Chapter 15-2: Processing of Polymers

ISSUES TO ADDRESS...

- Other issues in polymers
- What are the primary polymer processing methods?
Polymer Synthesis Reactions

• There are two types of polymerization reactions
  – Addition (or chain) polymerization
  – Condensation (step) polymerization
Addition (Chain) Polymerization

- **Initiation**

\[ R^- + \text{C} = \text{C} \xrightarrow{\cdot} R^-\text{C} = \cdot \]

- **Propagation**

\[ R^-\text{C} = \cdot + \text{C} = \text{C} \xrightarrow{\cdot} R^-\text{C} = \cdot \text{C} = \cdot \]

- **Termination**

\[ R^-\text{C} = \cdot \text{C} = \cdot + \cdot\text{C} = \cdot \text{C} = \cdot \xrightarrow{\cdot} \]

- **Disproportionation**

\[ R^-\text{C} = \cdot \text{C} = \cdot + \text{C} = \cdot \text{C} = \cdot \text{C} = \cdot \]

**Combination**

\[ R^-\text{C} = \cdot \text{C} = \cdot + \text{C} = \cdot \text{C} = \cdot \text{C} = \cdot \text{C} = \cdot \text{C} = \cdot \]
Condensation (Step) Polymerization

\[
\text{H}_2\text{N}-(\text{CH}_2)_6\text{N}-\text{H} + \text{HO-}\text{C-(CH}_2)_4\text{C-OH} \rightarrow \text{H}_2\text{N}-(\text{CH}_2)_6\text{N-C-(CH}_2)_4\text{C-OH} + \text{H}_2\text{O}
\]

hexamethylene diamine + adipic acid

nylon-6,6
Polymer Additives

Improve mechanical properties, processability, durability, etc.

• **Fillers**
  – Added to improve tensile strength & abrasion resistance, toughness & decrease cost
  – ex: carbon black, silica gel, glass, limestone, talc, etc.

• **Plasticizers**
  – Added to reduce the glass transition temperature $T_g$
  – Presence of plasticizer transforms brittle polymer to a plastic (ductile) one
  – Example: add plasticizer to PVC ($T_g=87 \, ^\circ C$) to make flexible tubings
Polymer Additives (cont.)

- **Stabilizers**
  
  Examples: Antioxidants or UV protectants

- **Colorants**
  
  - Dyes (small molecule that dissolves) and pigments (solid inorganic particles with colors)

- **Flame Retardants**
  
  - Substances containing chlorine, fluorine, and boron
Processing of Plastics

- **Thermoplastic**
  - can be reversibly cooled & reheated, i.e. recycled
  - heat until soft, shape as desired, then cool
  - ex: polyethylene, polypropylene, polystyrene.

- **Thermoset**
  - when heated they would form 3D molecular networks (chemical reaction)
  - degrades (doesn’t melt) when heated to high temp
  - a prepolymer molded into desired shape, then the chemical reaction occurs (up heating or addition of cross-linking agents) to form network
  - ex: epoxy, phenolic resin
Processing Plastics – Compression Molding

Thermoplastics and thermosets
• polymer and additives placed in mold cavity
• mold heated and pressure applied
• fluid polymer 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

Thermoplastics and some thermosets

- when ram retracts, plastic pellets drop from hopper into barrel
- ram forces plastic into the heating chamber (around the spreader) where the plastic melts as it moves forward
- molten plastic is forced under pressure (injected) into the mold cavity 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

thermoplastics
• plastic pellets drop from hopper onto the turning screw
• plastic pellets melt as the turning screw pushes them forward by the heaters
• molten polymer is forced under pressure through the shaping die to form the final product (extrudate)

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 by Physical Forms (1)

Bulk

Fibers - length/diameter > 100

• Primary use is in textiles.
• Fiber characteristics:
  – high tensile strengths
  – high degrees of crystallinity
  – structures containing polar groups
• Formed by spinning
  – extrude polymer through a spinneret (a die containing many small orifices)
  – the spun fibers are drawn under tension
  – leads to highly aligned chains - fibrillar structure
Polymer by Physical Forms (2)

- **Films** – produced by blown film extrusion
- **Coatings** – thin polymer films applied to surfaces – i.e., paints, varnishes
  - protects from corrosion/degradation
  - decorative – improves appearance
  - can provide electrical insulation
- **Foams** – gas bubbles incorporated into plastic
- **Adhesives** – bonds two solid materials (**adherands**)  
  - bonding types:
    1. Secondary – van der Waals forces  
    2. Mechanical – penetration into pores/crevices
Other Advanced Polymers

Ultrahigh Molecular Weight Polyethylene (UHMWPE)

- Molecular weight ca. $4 \times 10^6$ g/mol
- Outstanding properties
  - high impact strength
  - resistance to wear/abrasion
  - low coefficient of friction
  - self-lubricating surface
- Important applications
  - bullet-proof vests
  - golf ball covers
  - hip implants (acetabular cup)

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

• Polymer Processing
  -- compression and injection molding, extrusion, blown film extrusion

• Polymer melting and glass transition temperatures

• Polymer applications
  -- elastomers
  -- coatings
  -- films
  -- advanced polymeric materials
  -- fibers
  -- adhesives
  -- foams