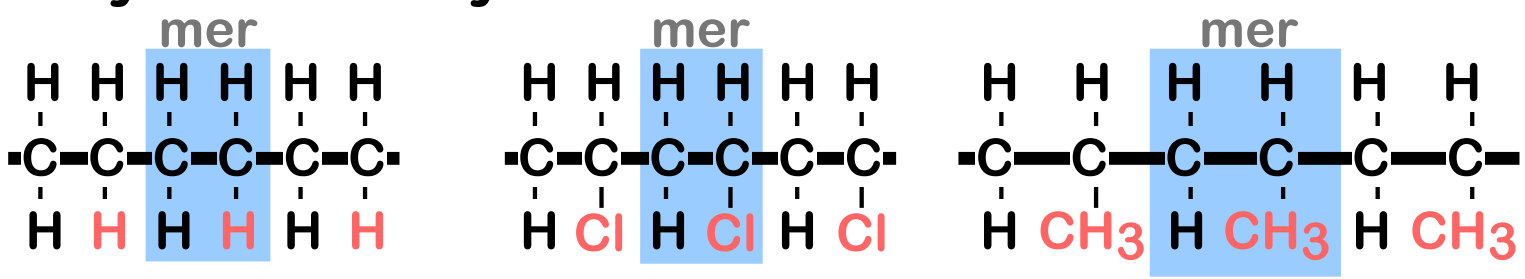
CHAPTERS 14/15: POLYMER STRUCTURES, APPLICATIONS, & PROCESSING

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

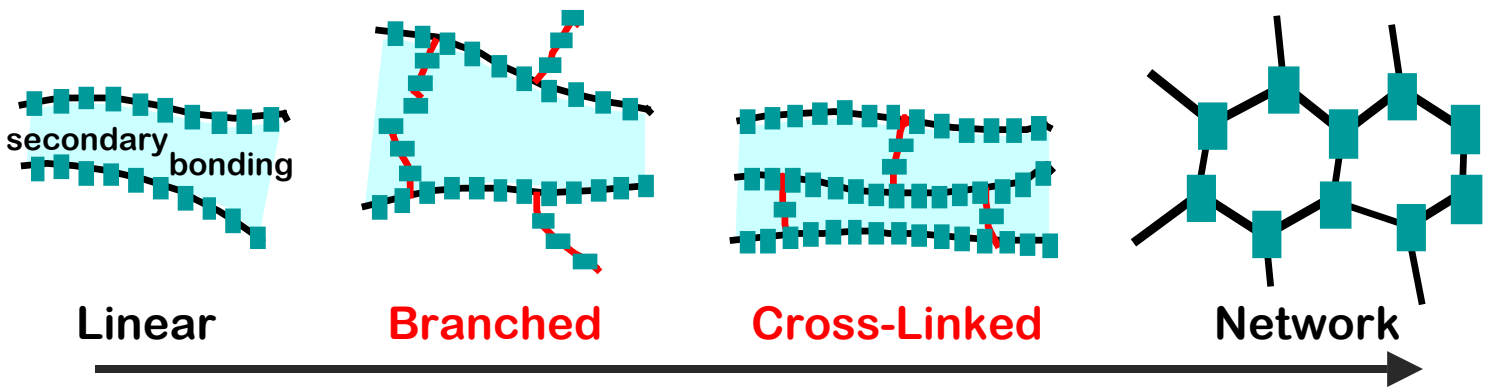
- Polymer = many mers



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

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

- Covalent chain configurations and strength:



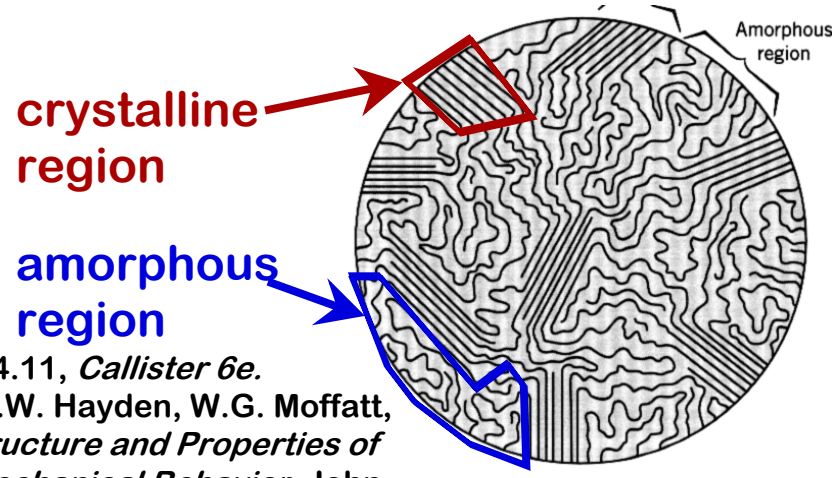
Adapted from Fig. 14.7, *Callister 6e.*

MOLECULAR WEIGHT & CRYSTALLINITY

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

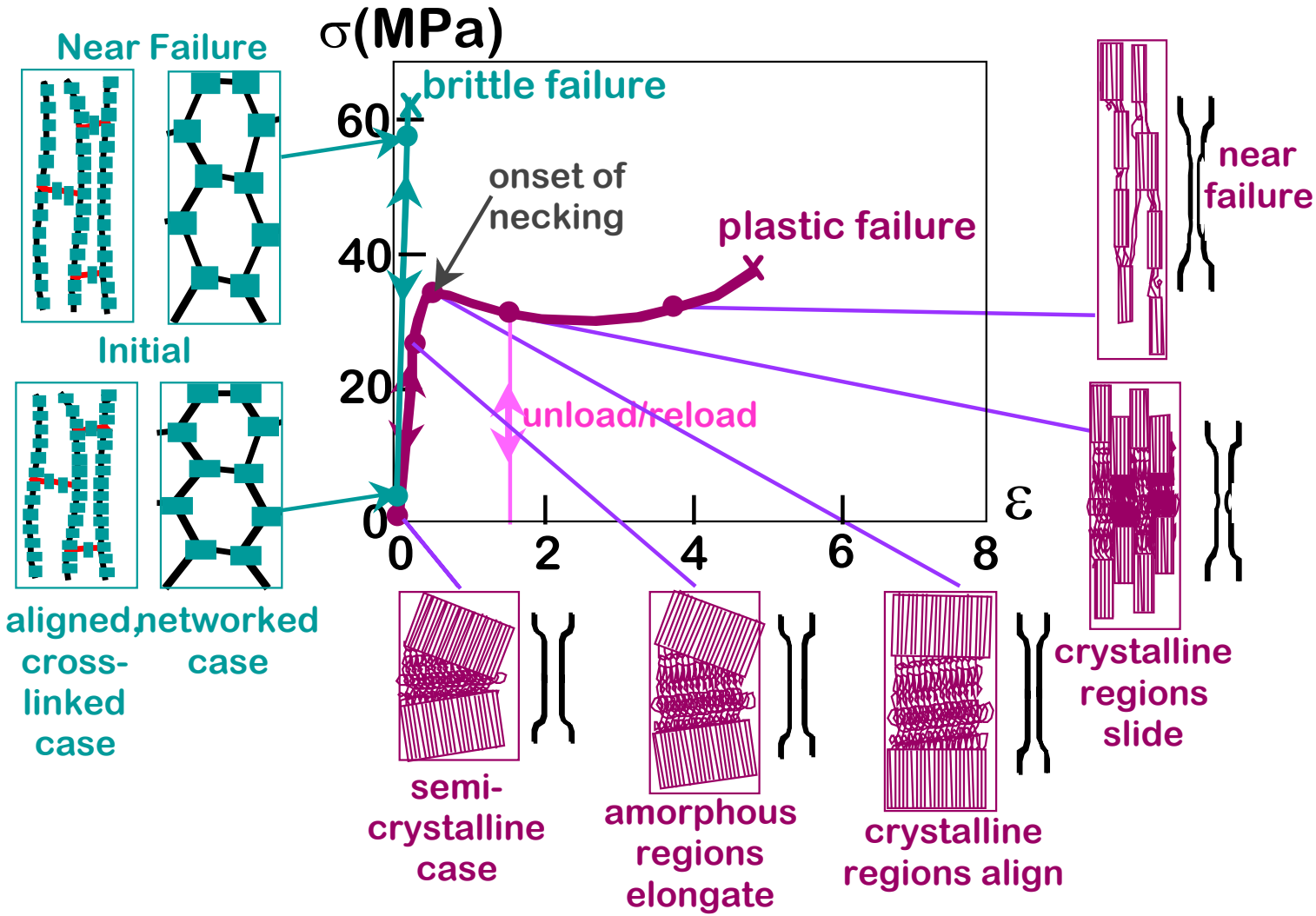
smaller M_W larger M_W

- 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.



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.)

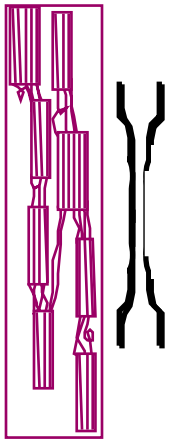
TENSILE RESPONSE: BRITTLE & PLASTIC



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.)

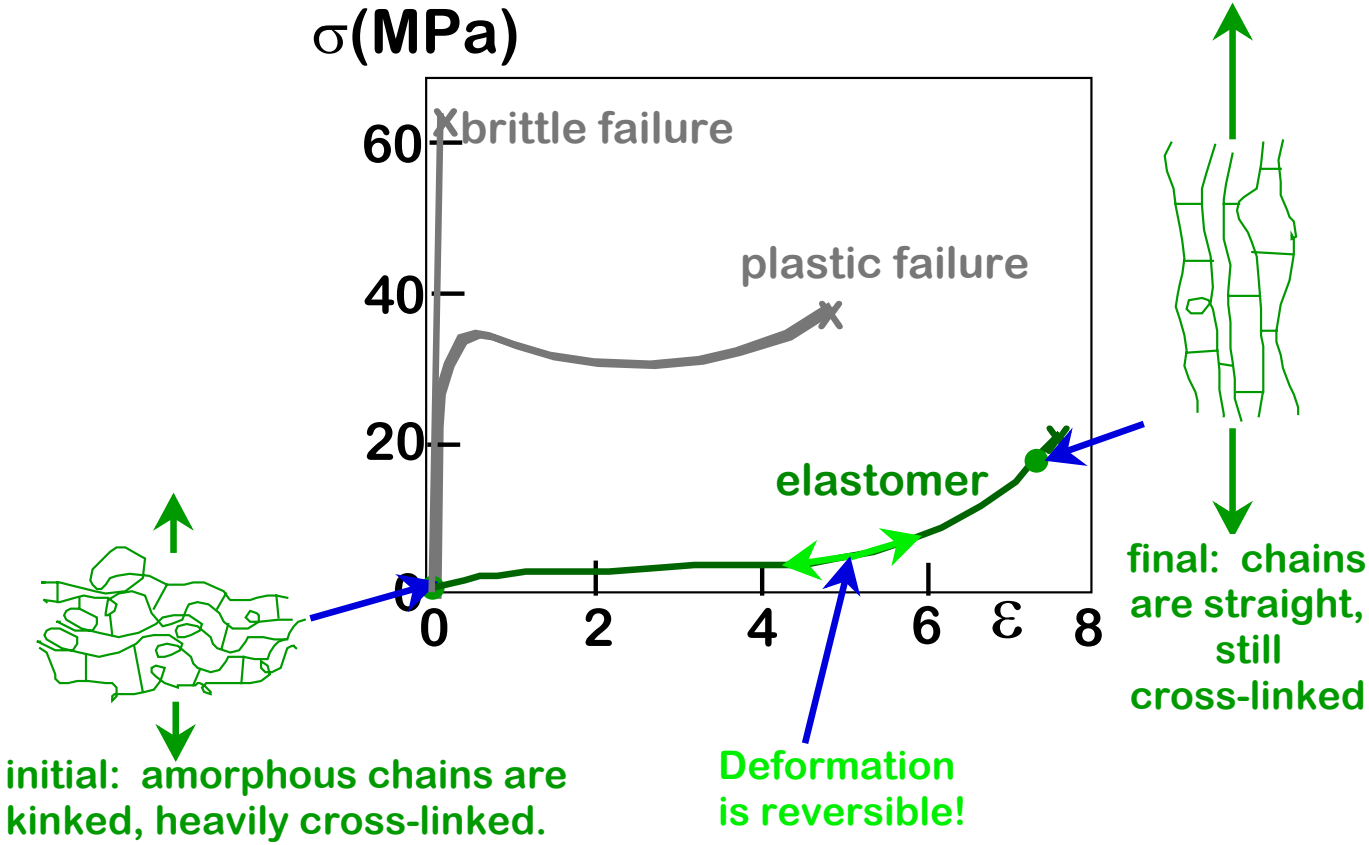
PREDEFORMATION BY DRAWING

- 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

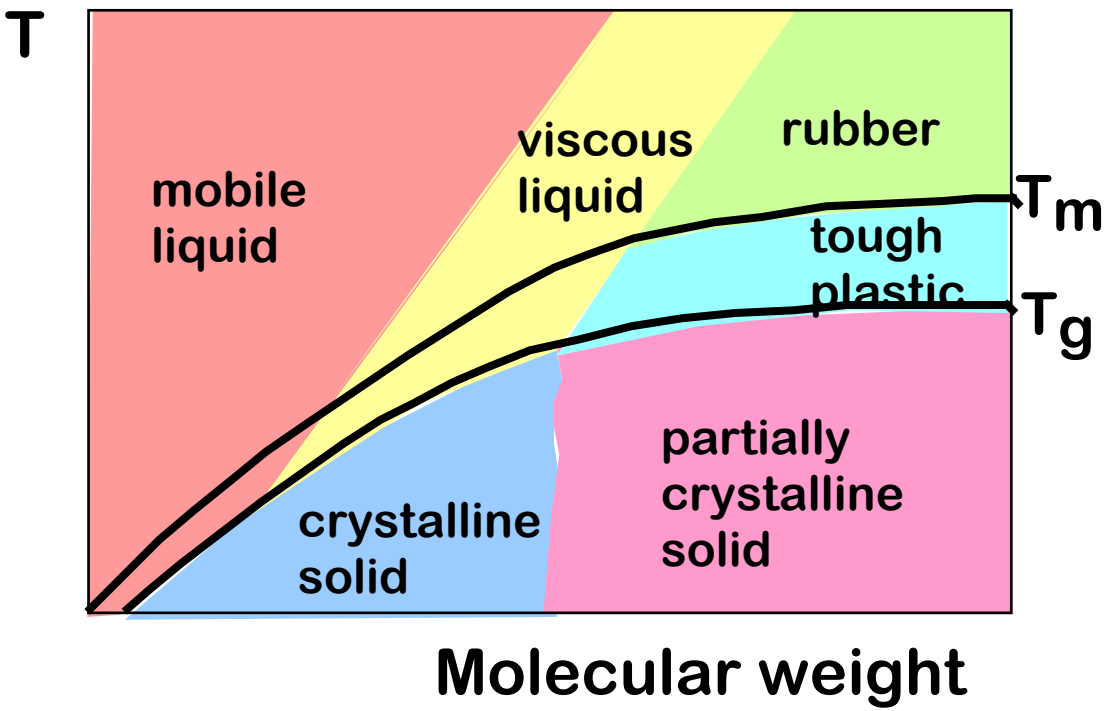


Stress-strain curves adapted from Fig. 15.1, *Callister 6e.* Inset figures along elastomer curve (green) adapted from Fig. 15.14, *Callister 6e*. (Fig. 15.14 is from Z.D. Jastrzebski, *The Nature and Properties of Engineering Materials*, 3rd ed., John Wiley and Sons, 1987.)

- **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)



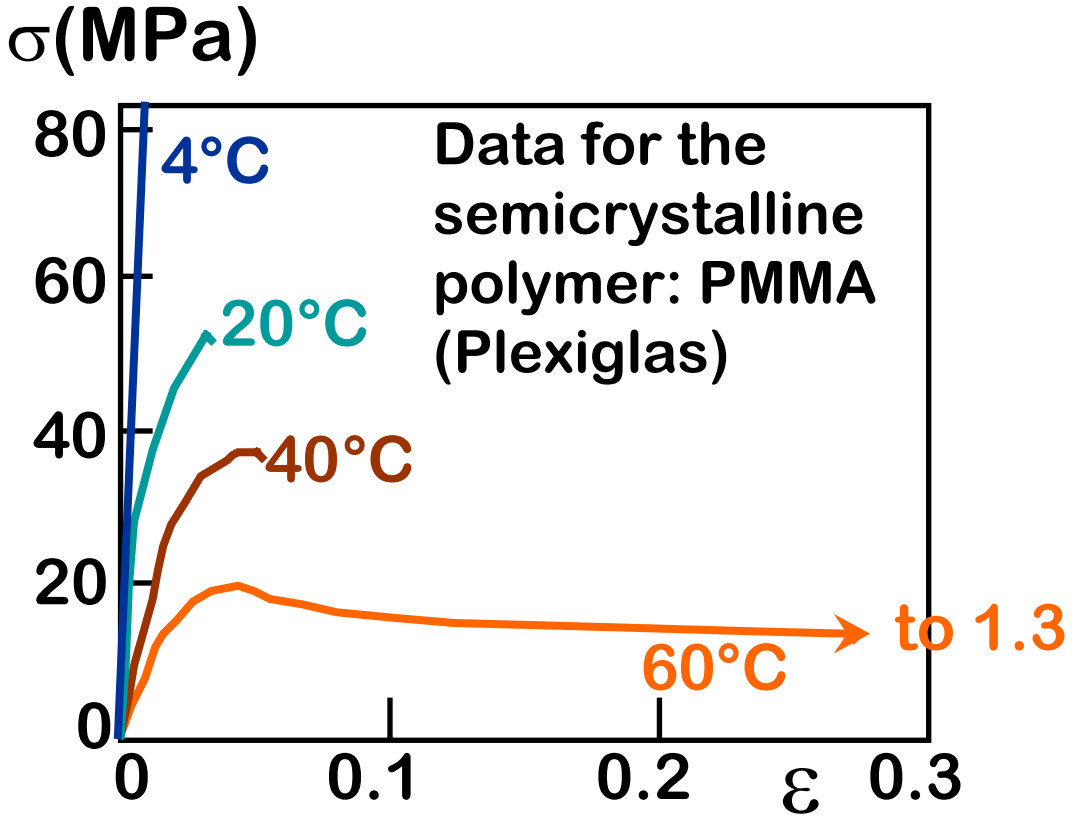
Adapted from Fig. 15.18, *Callister 6e*. (Fig. 15.18 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley and Sons, Inc., 1984.)

- **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.



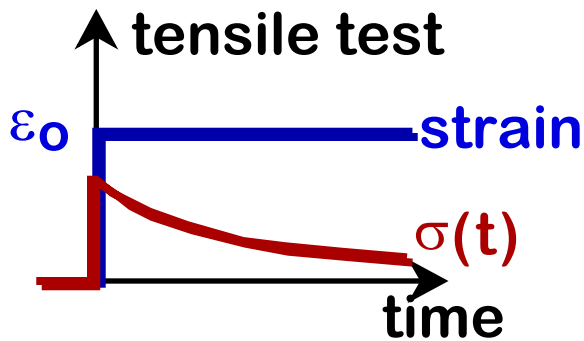
Adapted from Fig. 15.3, *Callister 6e*. (Fig. 15.3 is from T.S. Carswell and J.K. Nason, 'Effect of Environmental Conditions on the Mechanical Properties of Organic Plastics", *Symposium on Plastics*, American Society for Testing and Materials, Philadelphia, PA, 1944.)

TIME DEPENDENT DEFORMATION

- **Stress relaxation test:**

  --strain to ε_o and hold.

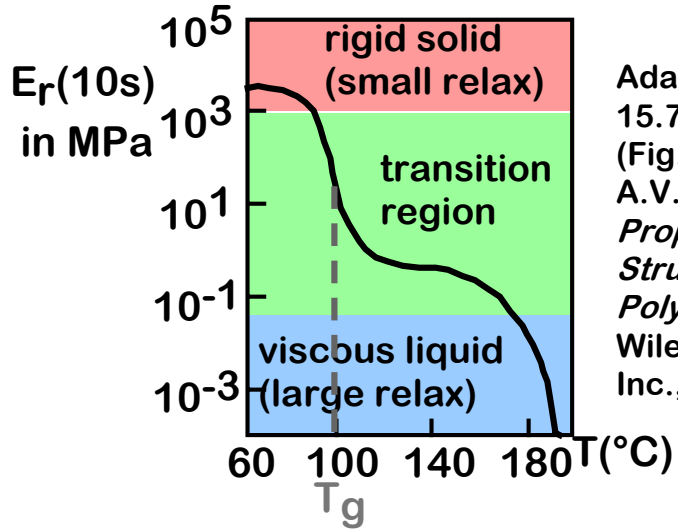
  --observe decrease in stress with time.



- **Relaxation modulus:**

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

- **Data: Large drop in E_r for T > Tg.** (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 Tg(C) values:**

PE (low Mw)	-110
PE (high Mw)	- 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.