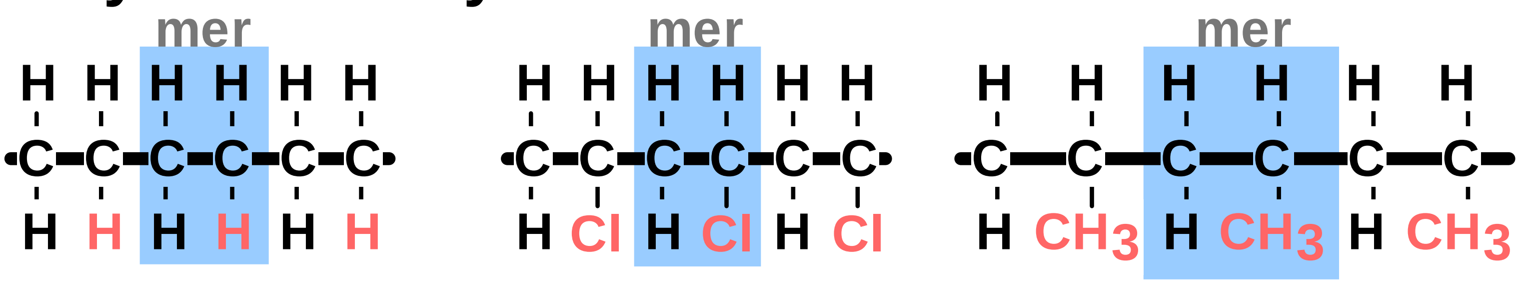
CHAPTERS 14/15: POLYMER STRUCTURES, APPLICATIONS, & PROCESSING

ISSUES TO ADDRESS...

- What are the basic microstructural features?
- How do these features dictate room T tensile response?
- Hardening, anisotropy, and annealing in polymers.
- How does elevated temperature mechanical response compare to ceramics and metals?

POLMER MICROSTRUCTURE

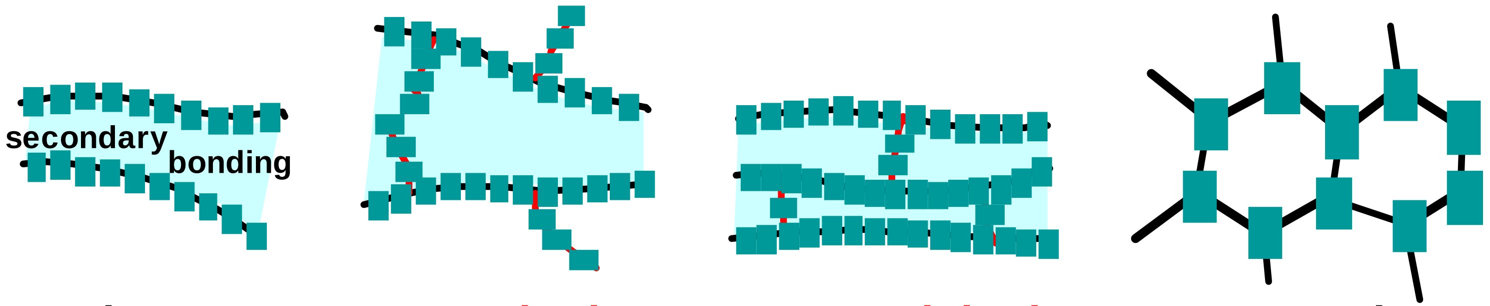
- **Poly*mer* = many *mers***



Polyethylene (PE) Polyvinyl chloride (PVC) Polypropylene (PP)

Adapted from Fig. 14.2, *Callister 6e.*

- **Covalent *chain* configurations and strength:**



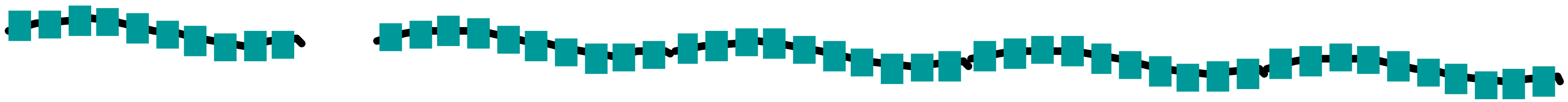
Linear Branched Cross-Linked Network

Direction of increasing strength

Adapted from Fig. 14.7, *Callister 6e.*

MOLECULAR WEIGHT & CRYSTALLINITY

- **Molecular weight**, M_W: **Mass of a mole of chains.**



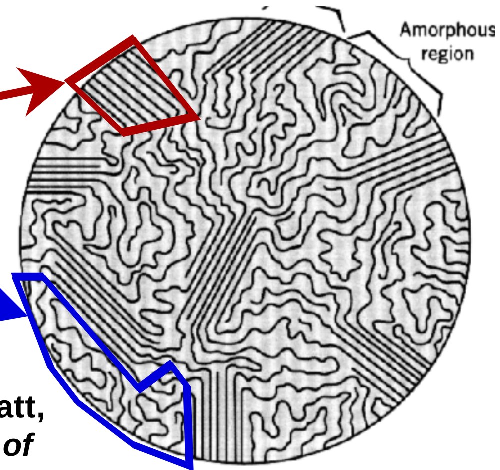
smaller M_W **larger M_W**

- **Tensile strength (TS):**
  --often increases with M_W.
  --Why? Longer chains are entangled (anchored) better.

- **% Crystallinity: % of material that is crystalline.**
  --TS and E often increase with % crystallinity.
  --Annealing causes crystalline regions to grow. % crystallinity increases.

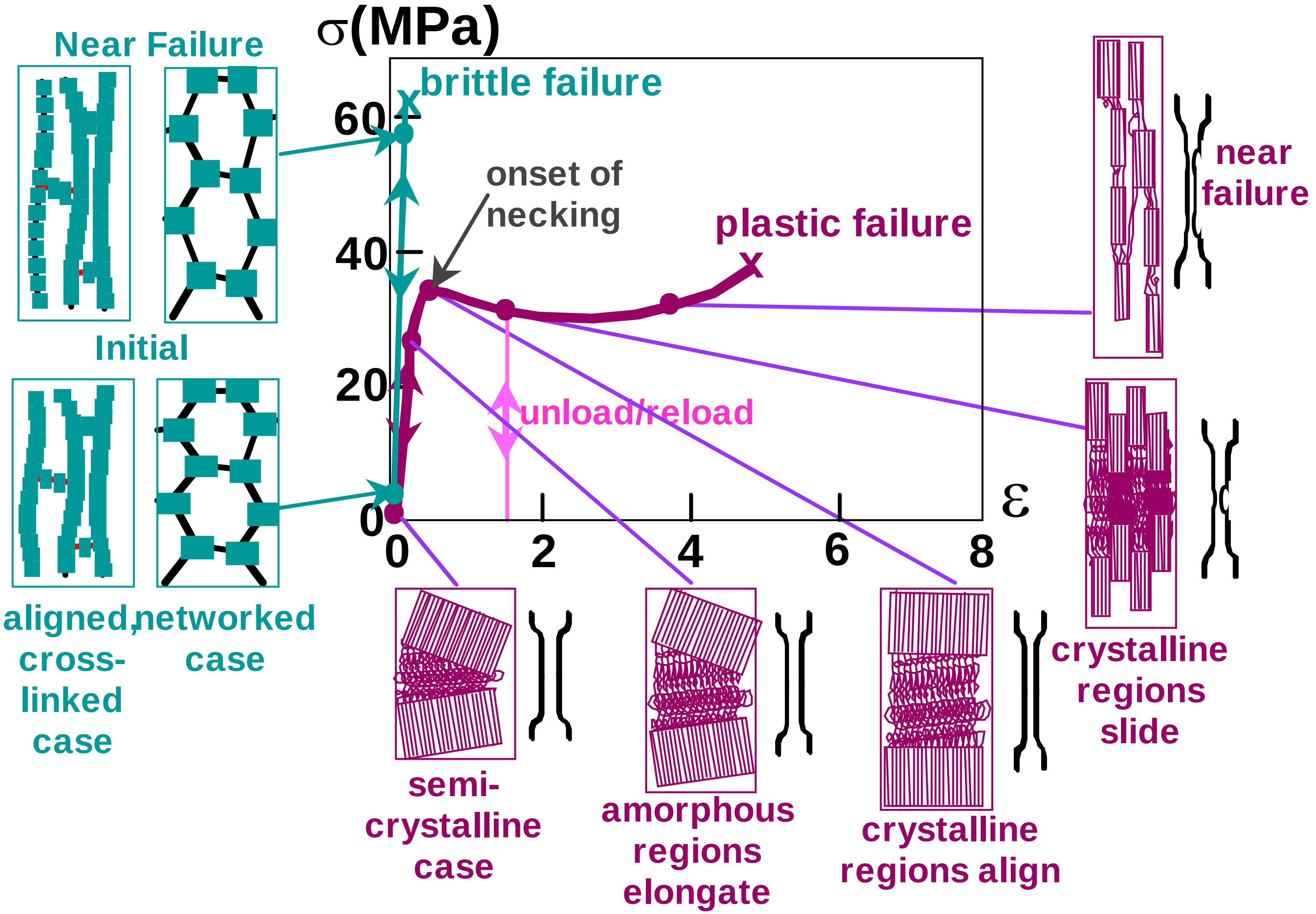
crystalline region

amorphous region



Adapted from Fig. 14.11, *Callister 6e.* (Fig. 14.11 is from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, John Wiley and Sons, Inc., 1965.)

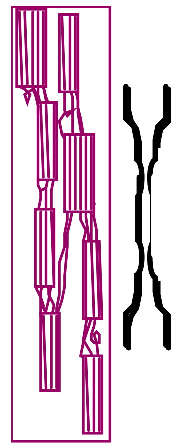
TENSILE RESPONSE: BRITTLE & PLASTIC



Stress-strain curves adapted from Fig. 15.1, *Callister 6e.* Inset figures along plastic response curve (purple) adapted from Fig. 15.12, *Callister 6e*. (Fig. 15.12 is from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)

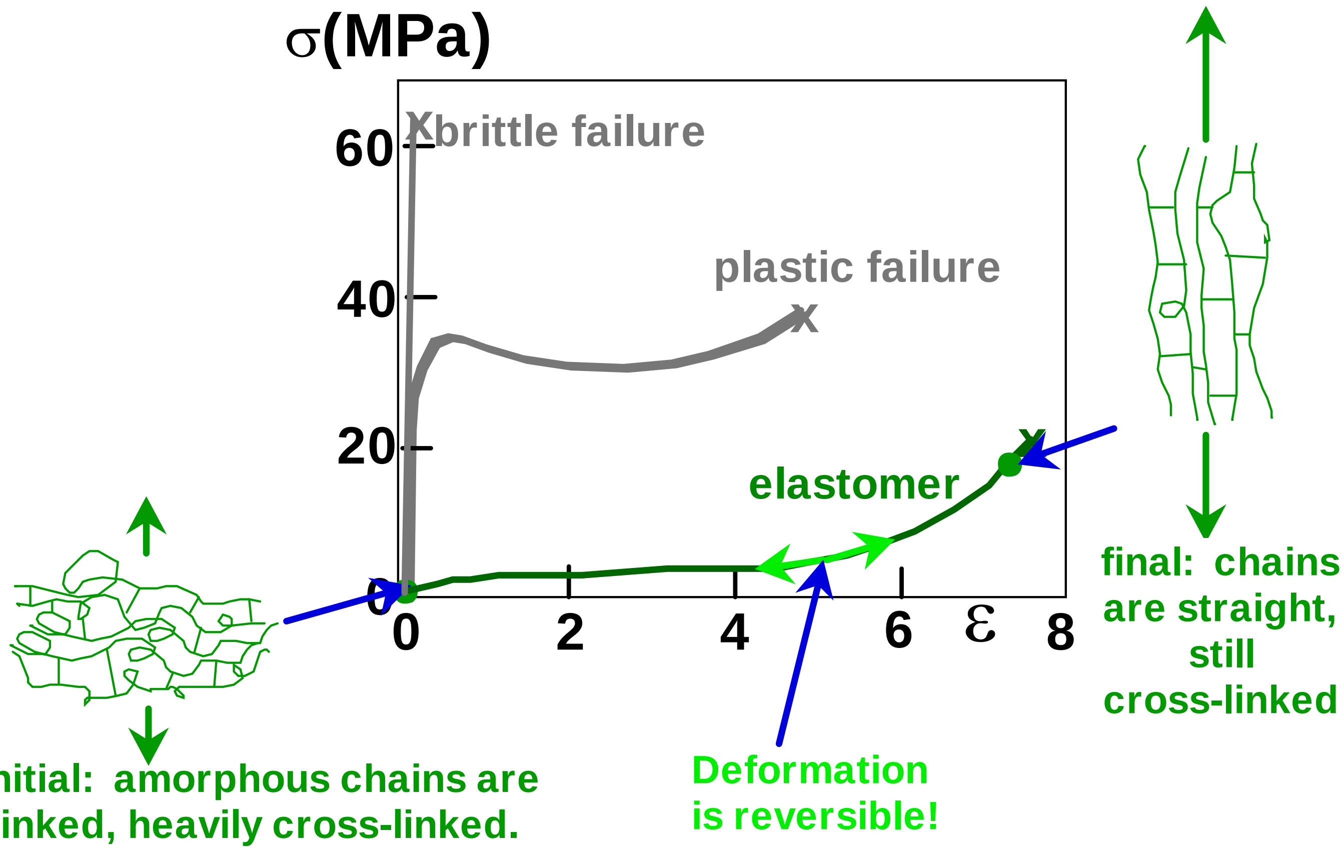
PREDEFORMATION BY DRAWING

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



Adapted from Fig. 15.12, *Callister 6e*. (Fig. 15.12 is from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)

TENSILE RESPONSE: ELASTOMER CASE

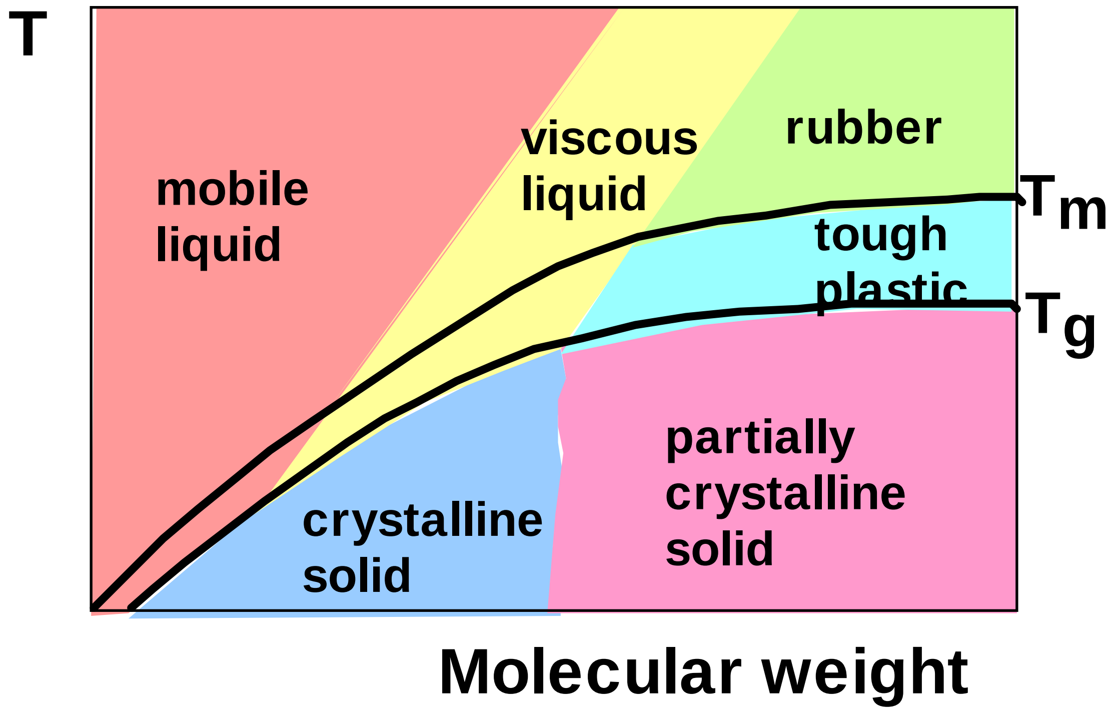


Stress-strain curves adapted from Fig. 15.1, *Callister 6e.* Inset figures along elastomer curve (green) adapted from Fig. 15.14, *Callister 6e*. (Fig. 15.14 is from Z.D. Jastrzebski, *The Nature and Properties of Engineering Materials*, 3rd ed., John Wiley and Sons, 1987.)

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

THERMOPLASTICS VS THERMOSETS

- **Thermoplastics**:
  --little cross linking
  --ductile
  --soften w/heating
  --polyethylene (#2)
  polypropylene (#5)
  polycarbonate
  polystyrene (#6)



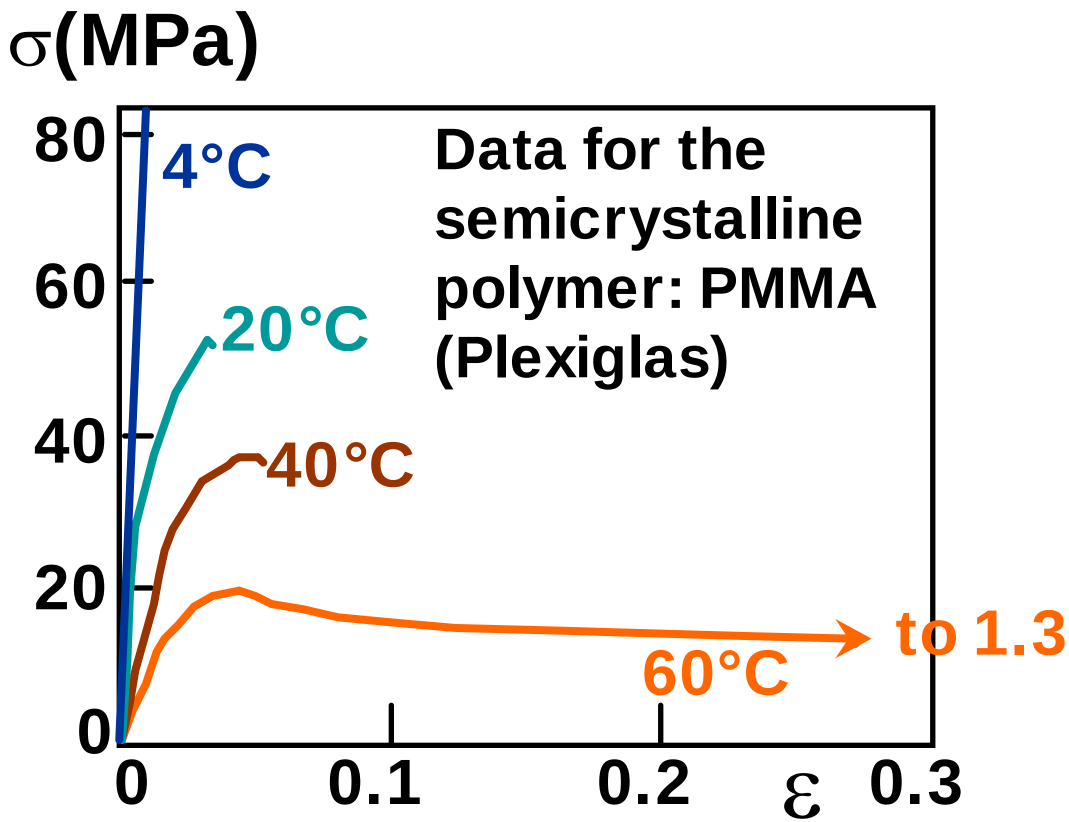
Adapted from Fig. 15.18, *Callister 6e*. (Fig. 15.18 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley and Sons, Inc., 1984.)

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

T AND STRAIN RATE: THERMOPLASTICS

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

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



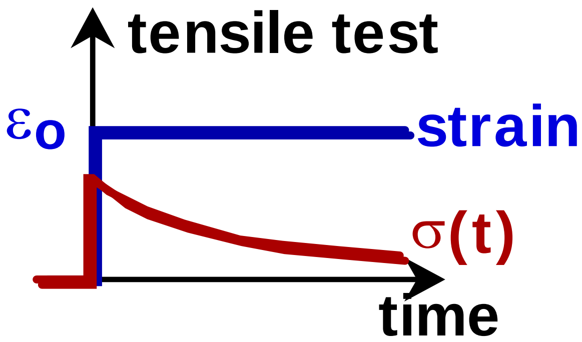
Adapted from Fig. 15.3, *Callister 6e*. (Fig. 15.3 is from T.S. Carswell and J.K. Nason, 'Effect of Environmental Conditions on the Mechanical Properties of Organic Plastics", *Symposium on Plastics*, American Society for Testing and Materials, Philadelphia, PA, 1944.)

TIME DEPENDENT DEFORMATION

- **Stress relaxation test:**

  --strain to ε_o and hold.

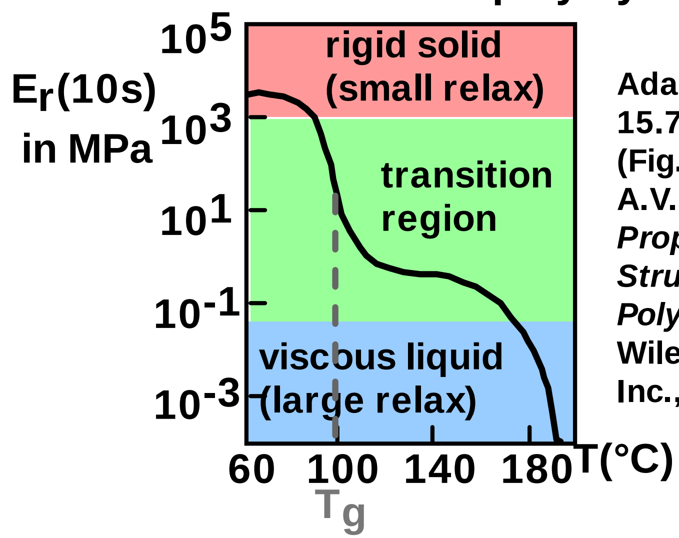
  --observe decrease in stress with time.



- **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 6e*. (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 M_w)	-110
PE (high M_w)	- 90
PVC	+ 87
PS	+100
PC	+150

Selected values from Table 15.2, *Callister 6e*.

SUMMARY

- General drawbacks to polymers:
  - -- E, σ_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, σ_y, $T_{application}$
  - -- Larger K_c
  - -- Easier to form and recycle
- Elastomers (rubber):
  - -- Large reversible strains!
- Thermosets (epoxies, polyesters):
  - -- Larger E, σ_y, $T_{application}$
  - -- Smaller K_c

Table 15.3 *Callister 6e*:

Good overview of applications and trade names of polymers.

ANNOUNCEMENTS

Reading:

Core Problems:

Self-help Problems: