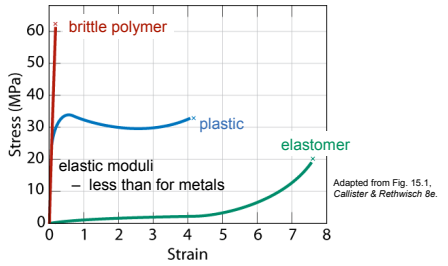
# Chapter 15: Characteristics, Applications & Processing of Polymers

**ISSUES TO ADDRESS...**

- What are the _____ of polymers and how are they affected by _____?
- Hardening, _____, and annealing in polymers.
- How does the _____ response of polymers compare to ceramics and metals?
- What are the _____ methods?



## Mechanical Properties of Polymers – Stress-Strain Behavior

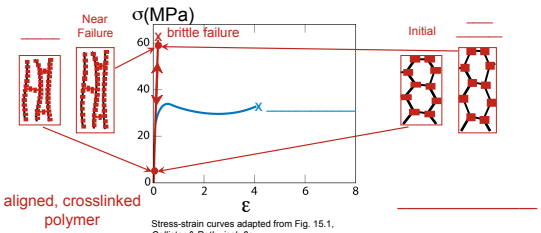



Adapted from Fig. 15.1, *Callister & Rethwisch 8e.*

- _____ of polymers ~ 10% of those for metals
- _____ strains for polymers > 1000%
  - for most metals, deformation strains < 10%

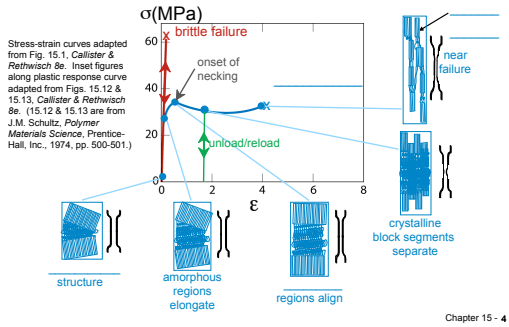


## Mechanisms of Deformation—Brittle Crosslinked and Network Polymers




Stress-strain curves adapted from Fig. 15.1, *Callister & Rethwisch 8e.*

## Mechanisms of Deformation — Semicrystalline (Plastic) Polymers




Stress-strain curves adapted from Fig. 15.1, *Callister & Rethwisch 8e.* Inset figures along plastic response curve adapted from Figs. 15.12 & 15.13, *Callister & Rethwisch 8e.* (15.12 & 15.13 are from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)



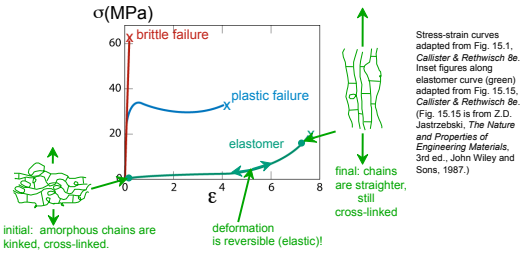
## Predeformation by Drawing

- _____…(ex: monofilament fishline)
  - -- stretches the polymer prior to use
  - -- aligns chains in the _____
- Results of drawing:
  - -- increases the elastic modulus (*E*) in the _____
  - -- increases the _____ (*TS*) in the stretching direction
  - -- decreases ductility (%*EL*)
- _____ after drawing...
  - -- _____ chain alignment
  - -- reverses effects of drawing (reduces *E* and *TS*, enhances %EL)
- Contrast to effects of cold working in metals!

Adapted from Fig. 15.13, *Callister & Rethwisch 8e.* (Fig. 15.13 is from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)



## Mechanisms of Deformation— Elastomers



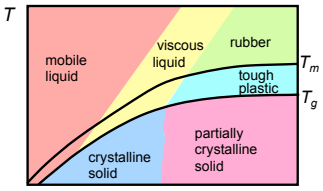

Stress-strain curves adapted from Fig. 15.1, *Callister & Rethwisch 8e.* Inset figures along elastomer curve (green) adapted from Fig. 15.15, *Callister & Rethwisch 8e.* (Fig. 15.15 is from Z.D. Jastrzebski, *The Nature and Properties of Engineering Materials*, 3rd ed., John Wiley and Sons, 1987.)

- Compare _____ of elastomers with the:
  - -- ____ behavior (of aligned, crosslinked & network polymers), and
  - -- plastic behavior (of _____ polymers)

  (as shown on previous slides)

## Thermoplastics vs. Thermosets

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



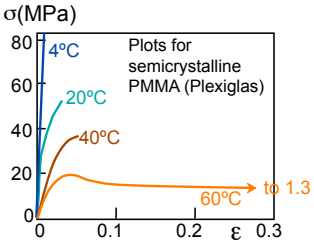

Adapted from Fig. 15.19, *Callister & Rethwisch 8e.* (Fig. 15.19 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley and Sons, Inc., 1984.)

- _____:
  - -- significant _____
    (10 to 50% of repeat units)
  - -- hard and brittle
  - -- do NOT soften w/heating
  - -- _____ rubber, epoxies,
    polyester resin, phenolic resin



## Influence of *T* and Strain Rate on Thermoplastics

- _____ *T*...
  - -- increases *E*
  - -- _____ *TS*
  - -- decreases %*EL*
- _____
  strain rate...
  - -- same effects
    as decreasing *T*.



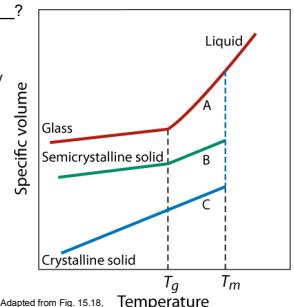

Adapted from Fig. 15.3, *Callister & Rethwisch 8e.* (Fig. 15.3 is from T.S. Carswell and J.K. Nason, "Effect of Environmental Conditions on the Mechanical Properties of Organic Plastics", *Symposium on Plastics*, American Society for Testing and Materials, Philadelphia, PA, 1944.)



## Melting & Glass Transition Temps.

What _____?

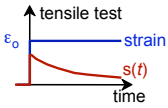
- Both $T_m$ *and* $T_g$ _____ with increasing chain stiffness
- Chain stiffness _____ by presence of
  1. Bulky sidegroups
  2. Polar groups or sidegroups
  3. Chain double bonds and aromatic chain groups
- _____ of repeat unit arrangements – affects $T_m$ only




Adapted from Fig. 15.18, *Callister & Rethwisch 8e.*

## Time-Dependent Deformation

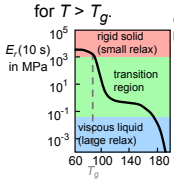
- Stress _____ test:
  - -- strain in tension to $\varepsilon_o$ and hold.
  - -- observe _____ in stress with time.




- _____ modulus:

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

- There is a large _____ in $E_r$ for $T > T_g$.




(amorphous polystyrene)

Adapted from Fig. 15.7, *Callister & Rethwisch 8e.* (Fig. 15.7 is from A.V. Tobolsky, *Properties and Structures of Polymers*, John Wiley and Sons, Inc., 1960.)

- Representative $T_g$ values (°C):

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

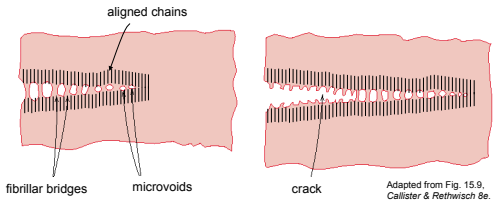
Selected values from Table 15.2, *Callister & Rethwisch 8e.*



## Crazing During Fracture of Thermoplastic Polymers

_____ formation prior to cracking

- during crazing, _____ of spherulites
- and formation of _____




Adapted from Fig. 15.9, *Callister & Rethwisch 8e.*

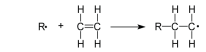


## Polymer Formation

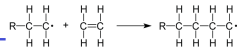
- There are two types of _____
  - – _____ polymerization
  - – _____ polymerization

## Addition (Chain) Polymerization

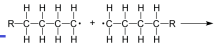
– Initiation

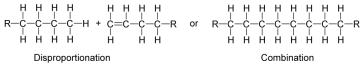


– _____



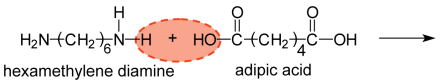
– _____

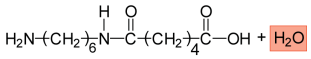







## Condensation (Step) Polymerization






## Polymer Additives

Improve mechanical properties, processability, durability, etc.

- Fillers
  - Added to improve _____ resistance, toughness & decrease cost
  - ex: carbon black, silica gel, wood flour, glass, limestone, talc, etc.
- _____
  - Added to _____ the glass transition temperature $T_g$ below room temperature
  - Presence of _____ transforms brittle polymer to a _____ one
  - Commonly added to PVC - otherwise it is brittle

## Polymer Additives (cont.)

- Stabilizers
  - _____
  - UV protectants
- _____
  - Added to allow _____
  - polymer "slides" through _____ easier
  - ex: sodium stearate
- Colorants
  - _____
- _____
  - Substances containing chlorine, fluorine, and boron



## Processing of Plastics

- _____ –
  - can be reversibly _____, i.e. recycled
  - heat until soft, _____, then cool
  - ex: polyethylene, polypropylene, polystyrene.
- Thermoset
  - when heated _____ (chemical reaction)
  - _____ (doesn't melt) when heated
  - a prepolymer molded into desired shape, then chemical reaction occurs
  - ex: urethane, epoxy



## Processing Plastics – Compression Molding

thermoplastics and thermosets

- _____ placed in mold cavity
- mold _____
- _____ assumes shape of mold

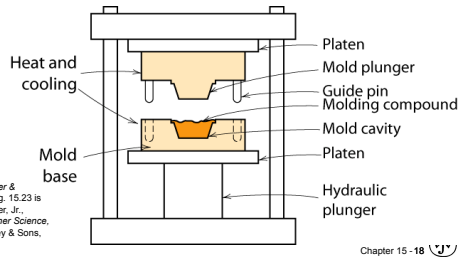



Fig. 15.23, *Callister & Rethwisch 8e.* (Fig. 15.23 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd ed., John Wiley & Sons, 1984.)

## Processing Plastics – Injection Molding

_____ and some thermosets

- when ram retracts, plastic pellets drop from _____ into barrel
- ram forces plastic into the heating chamber (around the spreader) where the _____
- molten plastic is forced under pressure (_____) into the mold _____ where it assumes the shape of the mold

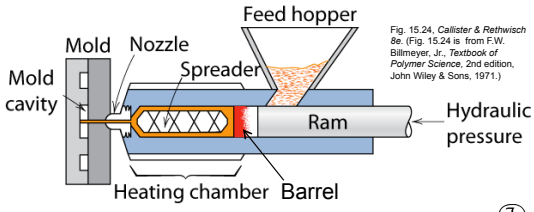



Fig. 15.24, *Callister & Rethwisch 8e.* (Fig. 15.24 is from F.W. Billmeyer, Jr., *Textbook of Polymer Science*, 2nd edition, John Wiley & Sons, 1971.)



## Processing Plastics – Extrusion

_____

- plastic pellets drop from hopper onto the _____
- plastic melts _____ passed the heaters
- molten polymer is forced under pressure through the shaping die to form the shaped product (_____)

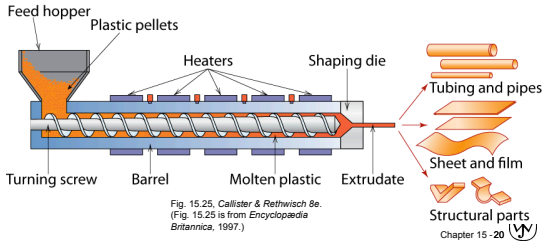



Fig. 15.25, *Callister & Rethwisch 8e.* (Fig. 15.25 is from *Encyclopædia Britannica*, 1997.)



## Processing Plastics – Blown-Film Extrusion

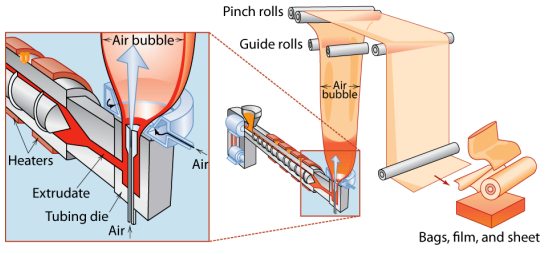



Fig. 15.26, *Callister & Rethwisch 8e.* (Fig. 15.26 is from *Encyclopædia Britannica*, 1997.)

## Polymer Types – Fibers

Fibers - length/diameter >100

- Primary use is _____.
- Fiber characteristics:
  - _____
  - high degrees of crystallinity
  - structures containing _____ groups
- Formed by spinning
  - extrude polymer through a _____ (a die containing many small orifices)
  - the spun fibers are drawn under tension
  - leads to highly aligned chains - _____



## Polymer Types – Miscellaneous

- _____ – thin polymer films applied to surfaces – i.e., paints, varnishes
  - _____
  - decorative – improves appearance
  - _____
- Adhesives – bonds two solid materials (_____)
  - bonding types:
    1. Secondary – van der Waals forces
    2. _____
- _____ – produced by blown film extrusion
- _____ – gas bubbles incorporated into plastic



## Advanced Polymers

Ultrahigh Molecular Weight Polyethylene (UHMWPE)

- Molecular weight ca. _____
- Outstanding properties
  - _____
  - resistance to wear/abrasion
  - _____
  - self-lubricating surface
- Important applications
  - _____
  - golf ball covers
  - hip implants (acetabular cup)


Adapted from chapter-opening photograph, Chapter 22, *Callister 7e.*

## Advanced Polymers

Thermoplastic Elastomers

Styrene-butadiene _____

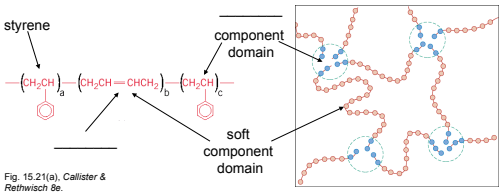



Fig. 15.21(a), *Callister & Rethwisch 8e.*



Fig. 15.22, *Callister & Rethwisch 8e.* (Fig. 15.22 adapted from *the Science and Engineering of Materials*, 5th Ed., D.R. Askeland and P.P. Phule, Thomson Learning, 2006.)



## Summary

- Limitations of polymers:
  -- $E$, $\sigma_y$, $K_c$, $T_{application}$ are generally small.
  -- Deformation is often time and temperature dependent.
- 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 & Rethwisch 8e:*

Good overview of applications and trade names of polymers.



## Summary

- Polymer Processing
  -- compression and injection molding, extrusion, blown film extrusion
- Polymer melting and glass transition temperatures
- Polymer applications
  -- elastomers
  -- fibers
  -- coatings
  -- adhesives
  -- films
  -- foams
  -- advanced polymeric materials