

CHAPTER 7

POLYMERS: STRUCTURE, GENERAL PROPERTIES AND
APPLICATIONS

RANGE OF MECHANICAL PROPERTIES FOR VARIOUS ENGINEERING PLASTICS

TABLE 7.1

Material	UTS (MPa)	E (GPa)	Elongation (%)	Poisson's ratio (ν)
ABS	28–55	1.4–2.8	75–5	—
ABS, reinforced	100	7.5	—	0.35
Acetal	55–70	1.4–3.5	75–25	—
Acetal, reinforced	135	10	—	0.35–0.40
Acrylic	40–75	1.4–3.5	50–5	—
Cellulosic	10–48	0.4–1.4	100–5	—
Epoxy	35–140	3.5–17	10–1	—
Epoxy, reinforced	70–1400	21–52	4–2	—
Fluorocarbon	7–48	0.7–2	300–100	0.46–0.48
Nylon	55–83	1.4–2.8	200–60	0.32–0.40
Nylon, reinforced	70–210	2–10	10–1	—
Phenolic	28–70	2.8–21	2–0	—
Polycarbonate	55–70	2.5–3	125–10	0.38
Polycarbonate, reinforced	110	6	6–4	—
Polyester	55	2	300–5	0.38
Polyester, reinforced	110–160	8.3–12	3–1	—
Polyethylene	7–40	0.1–1.4	1000–15	0.46
Polypropylene	20–35	0.7–1.2	500–10	—
Polypropylene, reinforced	40–100	3.5–6	4–2	—
Polystyrene	14–83	1.4–4	60–1	0.35
Polyvinyl chloride	7–55	0.014–4	450–40	—

CHAPTER 7 OUTLINE

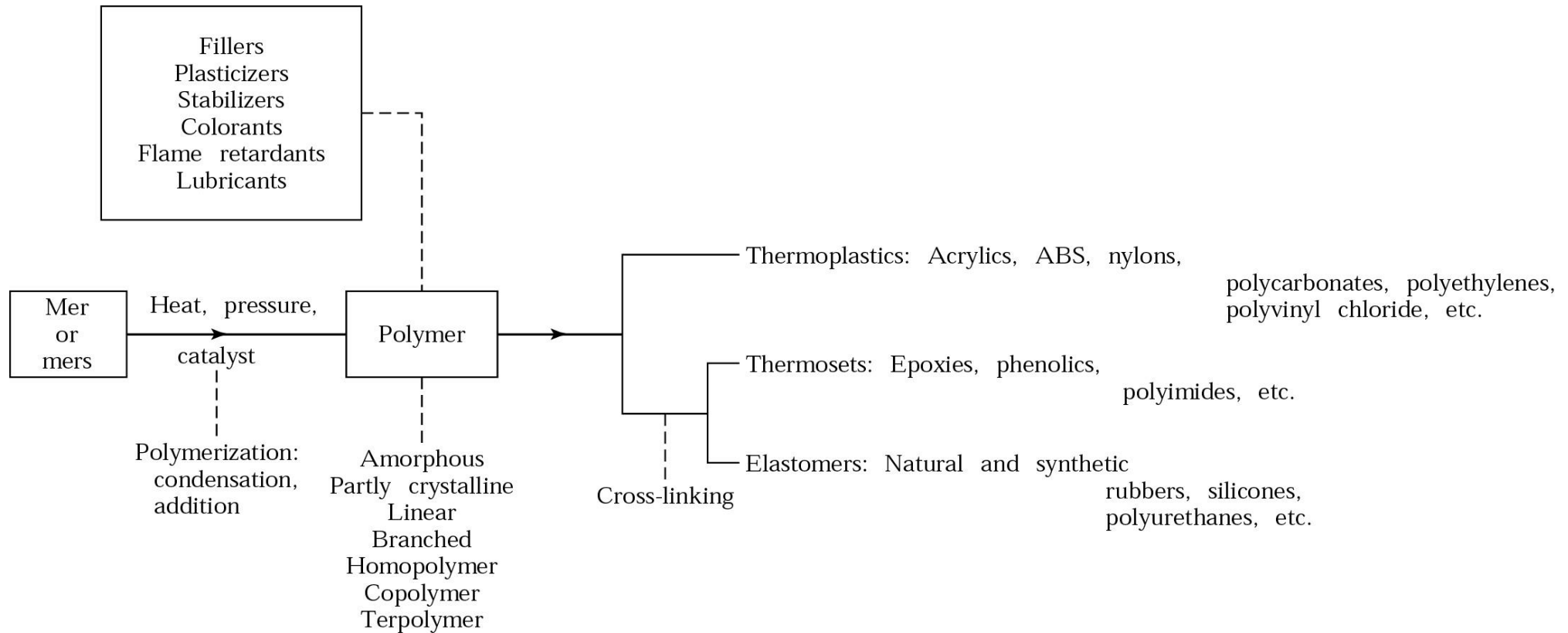


Figure 7.1 Outline of the topics described in Chapter 7

STRUCTURE OF POLYMER MOLECULES

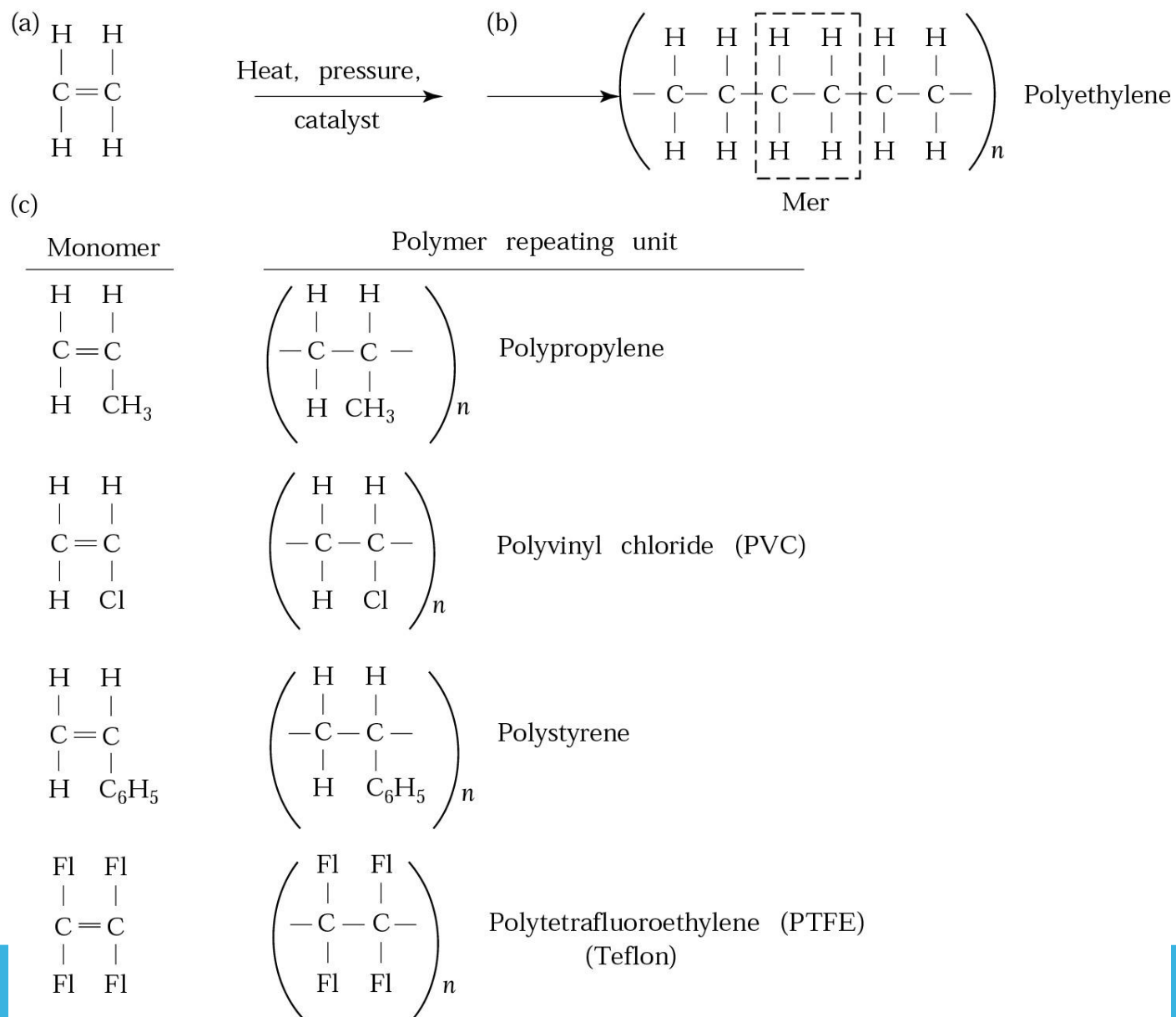


Figure 7.2 Basic structure of polymer molecules: (a) ethylene molecule; (b) polyethylene, a linear chain of many ethylene molecules; © molecular structure of various polymers. These are examples of the basic building blocks for plastics

MOLECULAR WEIGHT AND DEGREE OF POLYMERIZATION

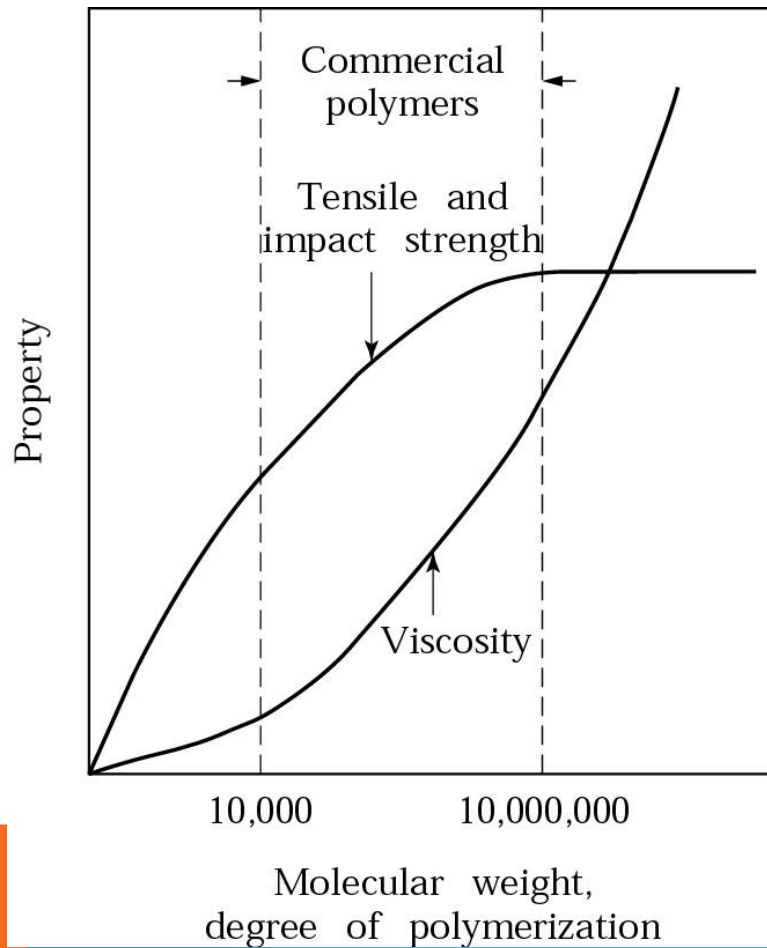
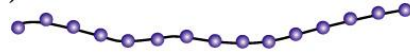


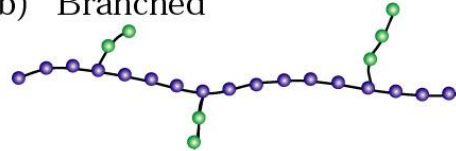
Figure 7.3 Effect of molecular weight and degree of polymerization on the strength and viscosity of polymers.

POLYMER CHAINS

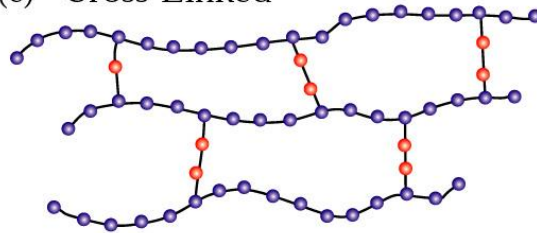
(a) Linear



(b) Branched



(c) Cross-Linked



(d) Network

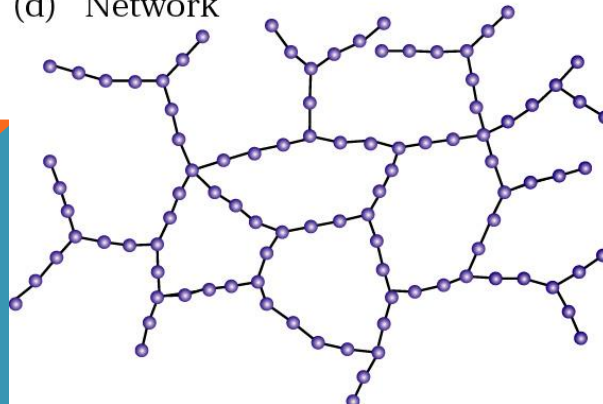
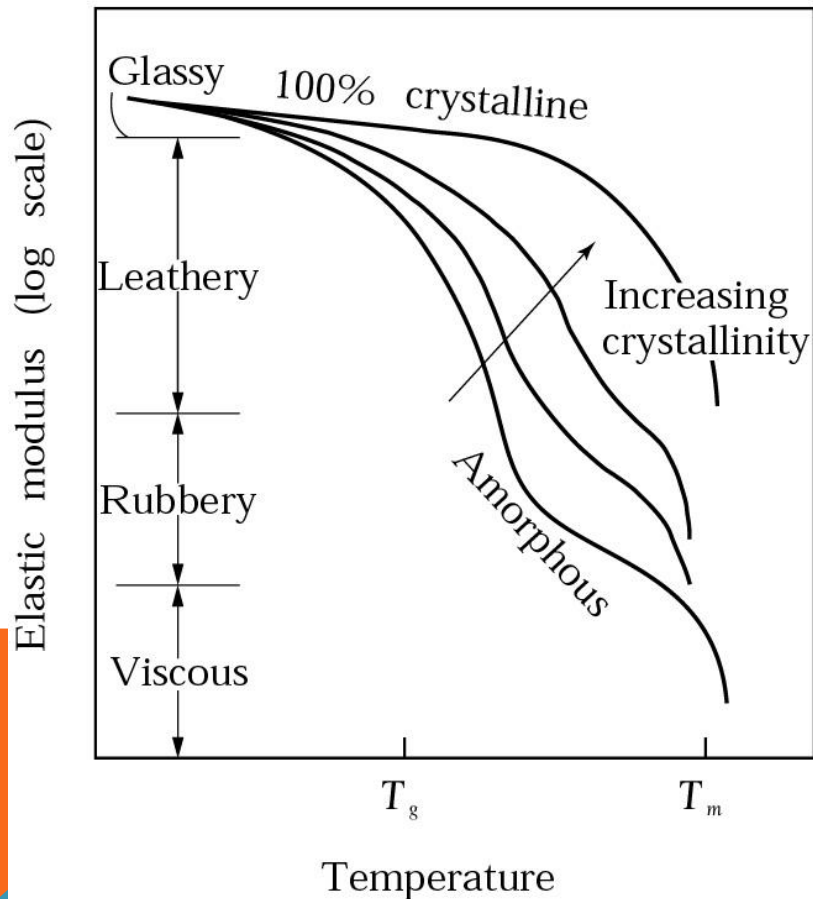


Figure 7.4 Schematic illustration of polymer chains. (a) Linear structure--thermoplastics such as acrylics, nylons, polyethylene, and polyvinyl chloride have linear structures. (b) Branched structure, such as in polyethylene. (c) Cross-linked structure--many rubbers or elastomers have this structure, 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.

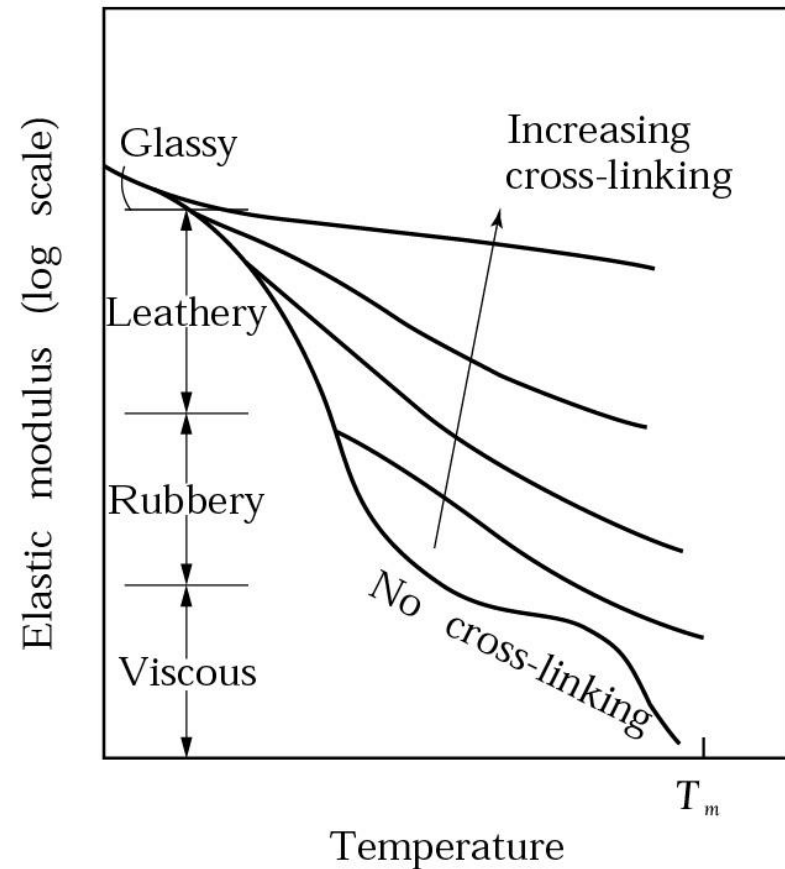
POLYMER BEHAVIOR

Figure 7.5 Behavior of polymers as a function of temperature and (a) degree of crystallinity and (b) cross-linking. The combined elastic and viscous behavior of polymers is known as viscoelasticity.

(a)

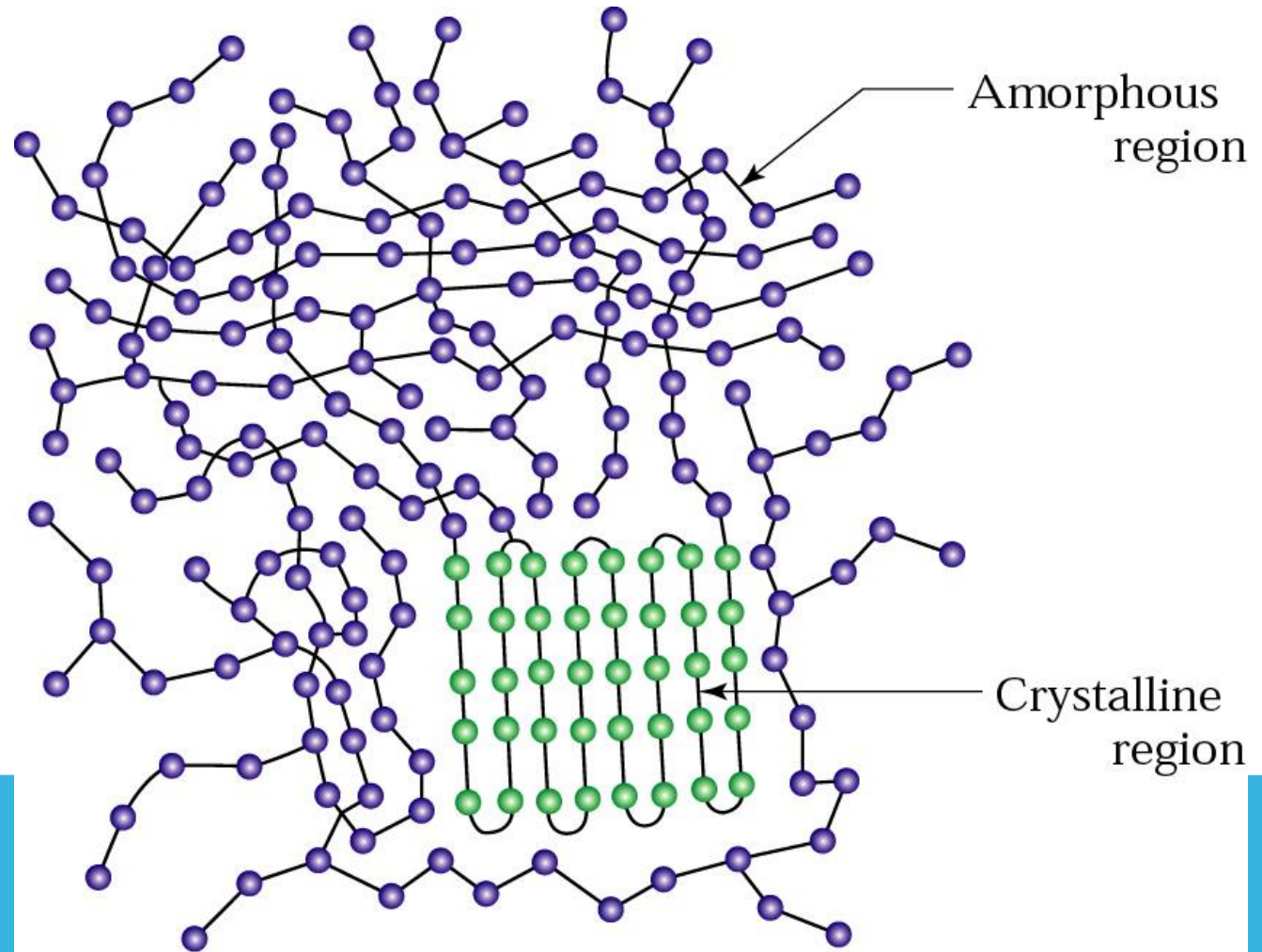


(b)



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.



SPECIFIC VOLUME AS A FUNCTION OF TEMPERATURE

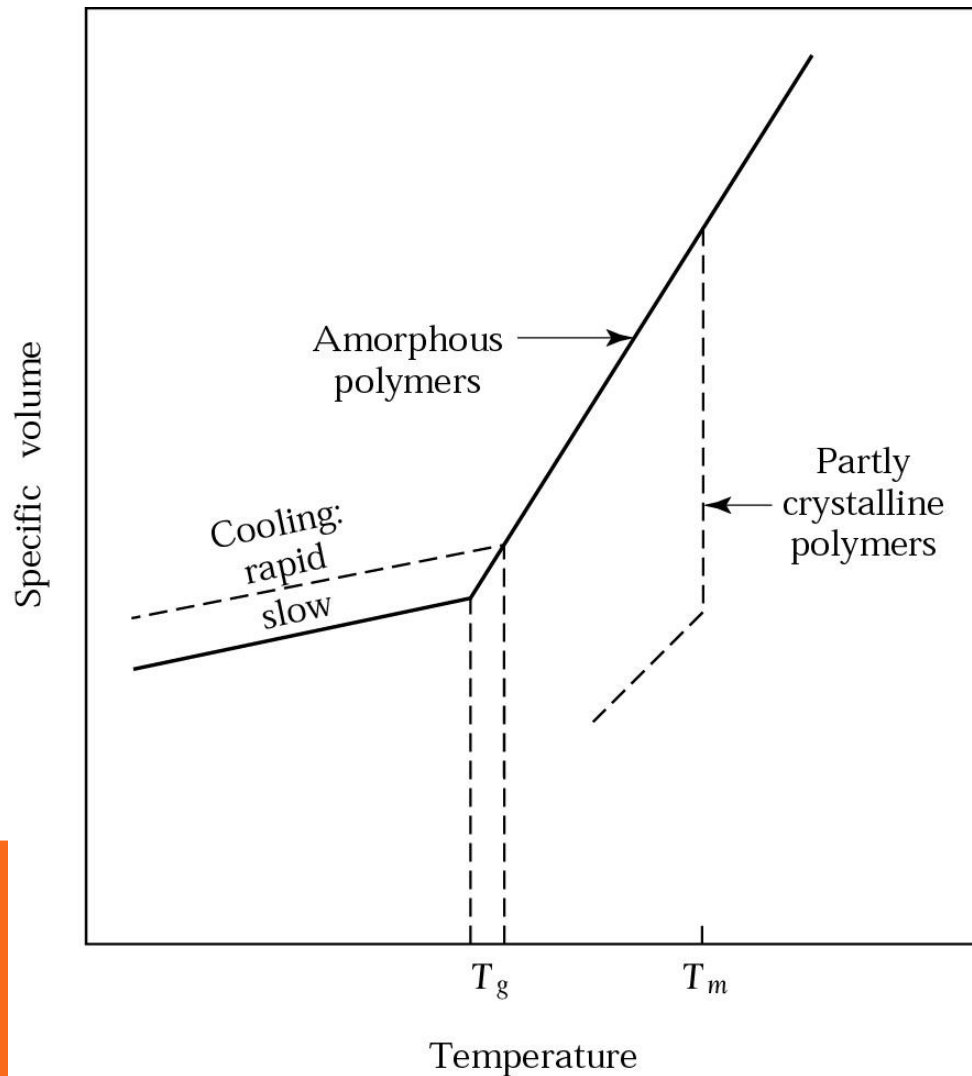


Figure 7.7 Specific volume of polymers as a function of temperature. Amorphous polymers, such as acrylic and polycarbonate, have a glass-transition temperature, T_g , but do not have a specific melting point, T_m . Partly crystalline polymers, such as polyethylene and nylons, contract sharply while passing through their melting temperatures during cooling.

GLASS-TRANSITION AND MELTING TEMPERATURES OF SOME POLYMERS

TABLE 7.2

Material	T_g (°C)	T_m (°C)
Nylon 6,6	57	265
Polycarbonate	150	265
Polyester	73	265
Polyethylene		
High density	-90	137
Low density	-110	115
Polymethylmethacrylate	105	—
Polypropylene	-14	176
Polystyrene	100	239
Polytetrafluoroethylene	-90	327
Polyvinyl chloride	87	212
Rubber	-73	—

BEHAVIOR OF PLASTICS

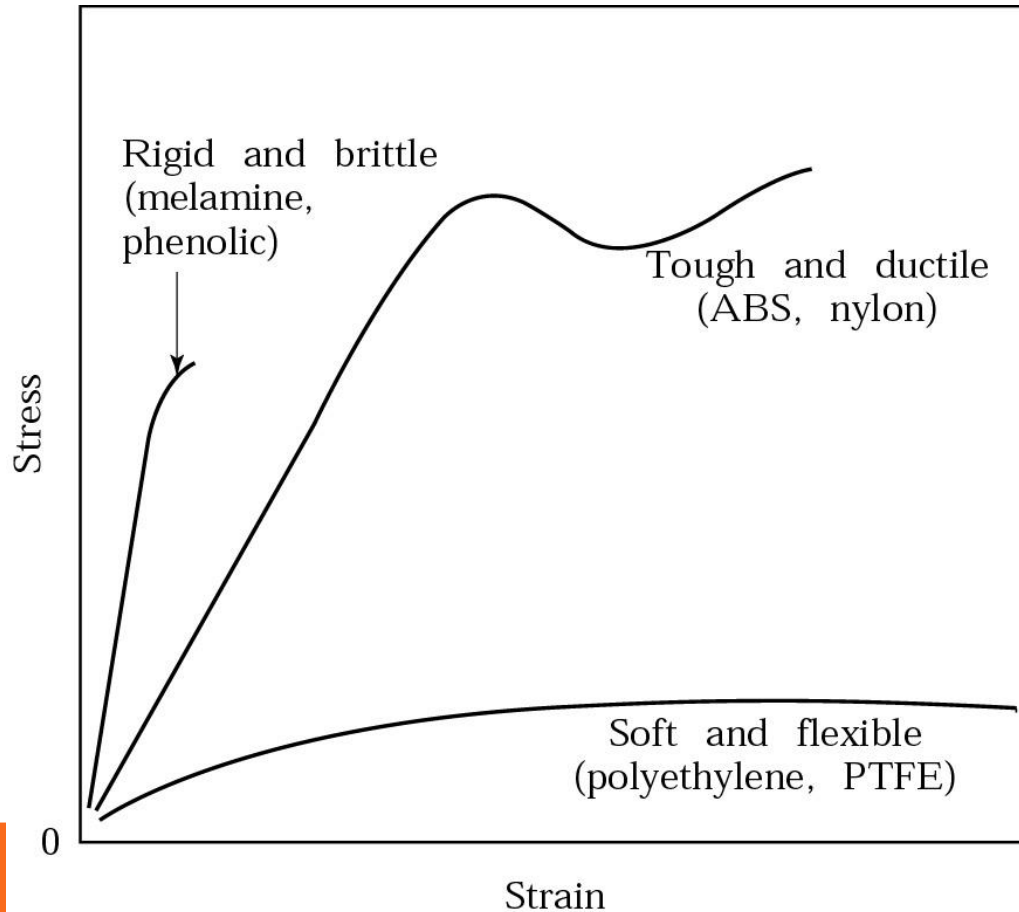


Figure 7.8 General terminology describing the behavior of three types of plastics. PTFE (polytetrafluoroethylene) has *Teflon* as its trade name. *Source: R. L. E. Brown.*

TEMPERATURE EFFECTS

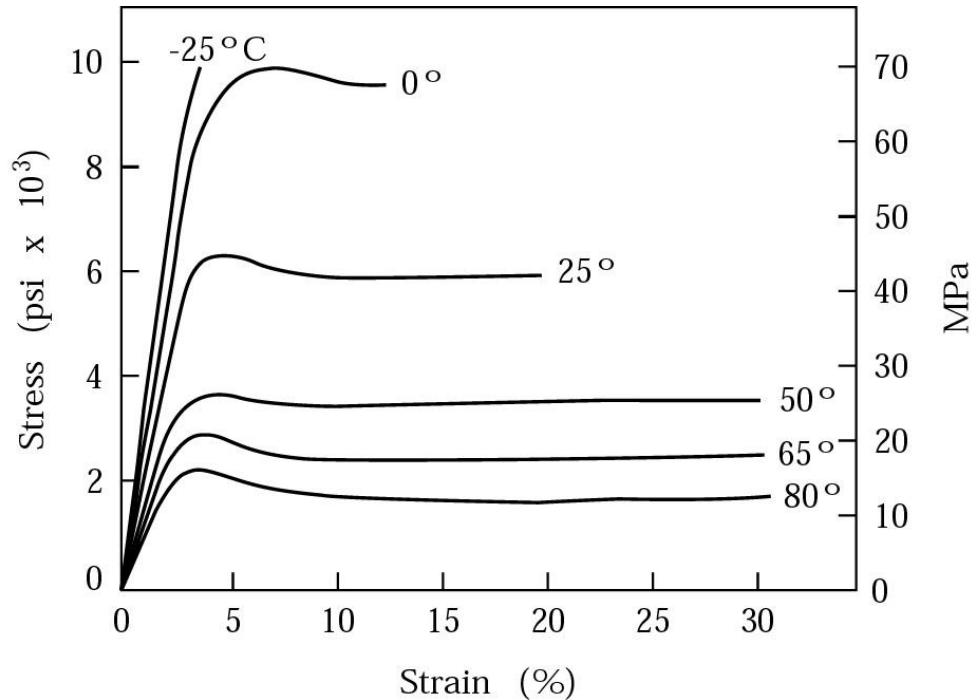


Figure 7.9 Effect of temperature on the stress-strain curve for cellulose acetate, a thermoplastic. Note the large drop in strength and the large increase in ductility with a relatively small increase in temperature. *Source:* After T. S. Carswell and H. K. Nason.

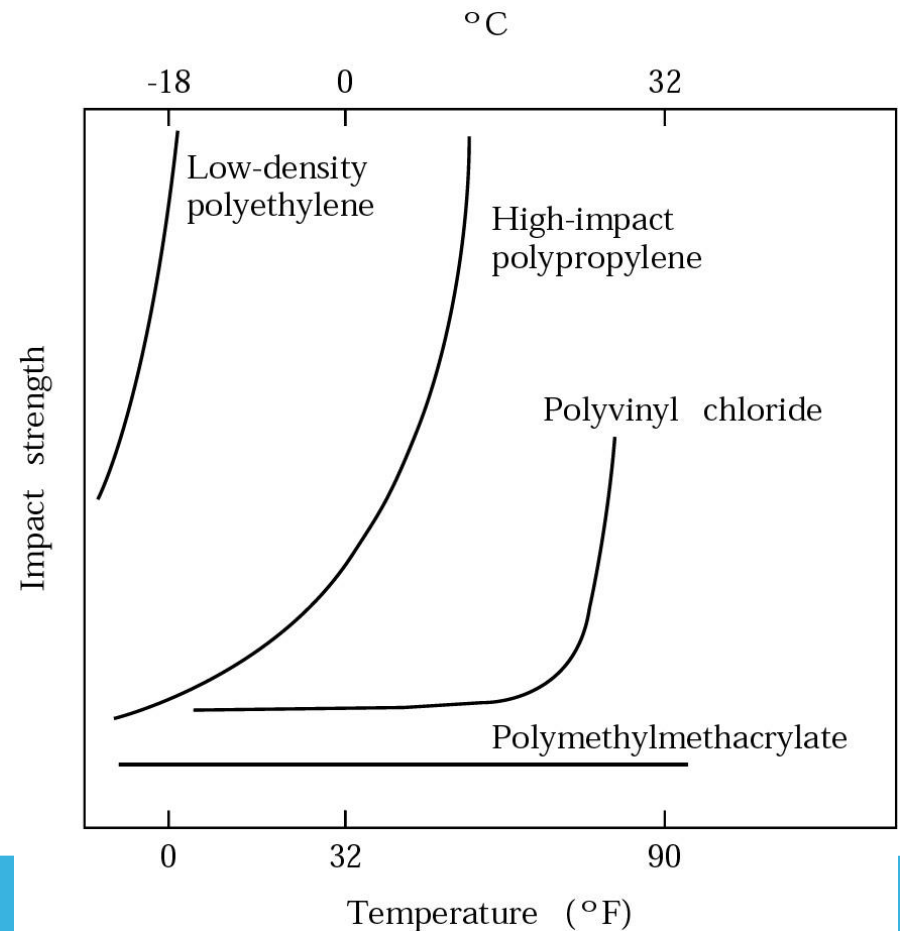
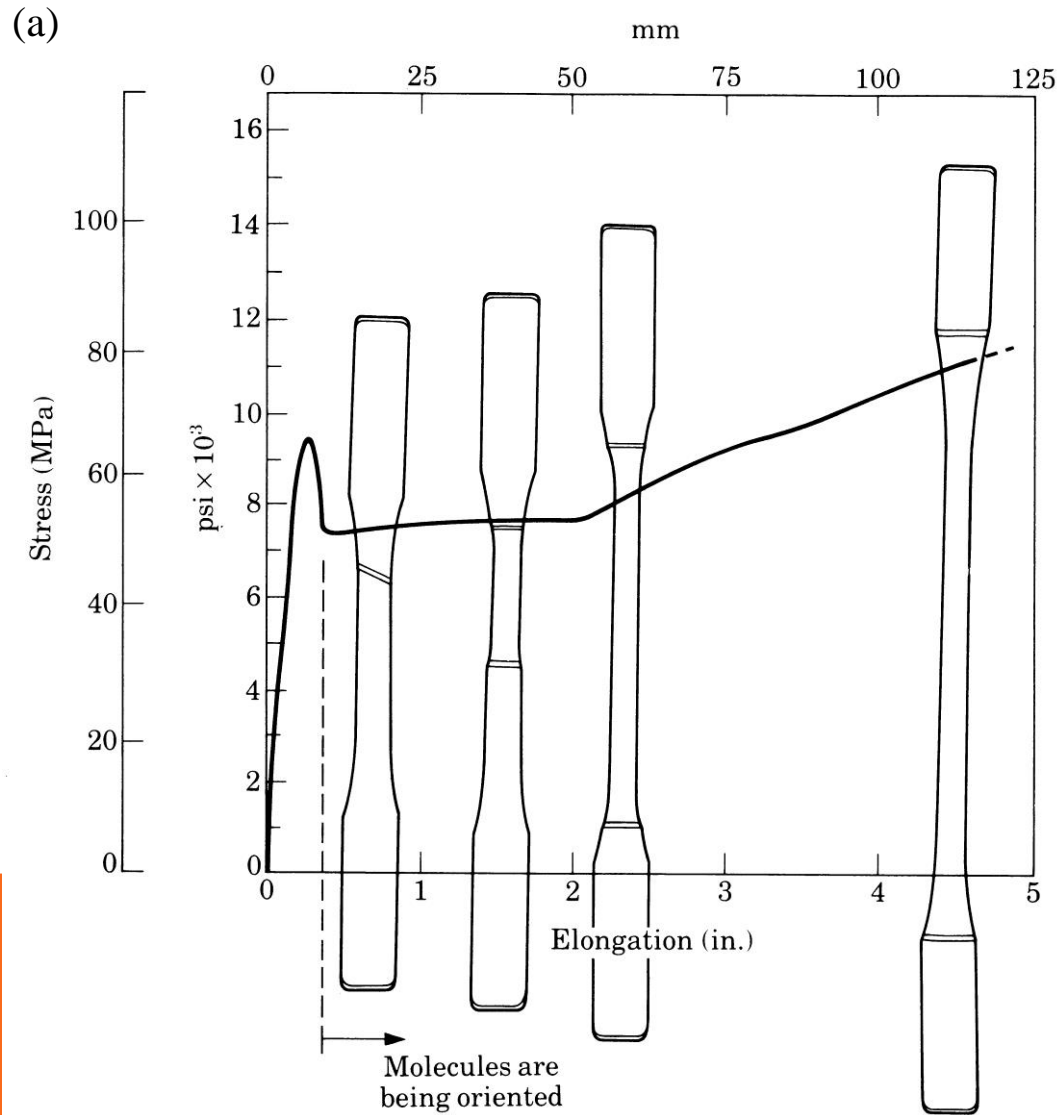


Figure 7.10 Effect of temperature on the impact strength of various plastics. Small changes in temperature can have a significant effect on impact strength. *Source:* P. C. Powell.

ELONGATION



(b)

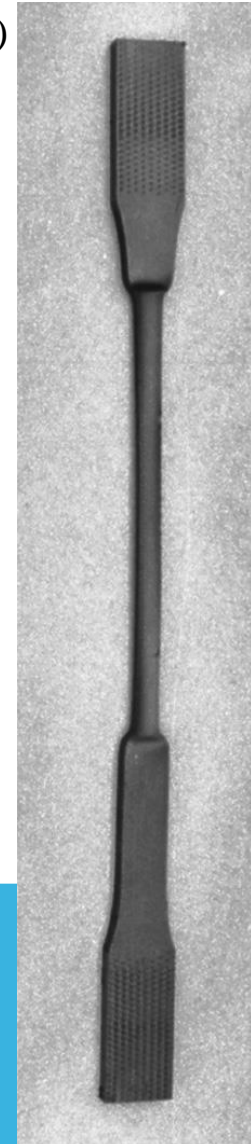


Figure 7.11 (a) Load-elongation curve for polycarbonate, a thermoplastic. *Source:* R. P. Kambour and R. E. Robertson. (b) High-density polyethylene tensile-test specimen, showing uniform elongation (the long, narrow region in the specimen).

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 loop, indicating the loading and the unloading paths, displays the hysteresis loss. Hysteresis gives rubbers the capacity to dissipate energy, damp vibration, and absorb shock loading, as is necessary in automobile tires and in vibration dampers placed under machinery.

