Lec-8 Polymers

Overview

- What is a polymer?
- Why are polymers good?
- Types / examples
- Crystallinity
- Melting properties
- Heat transfer
- Fluids
- Behavior during processing

Polymer production

- 107 billion pounds produced in US and Canada in 2003
  - volume = 44 million m3
- 217 billion pounds of steel produced in US in 2001
  - volume = 12.5 million m3

Polymers

- poly = many
- meros = units
- long-chain hydrocarbons
  - 1,000 - 10,000 units long
  - 104 - 106 gm/gm-mole

Polymers Stuctures

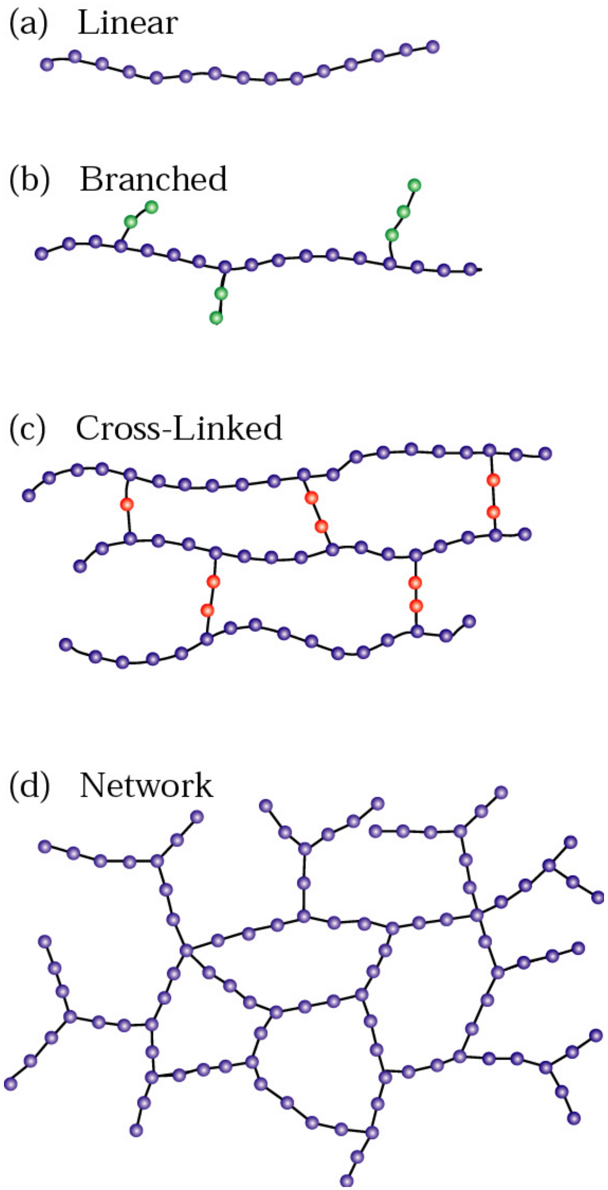


Figure 7.4 Schematic illustration of polymer chains. (a) Linear structure--thermoplastics such as acrylics, nylons, polyethylene, and polyvinyl chloride have linear structures. (b) Branched structure, such as in polyethylene. (c) Cross-linked structure--many rubbers or elastomers have this structure, and the vulcanization of rubber produces this structure. (d) Network structure, which is basically highly cross-linked--examples are thermosetting plastics, such as epoxies and phenolics.

Why are polymers good?

- Light
- Corrosion resistant
- Strong
- Easily formed into complex, 3D shapes
  - no further machining necessary
- Good filters
  - water / gas - permeable / impermeable
    - reverse osmosis
    - oxygenators

Polymers

- Thermoplastics - reversible in phase by heating and cooling. Solid phase at room temperature and liquid phase at elevated temperature.
- Thermosets - irreversible in phase by heating and cooling. Change to liquid phase when heated, then follow with an irreversible exothermic chemical reaction. Remain in solid phase subsequently.
- Elastomers - Rubbers

Types of polymers

- **Thermoplastics**
  - can be melted and solidified repeatedly
- **Thermosets**
  - react to polymerize during forming
  - cross-linked networks
  - can’t be remelted
  - decompose with too much heat
- **Elastomers**
  - large, recoverable, elastic deformations
  - soft
  - low glass transition temperatures
  - partially cross-linked networks
  - can be thermoset or thermoplastic

Thermoplastics

- Acetals
- Acrylics - PMMA
- Acrylonitrile-Butadiene-Styrene - ABS
- Cellulosics
- Fluoropolymers - PTFE , Teflon
- Polyamides (PA) - Nylons, Kevlar
- Polysters - PET
- Polyethylene (PE) - HDPE, LDPE
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl chloride (PVC)

Thermosets

- Amino resins
- Epoxies
- Phenolics
- Polyesters
- Polyurethanes
- Silicones

Elastomers

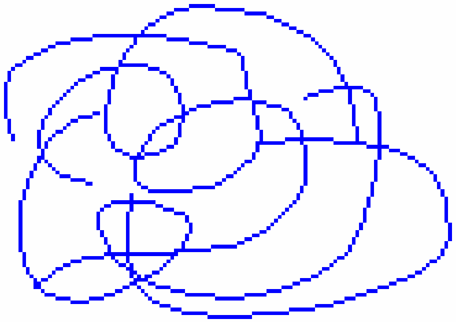
- Natural rubber
- Synthetic rubbers
  - butadiene rubber
  - butyl rubber
  - chloroprene rubber
  - ethylene-propylene rubber
  - isoprene rubber
  - nitrile rubber
  - polyurethanes
  - silicones
  - styrene-butadiene rubber
  - thermoplastic elastomers

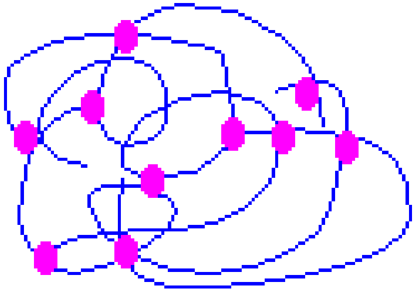
Polyethylene (PE)	**• trash bags, electrical insulation • thermoplastic**	**Polycarbonate (PC)**	**• Lexan • thermoplastic**
Polypropylene (PP)	• margarine tubs, food containers • thermoplastic	Polymethylmethacrylate (PMMA)	• Lucite, plexiglas • thermoplastic
Polystyrene (PS)	• coffee cups (styrofoam) • clear plastic boxes • thermoplastic	Polytetrafluroethylene (PTFE)	• Teflon • bearings • coatings • thermoplastic
Polyvinylchloride (PVC)	• credit cards • pipes • thermoplastic	Polyester (PET)	• bottles • carpets • thermoplastic
Epoxy	• adhesive • composite matrix • thermoset	Rubber – vulcanization (1844)	• elastomer • thermoset

Bonding

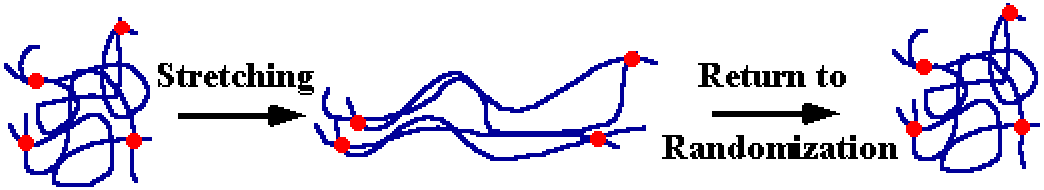
- Leads to all mechanical properties
- Primary
  - covalent (C-C, C-O, C-H, C-N)
  - along chain, interchain
- Secondary
  - van der Waals
  - hydrogen
  - ionic
  - interchain

Bonding





- Thermoplastics
  - – covalent along chain
  - – secondary between chains
  - – 2D structure
- Thermosets
  - – covalent along and between (cross link) chains
- – 3D network
- Elastomers
  - – partially cross-linked
  - – 2.5 D network



Crystallinity

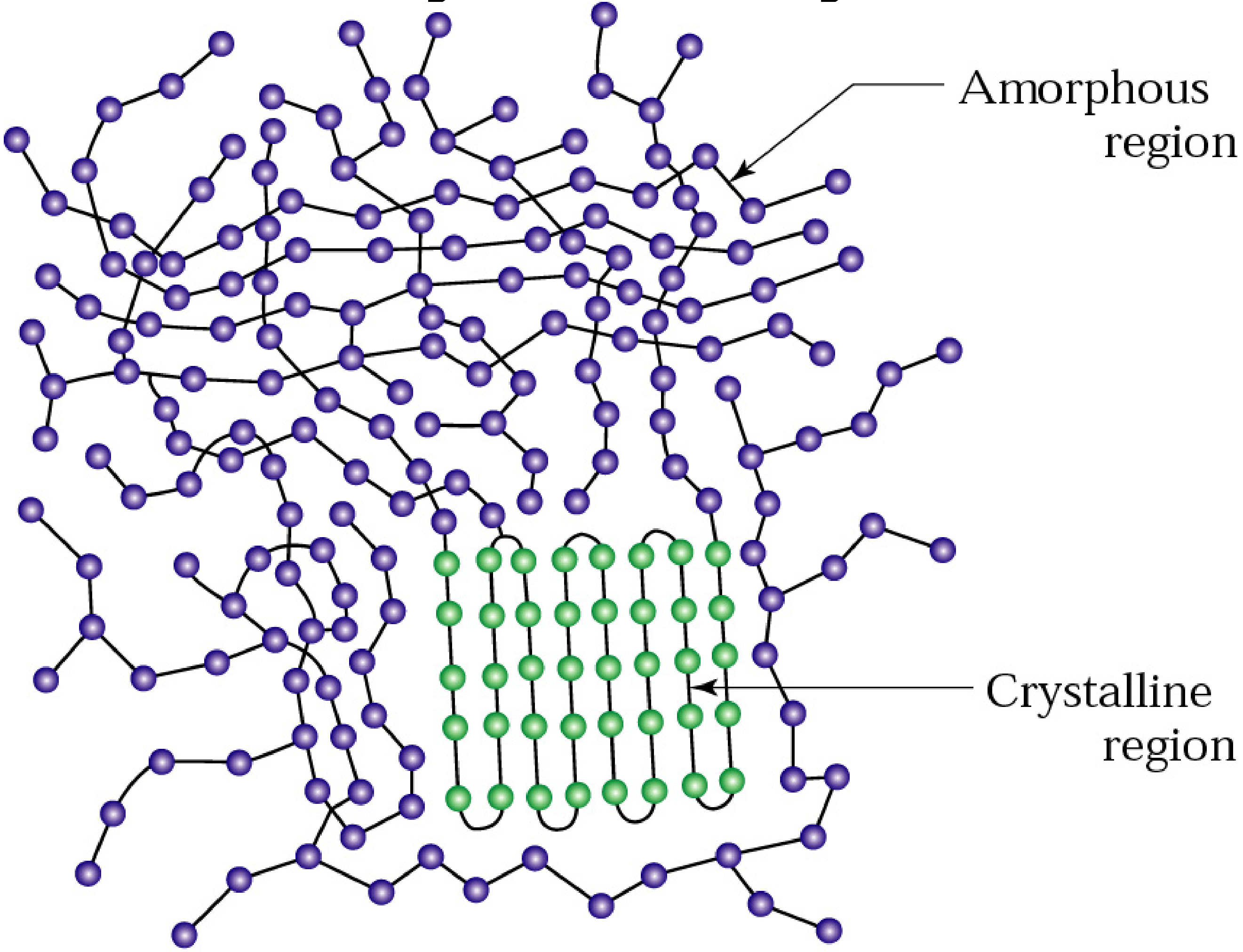
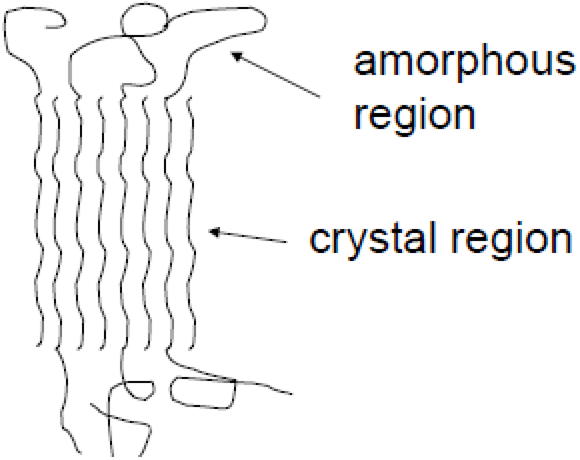
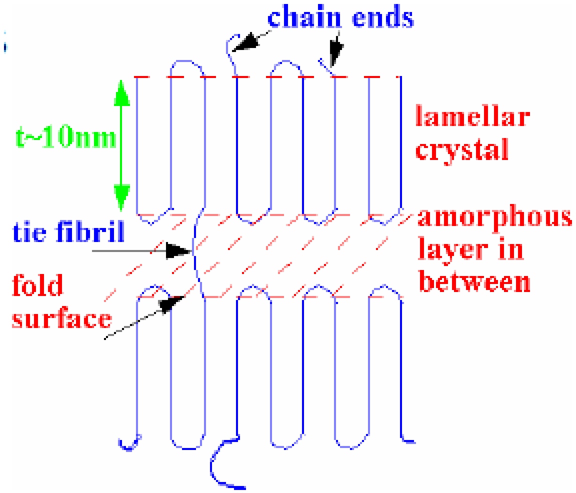


Figure 7.6 Amorphous and crystalline regions in a polymer. The crystalline region (crystallite) has an orderly arrangement of molecules. The higher the crystallinity, the harder, stiffer, and less ductile the polymer.

Crystallinity

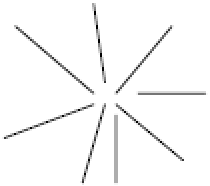
- Short range order (1,000s of Å)
- Amorphous
  - PS, PC
    - bulky side groups prevent packing
- Semi-crystalline
  - PE, PP
    - small or no side groups allow packing
- Tightly packed
- Rigid
- Large secondary bonds

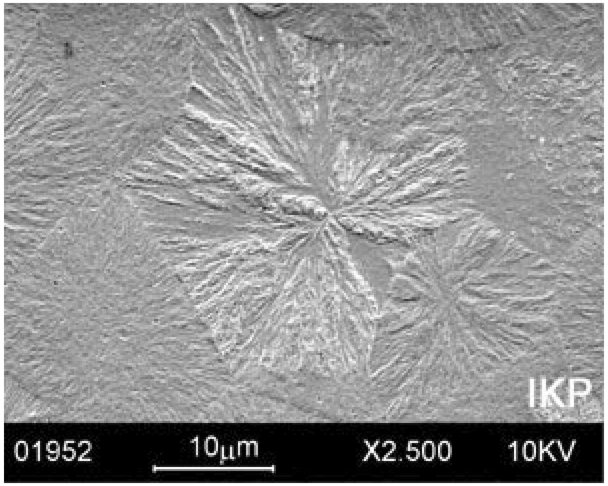




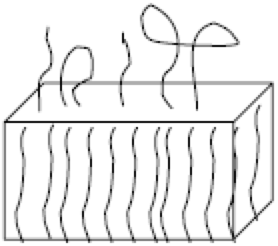
Crystallinity

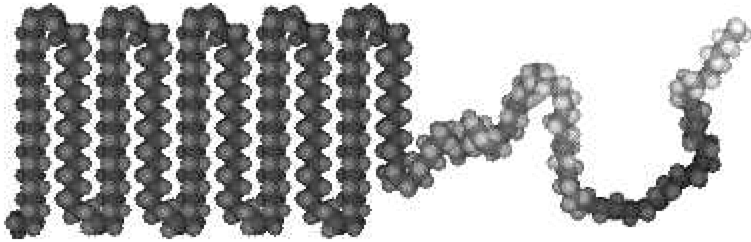
- Spherulites (PP)





- Platelets (PE)

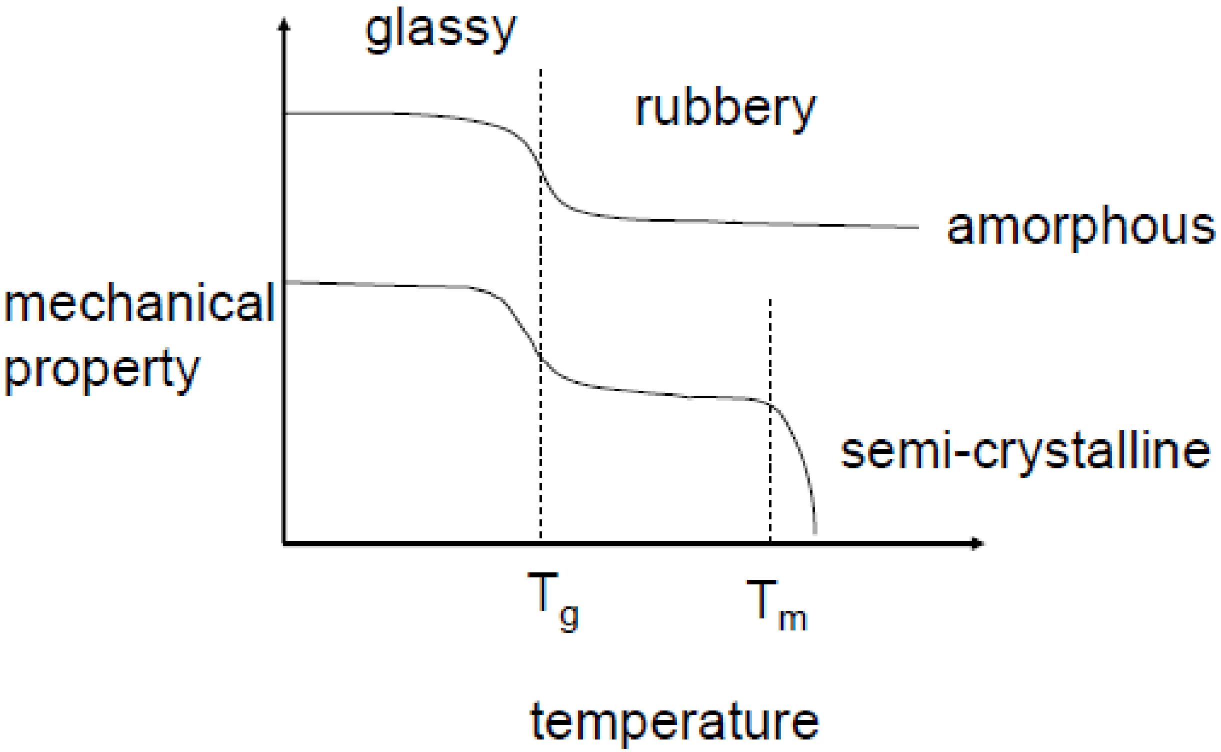




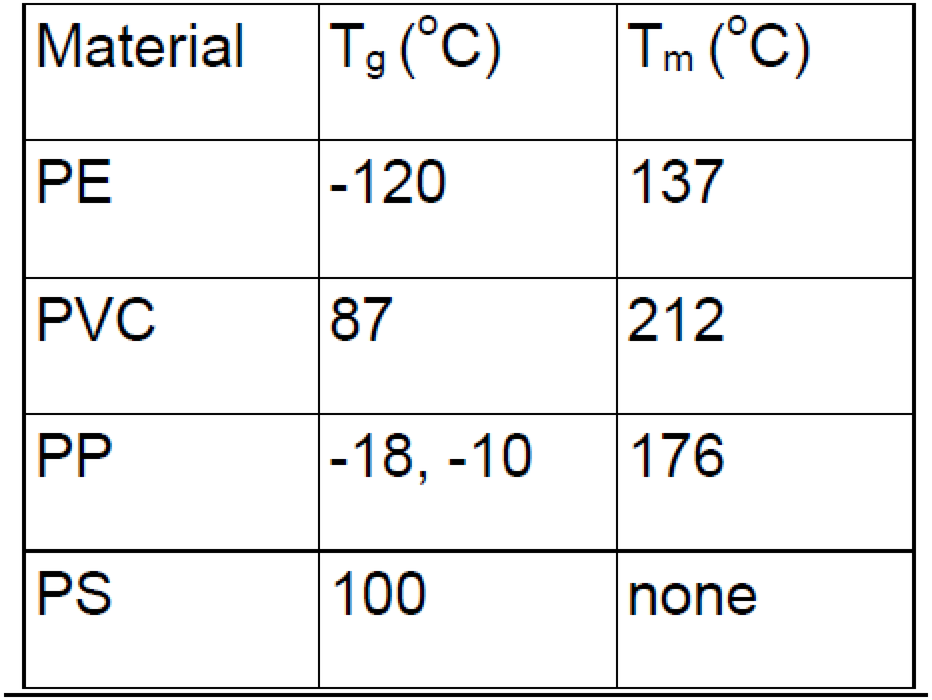
Effects of crystallinity

- Increased stiffness
  - matrix reinforcement
- Increased solvent resistance
  - large secondary bonds prevent solvent molecules from entering
- Crystallinity can go from 0 to 90+%

Melting properties

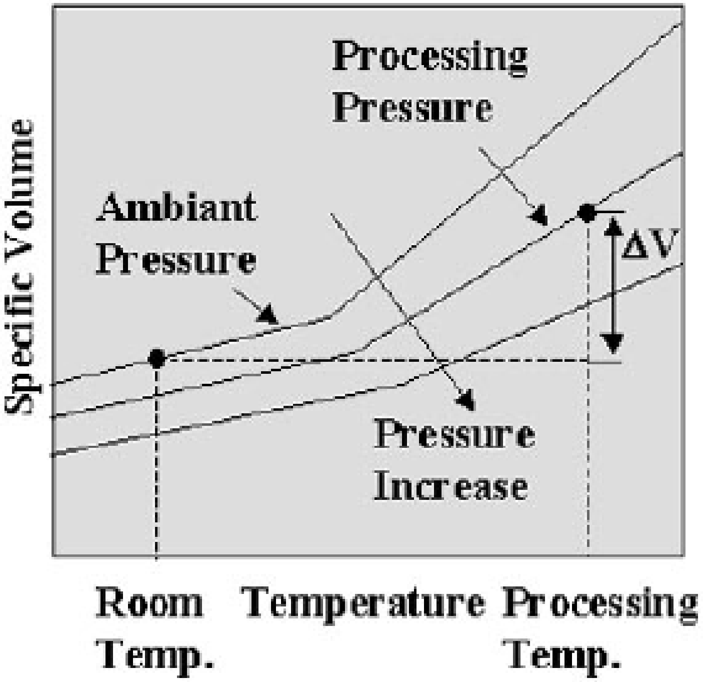


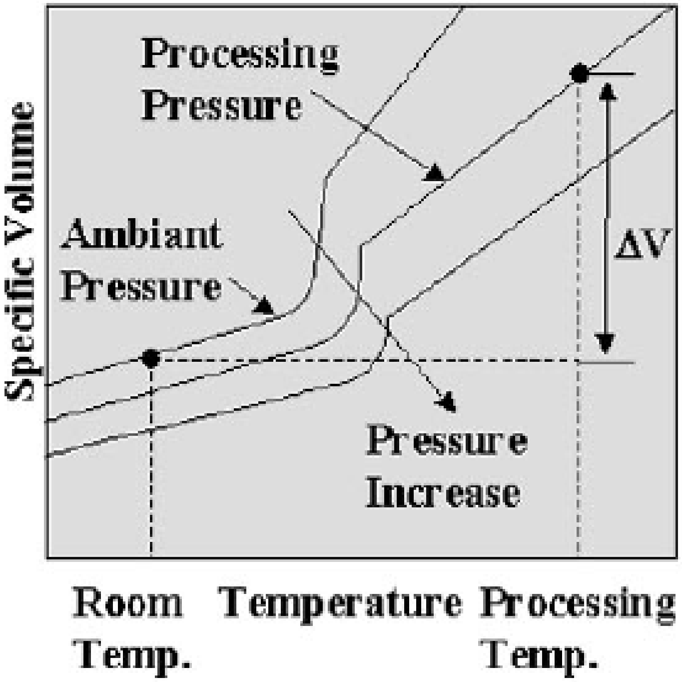
Transitions



Material	T_g (°C)	T_m (°C)
PE	-120	137
PVC	87	212
PP	-18, -10	176
PS	100	none

Pressure – Volume – Temperature (pvT) diagram


Amorphous Polymers


Crystalline Polymers

Behavior of Plastics

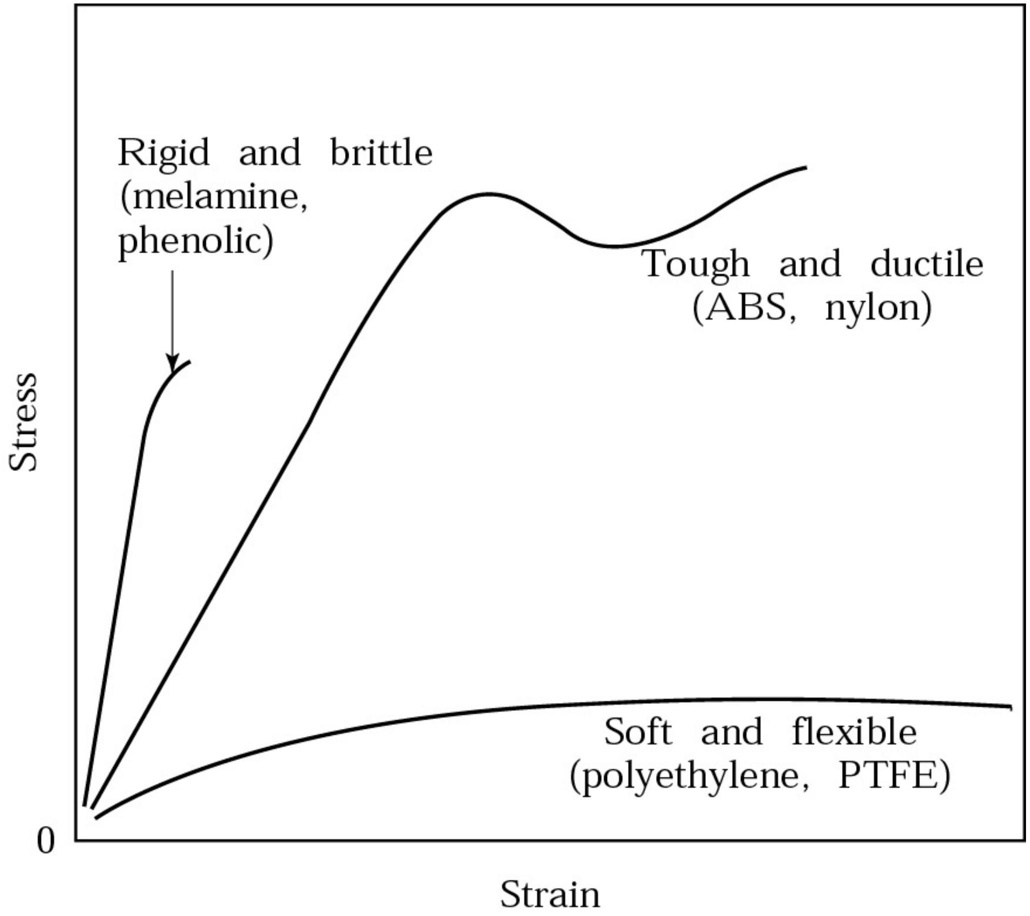


Figure 7.8 General terminology describing the behavior of three types of plastics. PTFE (polytetrafluoroethylene) has *Teflon* as its trade name. *Source*: R. L. E. Brown.

Temperature Effects

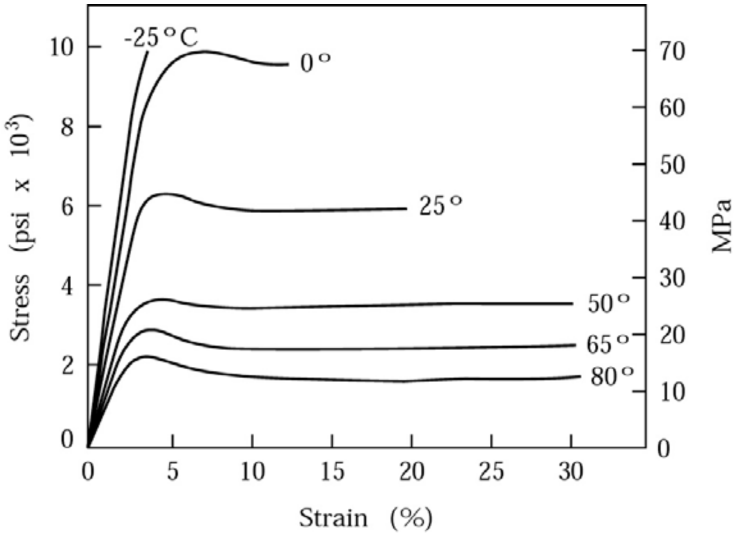


Figure 7.9 Effect of temperature on the stress-strain curve for cellulose acetate, a thermoplastic. Note the large drop in strength and the large increase in ductility with a relatively small increase in temperature. *Source*: After T. S. Carswell and H. K. Nason.

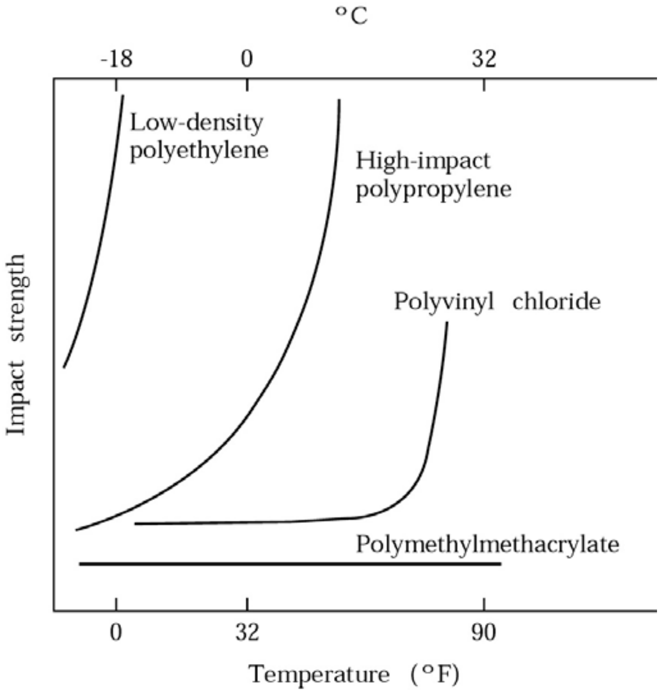


Figure 7.10 Effect of temperature on the impact strength of various plastics. Small changes in temperature can have a significant effect on impact strength. *Source*: P. C. Powell.

Elongation

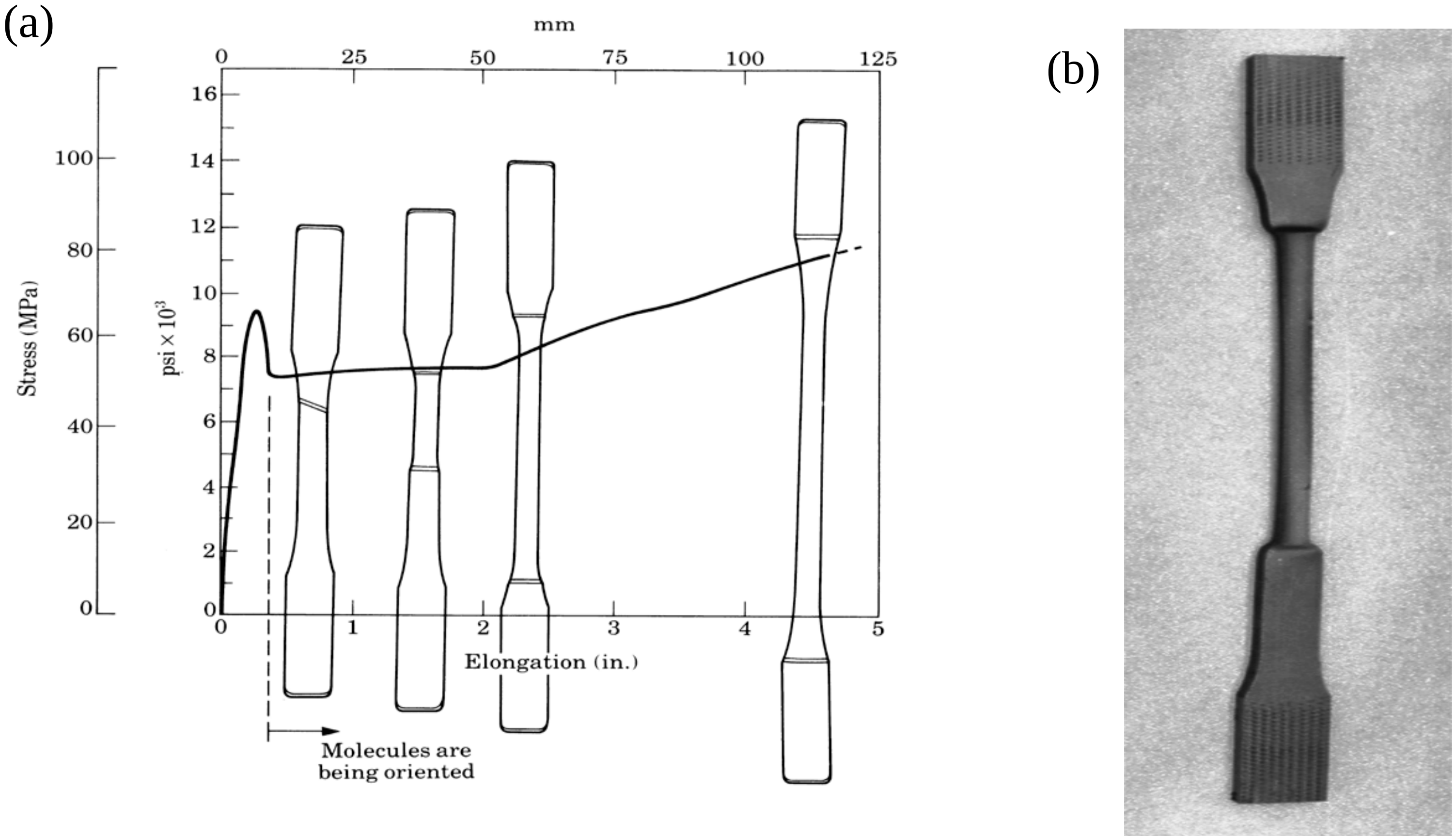


Figure 7.11 (a) Load-elongation curve for polycarbonate, a thermoplastic. *Source*: R. P. Kambour and R. E. Robertson. (b) High-density polyethylene tensile-test specimen, showing uniform elongation (the long, narrow region in the specimen).

General Recommendations for Plastic Products

TABLE 7.3

Design requirement	Applications	Plastics
Mechanical strength	Gears, cams, rollers, valves, fan blades, impellers, pistons	Acetal, nylon, phenolic, polycarbonate
Functional and decorative	Handles, knobs, camera and battery cases, trim moldings, pipe fittings	ABS, acrylic, cellulosic, phenolic, polyethylene, polypropylene, polystyrene, polyvinyl chloride
Housings and hollow shapes	Power tools, pumps, housings, sport helmets, telephone cases	ABS, cellulosic, phenolic, polycarbonate, polyethylene, polypropylene, polystyrene
Functional and transparent	Lenses, goggles, safety glazing, signs, food-processing equipment, laboratory hardware	Acrylic, polycarbonate, polystyrene, polysulfone
Wear resistance	Gears, wear strips and liners, bearings, bushings, roller-skate wheels	Acetal, nylon, phenolic, polyimide, polyurethane, ultrahigh molecular weight polyethylene

Load-Elongation Curve for Rubber

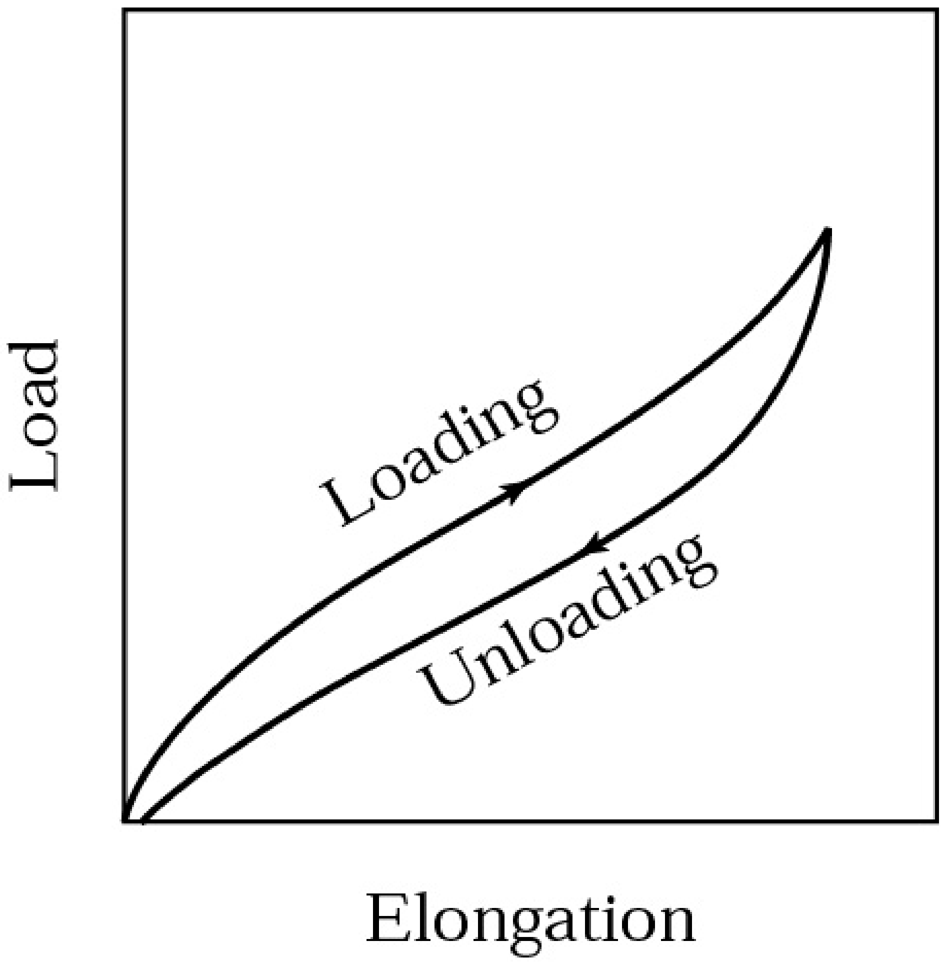


Figure 7.12 Typical load-elongation curve for rubbers. The clockwise lop, indicating the loading and the unloading paths, displays the hysteresis loss. Hysteresis gives rubbers the capacity to dissipate energy, damp vibraion, and absorb shock loading, as is necessary in automobile tires and in vibration dampers placed under machinery.

Viscoelastic Behavior

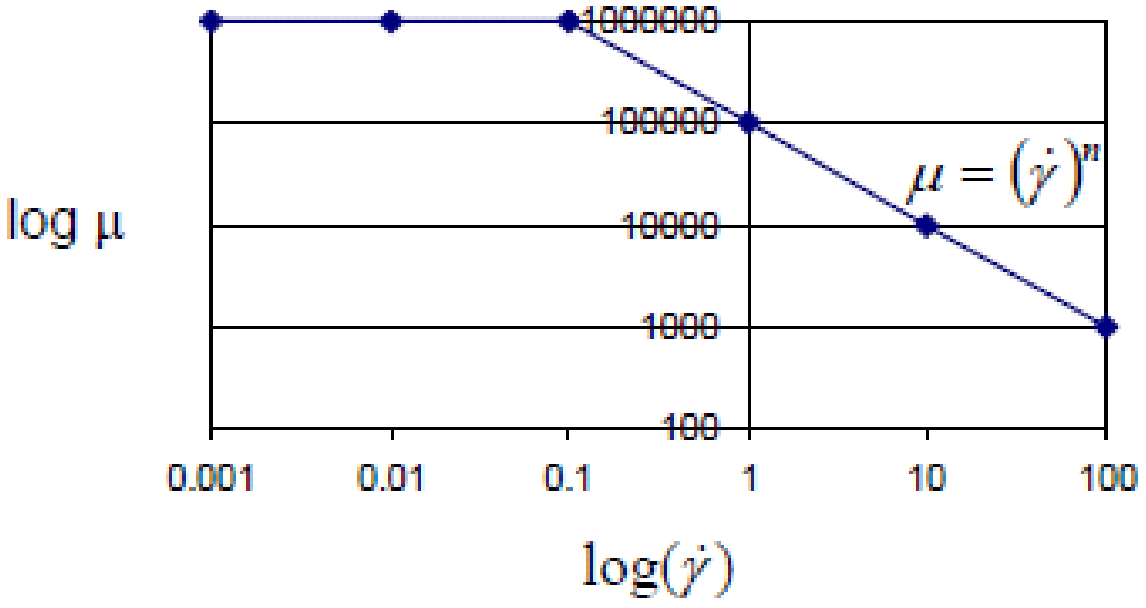
- Fast loading or cold = acts like elastic
- Slow loading or hot = acts like a viscous fluid
- Example: Silly Putty

Behavior

- Polymers do not follow a linear stress-strain rate curve

  non-Newtonian behavior

- At high stress, μ appears to drop



Power-law behavior - shear thinning