Global Manufacturing

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Fabrication of Plastics, Ceramics and Composites [#5]

Fabrication of Plastics, Ceramics and Composites

- Plastics, ceramics, and composites tend to be used closer to their design limits, and many of the fabrication processes convert the raw material into a finished product in a single operation.
- Large, complex shapes can often be formed as a single unit, eliminating the need for multipart assembly operations.
- Materials in these classes can often provide integral and variable color, and the processes used to manufacture the shape can frequently produce the desired finish and precision.
- Finishing operations are often unnecessary—an attractive feature because altering the final dimensions or surface would be both difficult and costly for some of these materials.
- The joining and fastening operations also tend to be different from those used with metals.

Polymers

A polymer is a compound formed of repeating structural units called **mers**, whose atoms share electrons to form very large molecules. Polymers usually consist of carbon plus one or more other elements such as hydrogen, nitrogen, oxygen, and chlorine.

Polymers are divided into three categories:

(1) thermoplastic polymers TP, **[PLASTICS]**
(2) thermosetting polymers TS, **[PLASTICS]** and
(3) elastomers E **[RUBBERS]**.

(1) low density relative to metals and ceramics;
(2) good strength-to-weight ratios for certain (but not all) polymers;
(3) High corrosion resistance; and
(4) low electrical and thermal conductivity.

Produced by chemical reactions using monomers

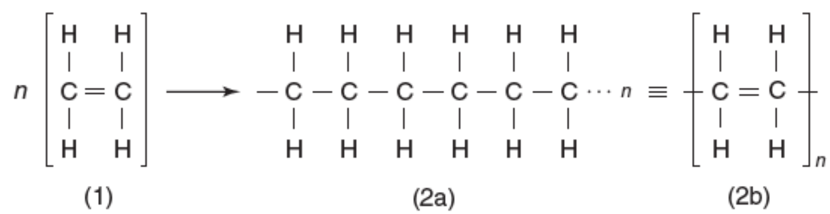


FIGURE 2.4 Synthesis of polyethylene from ethylene monomers: (1) *n* ethylene monomers yields (2a) polyethylene of chain length *n*; (2b) concise notation for depicting the polymer structure of chain length *n*. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



Structures of polymer molecules

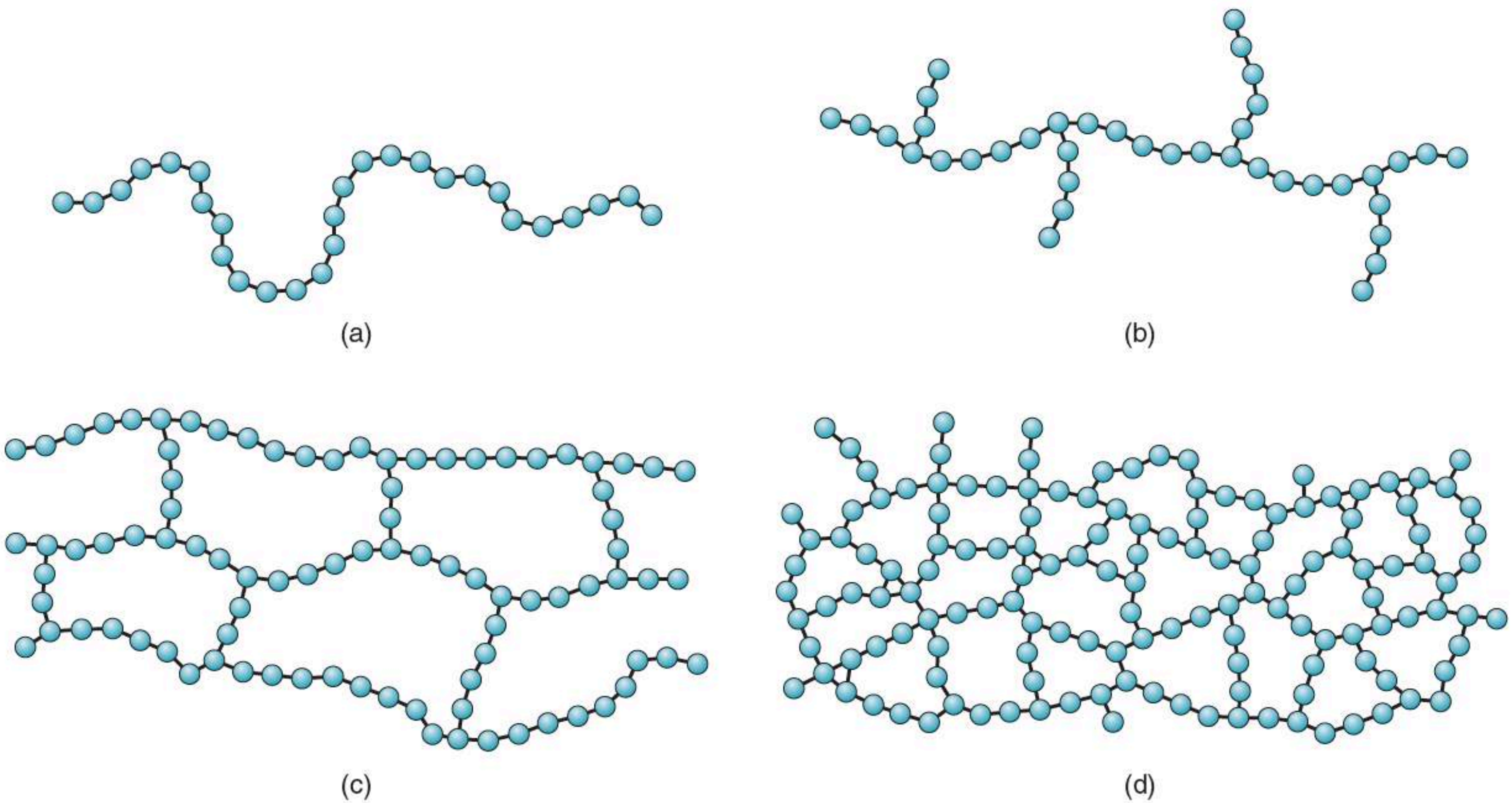
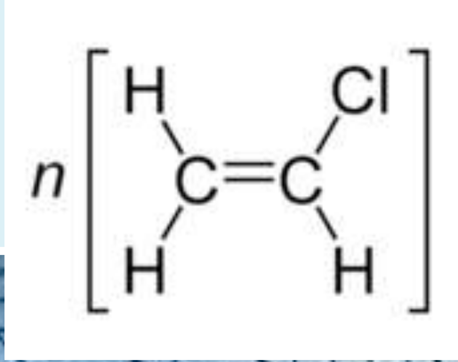
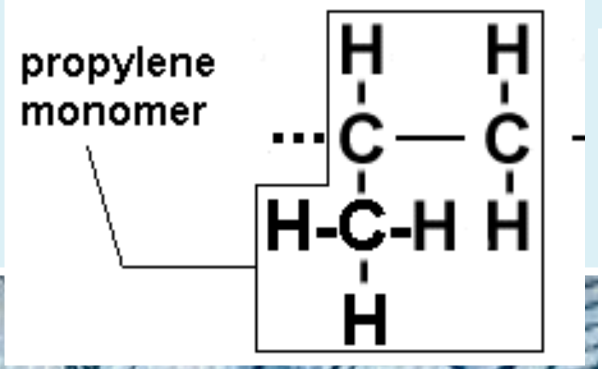


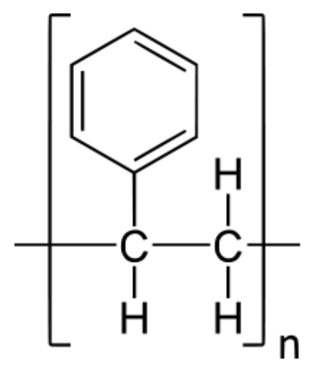
FIGURE 2.5 Various structures of polymer molecules: (a) linear, characteristic of thermoplastics; (b) branched; (c) loosely cross-linked as in an elastomer; and (d) tightly cross-linked or networked structure as in a thermoset. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Thermoplastic polymers

- Thermoplastic polymers can be subjected to multiple heating and cooling cycles without substantially altering the molecular structure of the polymer.
- Solid materials at room temperature, but they become viscous liquids when heated to temperatures of only a few hundred degrees.
- Easily shaped into products.
- around 70% of the tonnage of all synthetic polymers produced.



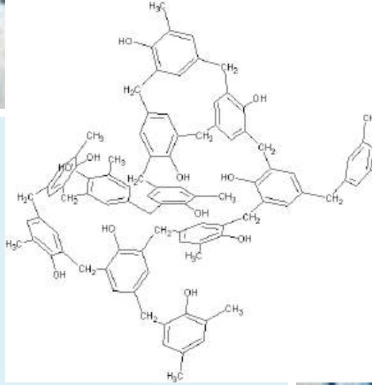




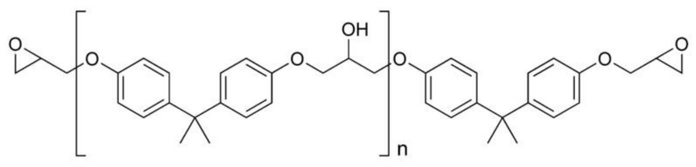
Examples

- **Acrylics.** Derived from acrylic acid ($C_3H_4O_2$) as polymethylmethacrylate (PMMA) or Plexiglas (trade name for PMMA). Excellent transparency (competitive with glass)
- **Acrylonitrile–Butadiene–Styrene** (ABS) excellent combination of mechanical properties.
- **Polyamides** (PA) Amide linkages (CO–NH) as Nylon; strong, highly elastic, tough, abrasion resistant, and self-lubricating. applications of nylon: 90% carpets, apparel, and tire cord. 10% engineering components (bearings, gears: strength and low friction) Aramids (aromatic polyamides) as Kevlar an important as a fiber in reinforced plastics.
- **Polycarbonate** (PC) excellent mechanical properties, high toughness and good creep resistance. heat resistant, transparent, and fire resistant. (housings machines, pump impellers, safety helmets, etc)
- **Polypropylene** (PP) lightest of the plastics with excelent strength-to-weight ratio; the high melting point of polypropylene allows certain applications for example, components that must be sterilized.
- **Polyvinylchloride** (PVC) is versatile polymer, with applications that include rigid pipe fittings, wire and cable insulation, film, sheets, food packaging, ...

Thermosetting polymers



- Distinguished by their highly cross-linked structure.
- Chemically transform (cure) into a rigid structure on cooling from a heated plastic condition [Some of these polymers cure by mechanisms other than heating]
- The formed part (e.g., pot handle or electrical switch cover) becomes one large macromolecule.
- Characteristics: (1) more rigid, (2) brittle, (3) less soluble in common solvents, (4) capable of higher service temperatures, and (5) not capable of being remelted—instead they degrade or burn.
- Examples: phenolics, amino resins, and epoxies.



Epoxi Resine

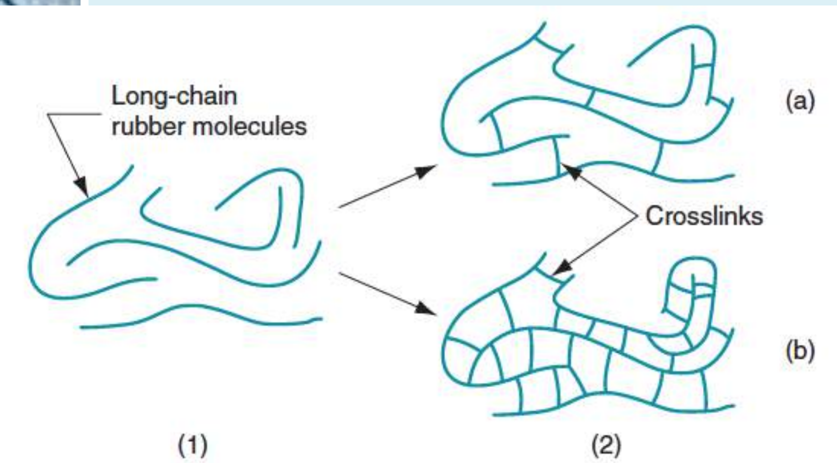
Examples:

- **Amino Resins**. amino group (NH_2) as the Melamine-formaldehyde plastic that is water resistant and is used for dishware and as a coating in laminated table and counter tops (trade name: Formica).
- **Epoxies.** Cured epoxies are noted for strength, adhesion, and heat and chemical resistance. Applications include surface coatings, industrial flooring, glass fiber-reinforced composites, and adhesives.
- **Polyesters.** Ester linkages (CO–O), can be thermosetting as well as thermoplastic. Thermosetting polyesters are used largely in reinforced plastics (composites) to fabricate large items such as pipes, tanks, boat hulls, auto body parts, and construction panels.
- **Polyurethanes.** The largest application of polyurethane is in foams. These can range between elastomeric and rigid, the latter being more highly cross-linked. Rigid foams are used as a filler material in hollow construction panels and refrigerator walls.

Elastomers

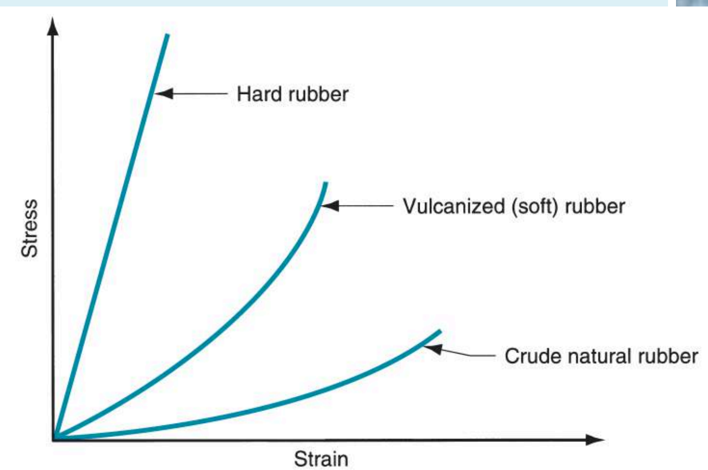
Elastomers are polymers that exhibit significant elastic behavior; hence, the name elastomer. They include natural rubber, neoprene, silicone, and polyurethane.

Curing is required to effect cross-linking in most elastomers. The term for curing used in the context of natural rubber (and certain synthetic rubbers) is **vulcanization**, which involves the formation of chemical cross-links between the polymer chains.

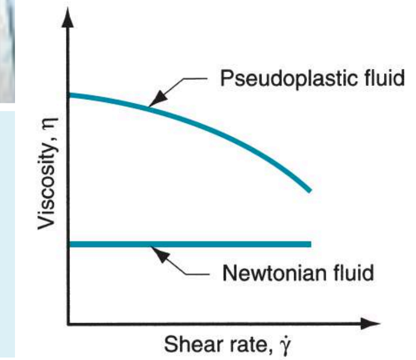


Vulcanized Rubber

FIGURE 2.6 Increase in stiffness as a function of strain for three grades of rubber: natural rubber, vulcanized rubber, and hard rubber. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



Viscosity and fluidity



$$\frac{F}{A} = \eta \frac{dv}{dy}$$

$$\tau = \frac{F}{A}$$

$$\dot{\gamma} = \frac{dv}{dy}$$

$$\eta = \frac{\tau}{\dot{\gamma}}$$

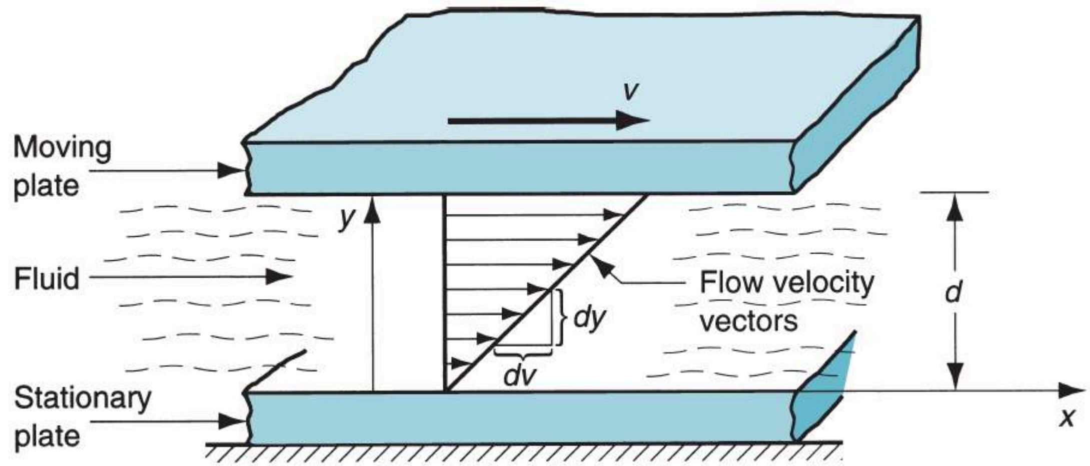


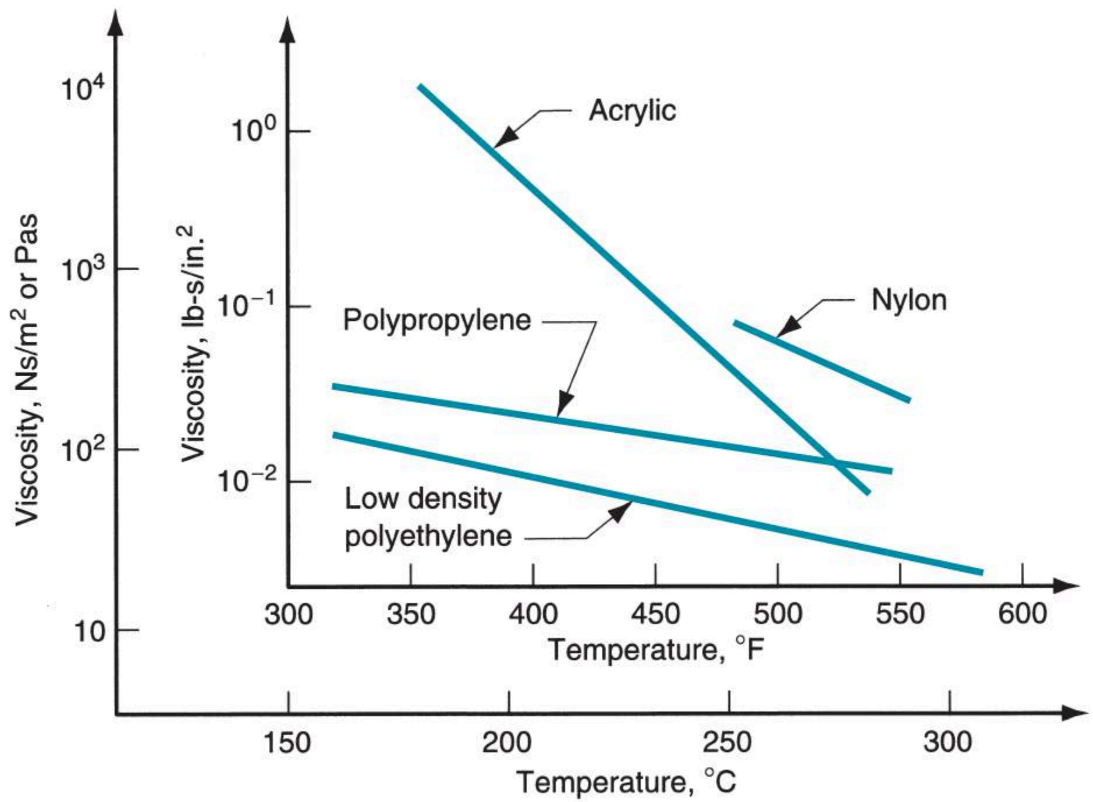
FIGURE 3.17 Fluid flow between two parallel plates, one stationary and the other moving at velocity *v*. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

TABLE 3.9 Viscosity values for selected fluids.

Material	Coefficient of Viscosity Pa-s	Coefficient of Viscosity lb-sec/in^2	Material	Coefficient of Viscosity Pa-s	Coefficient of Viscosity lb-sec/in^2
Glass[b], 540°C (1000°F)	10^{12}	10^8	Pancake syrup (room temp)	50	73×10^{-4}
Glass[b], 815°C (1500°F)	10^5	14	Polymer[a], 151°C (300°F)	115	167×10^{-4}
Glass[b], 1095°C (2000°F)	10^3	0.14	Polymer[a], 205°C (400°F)	55	80×10^{-4}
Glass[b], 1370°C (2500°F)	15	22×10^{-4}	Polymer[a], 260°C (500°F)	28	41×10^{-4}
Mercury, 20°C (70°F)	0.0016	0.23×10^{-6}	Water, 20°C (70°F)	0.001	0.15×10^{-6}
Machine oil (room temp.)	0.1	0.14×10^{-4}	Water, 100°C (212°F)	0.0003	0.04×10^{-6}

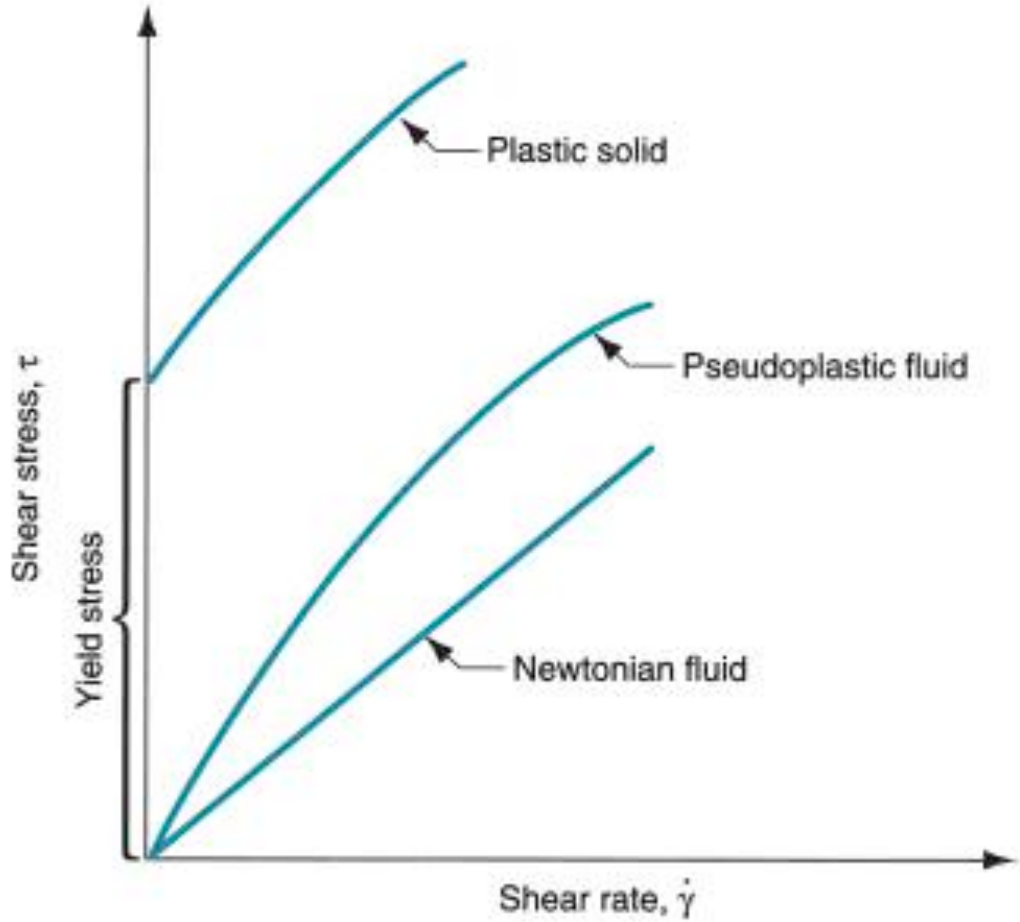
Viscosity and Temperature

FIGURE 8.2 Viscosity as a function of temperatures for selected polymers at a shear rate of $10^3\ s^{-1}$. Data compiled from [12]. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



VISCOELASTIC BEHAVIOR OF POLYMERS

FIGURE 3.18 Viscous behaviors of Newtonian and pseudoplastic fluids. Polymer melts exhibit pseudoplastic behavior. For comparison, the behavior of a plastic solid material is shown. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



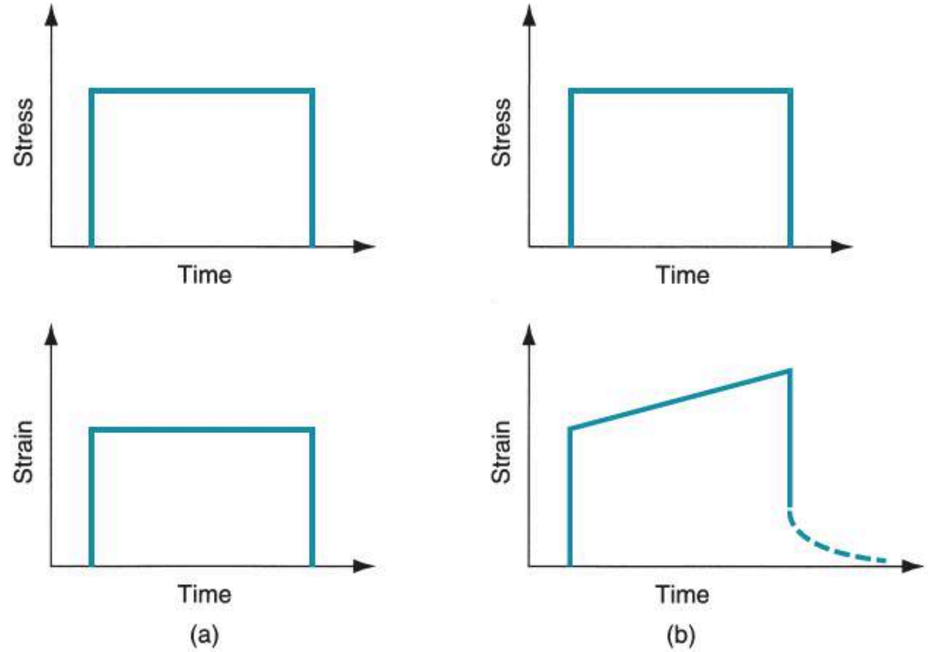
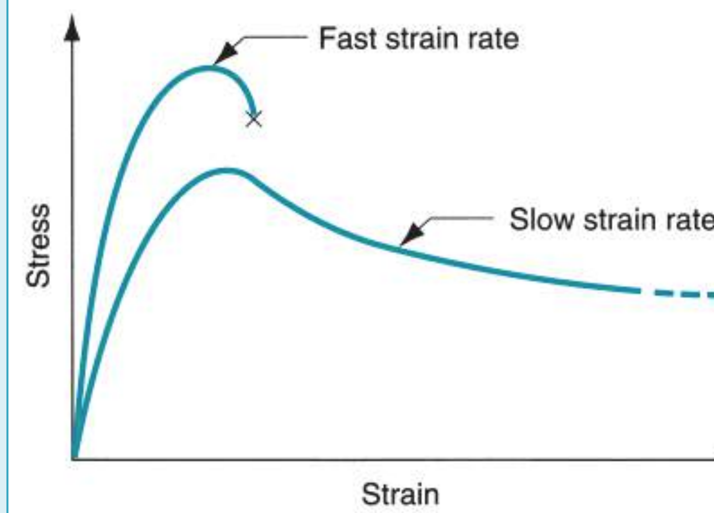
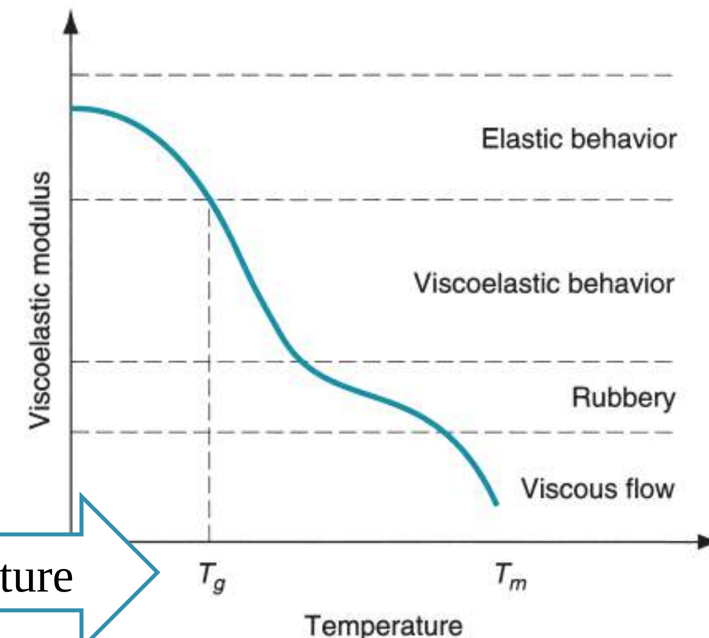


FIGURE 3.19 Comparison of elastic and viscoelastic properties: (a) perfectly elastic response of material to stress applied over time; and (b) response of a viscoelastic material under same conditions. The material in (b) takes a strain that is a function of time and temperature. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

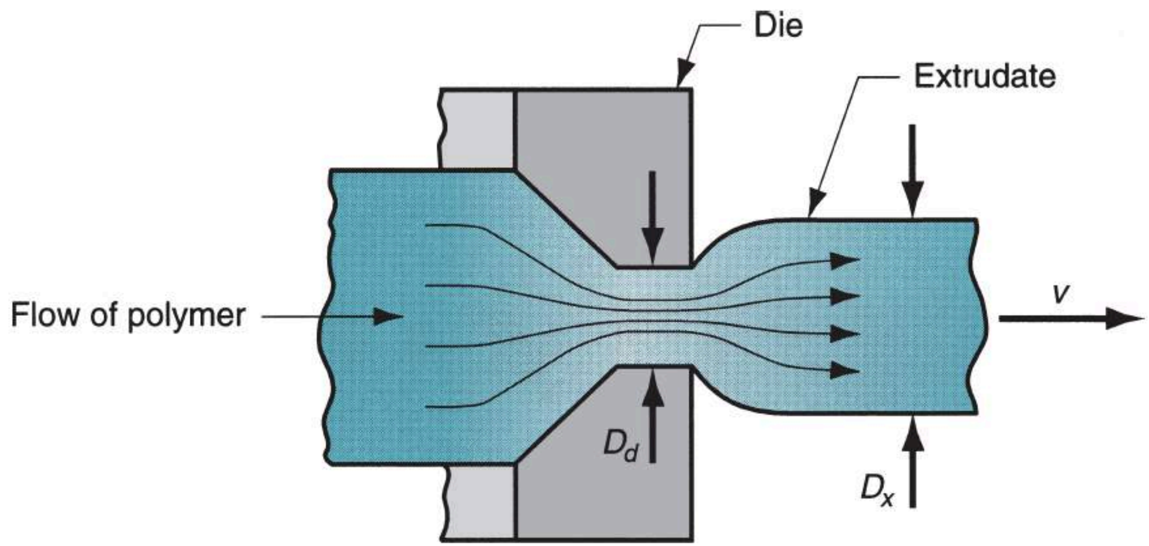




Glass Transition Temperature

Die Swell

FIGURE 8.3 Die swell, a manifestation of viscoelasticity in polymer melts, as depicted here on exiting an extrusion die. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



$$r_s = \frac{D_x}{D_d}$$

Plastic Manufacturing

Plastic-shaping processes can be classified according to the resulting product geometry as follows:

(1) continuous extruded products with constant cross section other than sheets, films, and filaments;

(2) continuous sheets and films;

(3) continuous filaments (fibers);

(4) molded parts that are mostly solid;

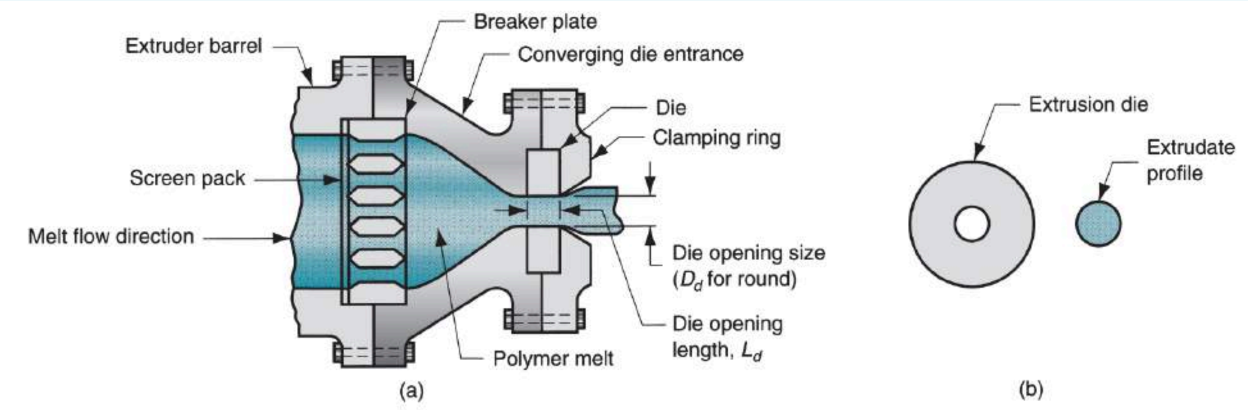
(5) hollow molded parts with relatively thin walls;

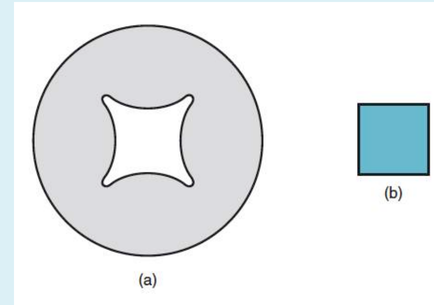
(6) discrete parts made of formed sheets and films;

(7) castings;

(8) Foamed products.

Polymer Extrusion





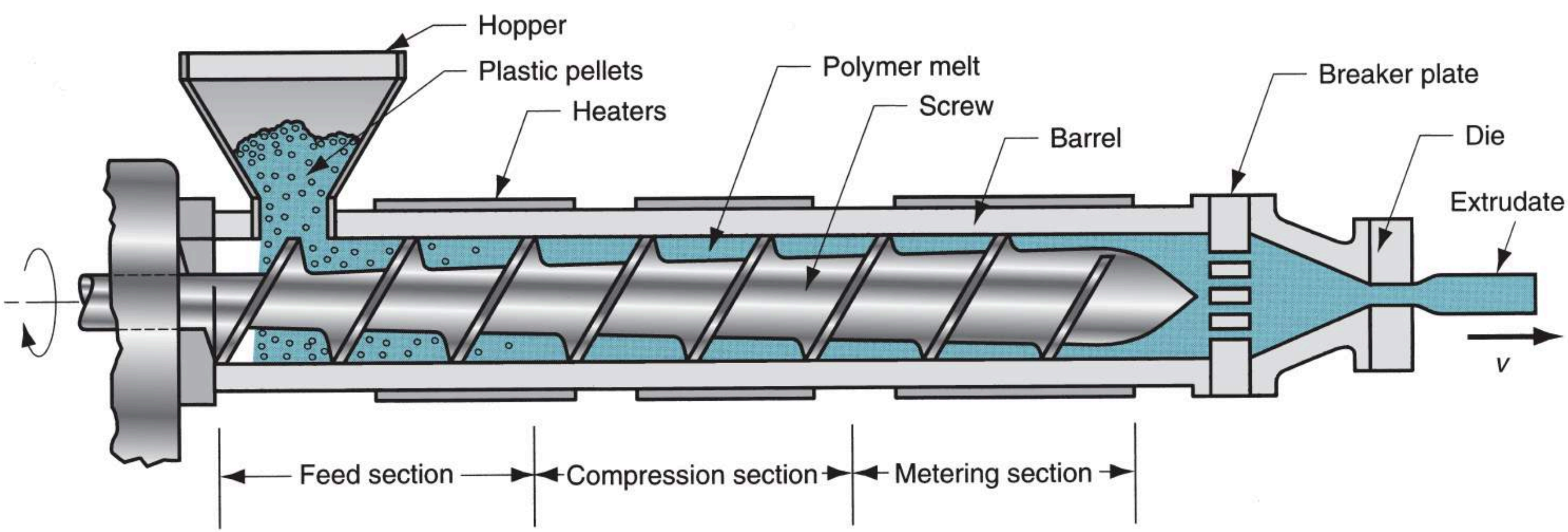


FIGURE 8.4 Components and features of a (single-screw) extruder for plastics and elastomers. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

PRODUCTION OF SHEET AND FILM

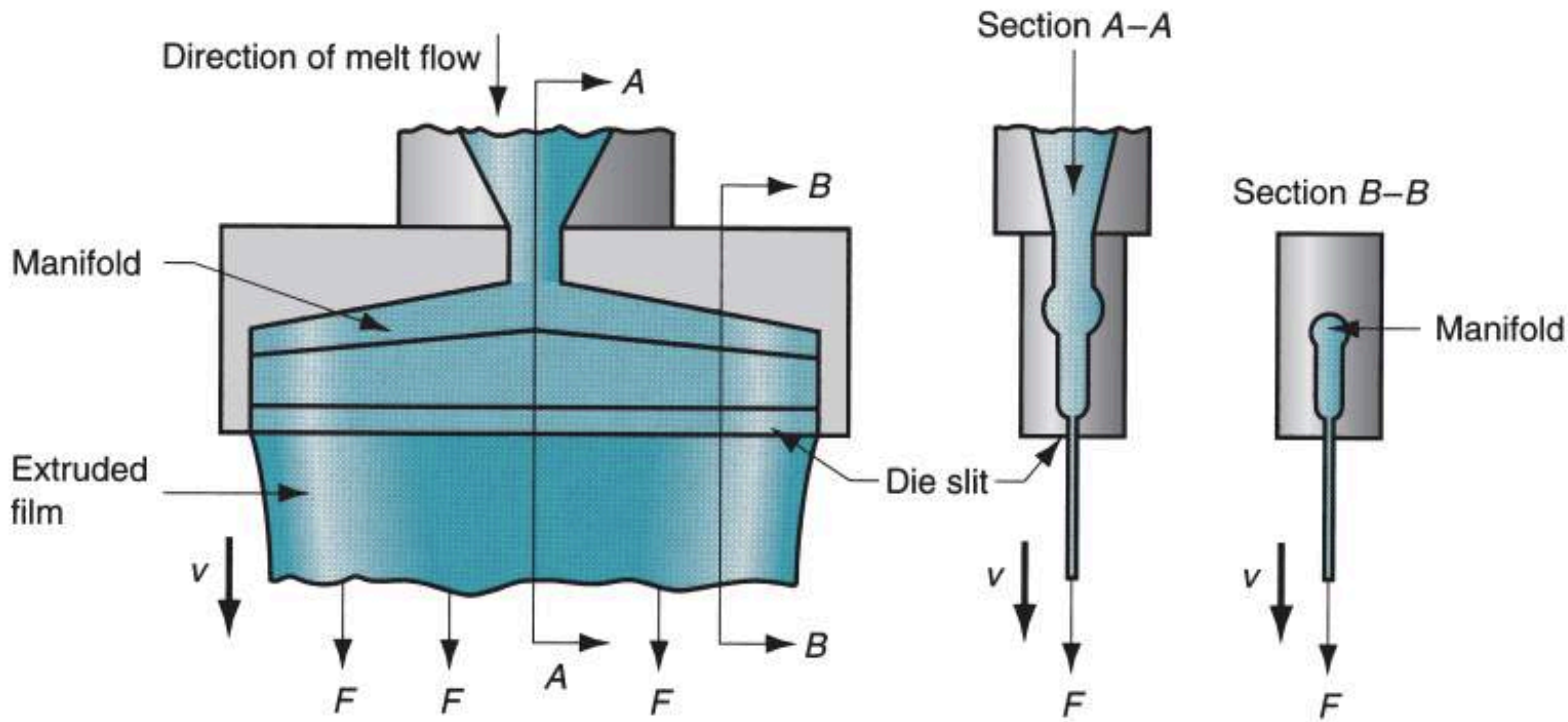
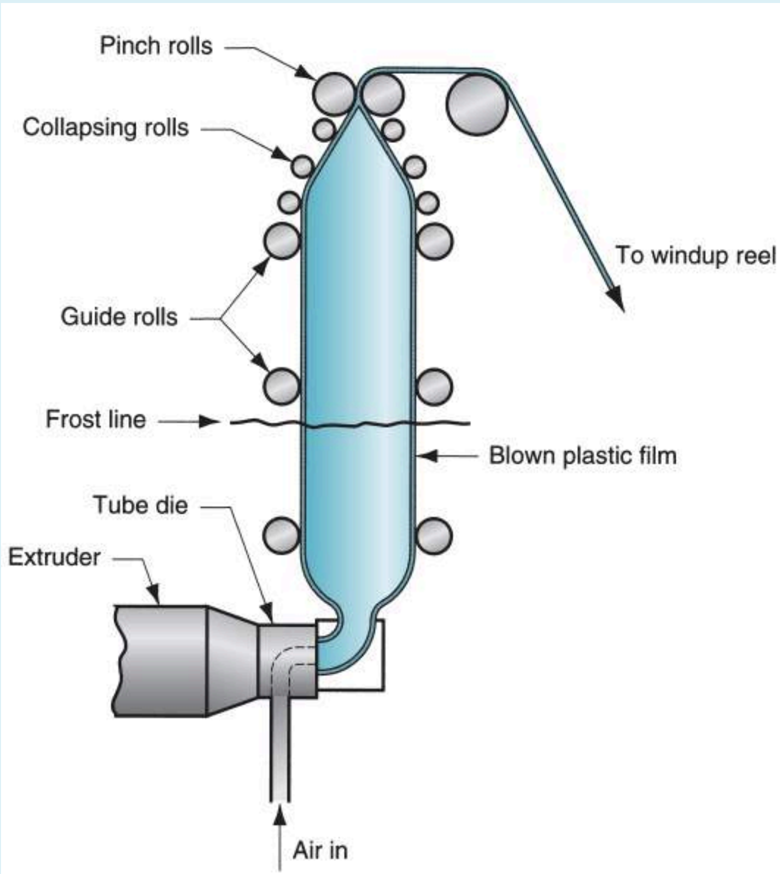
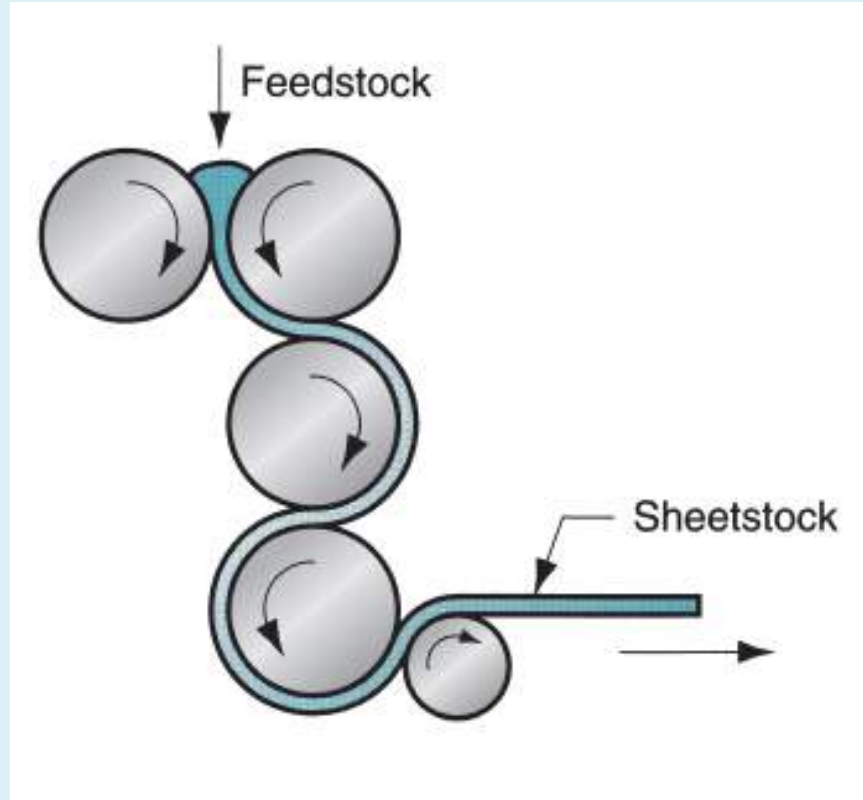


FIGURE 8.14 One of several die configurations for extruding sheet and film. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

PRODUCTION OF SHEET AND FILM



Calendering

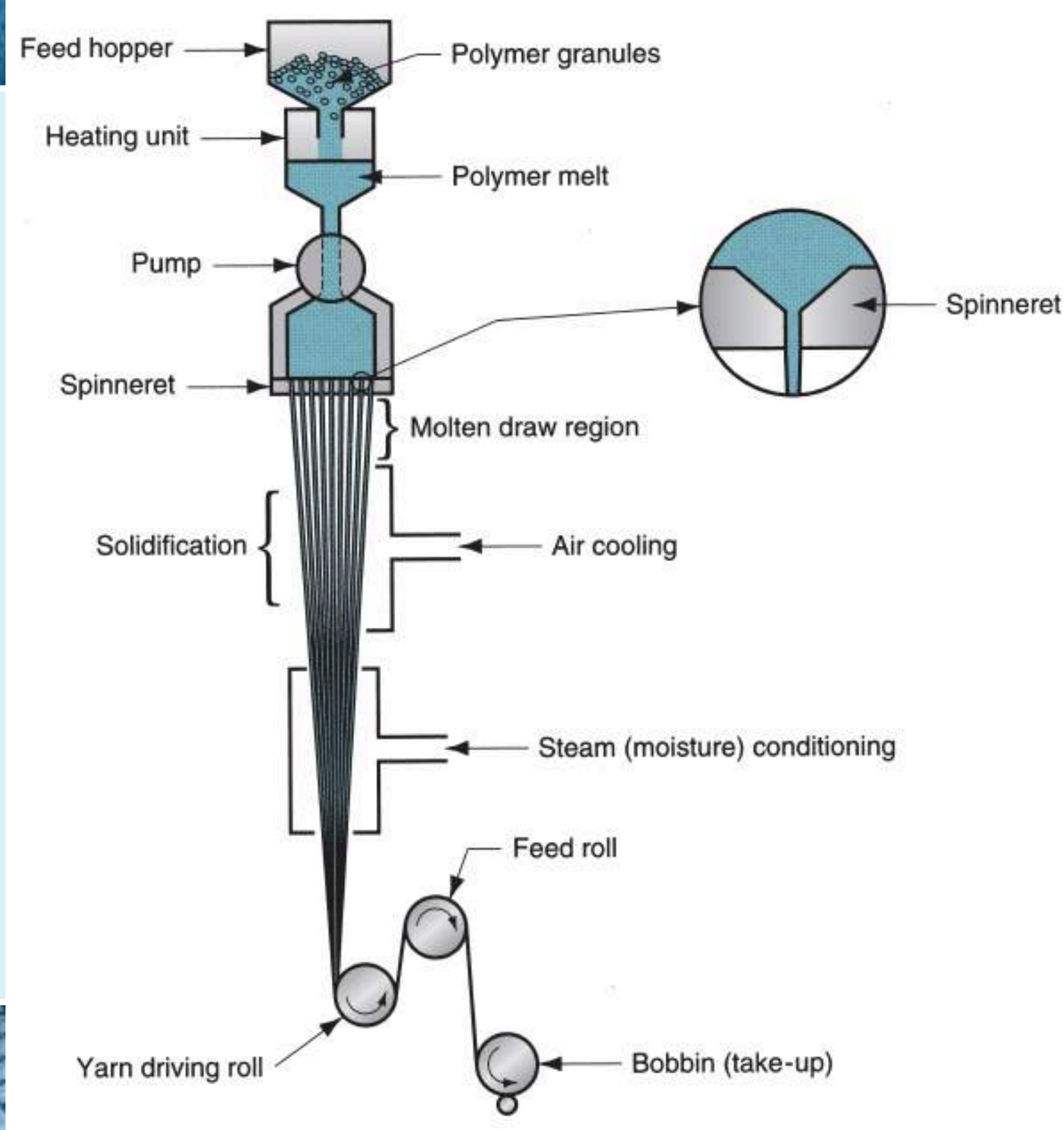


Calendering

FIBER AND FILAMENT PRODUCTION (SPINNING)

- A fiber can be defined as a long, thin strand of material whose length is finite. A filament is a strand of continuous length.
- Fibers can be natural or synthetic. Synthetic fibers constitute about 75% of the total fiber market today, polyester being the most important, followed by nylon, acrylics, and rayon. Natural fibers are about 25% of the total produced.
- The term spinning is a holdover from the methods used to draw and twist natural fibers into yarn or thread.
- In the production of synthetic fibers, the term refers to the process of extruding a polymer melt or solution through a spinneret (a die with multiple small holes) to make filaments that are then drawn and wound onto a bobbin.
- There are three principal variations in the spinning of synthetic fibers, depending on the polymer being processed: (1) melt spinning, (2) dry spinning, and (3) wet spinning.

Melt spinning of continuous filaments



Injection Molding

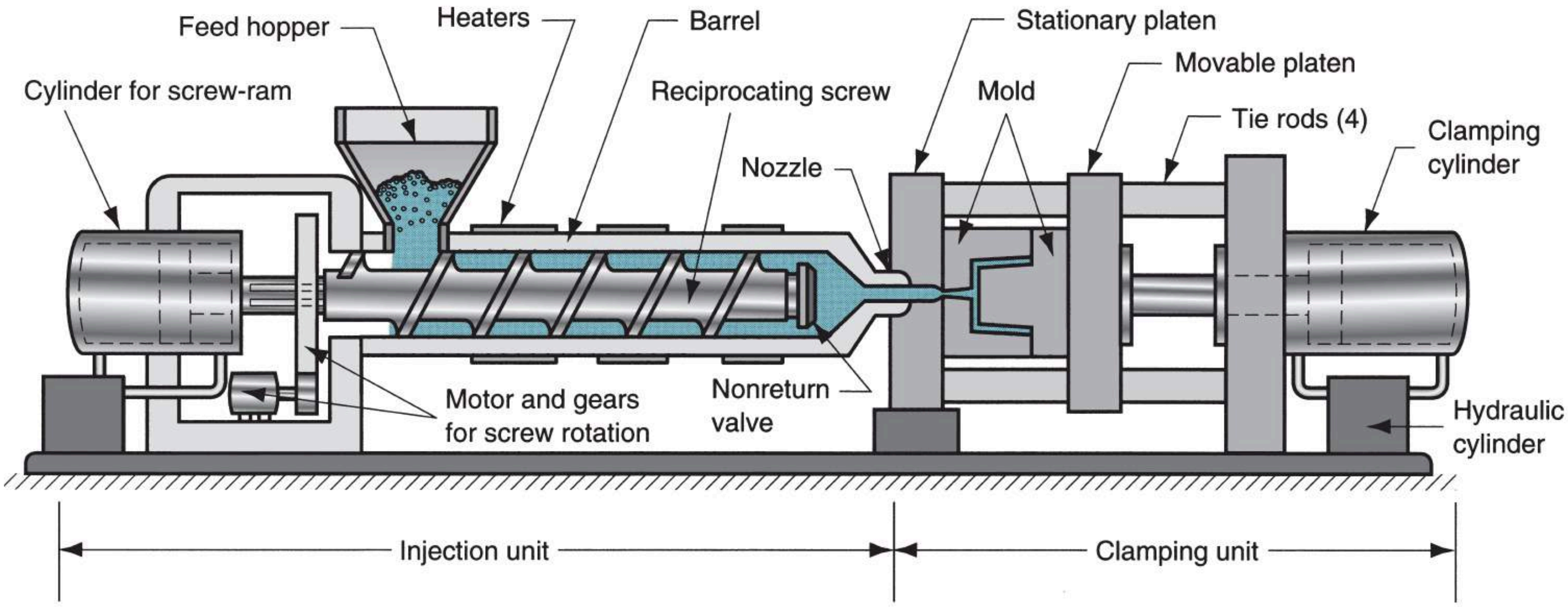


FIGURE 8.20 Diagram of an injection molding machine, reciprocating screw type (some mechanical details are simplified). (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Molds for Polymers

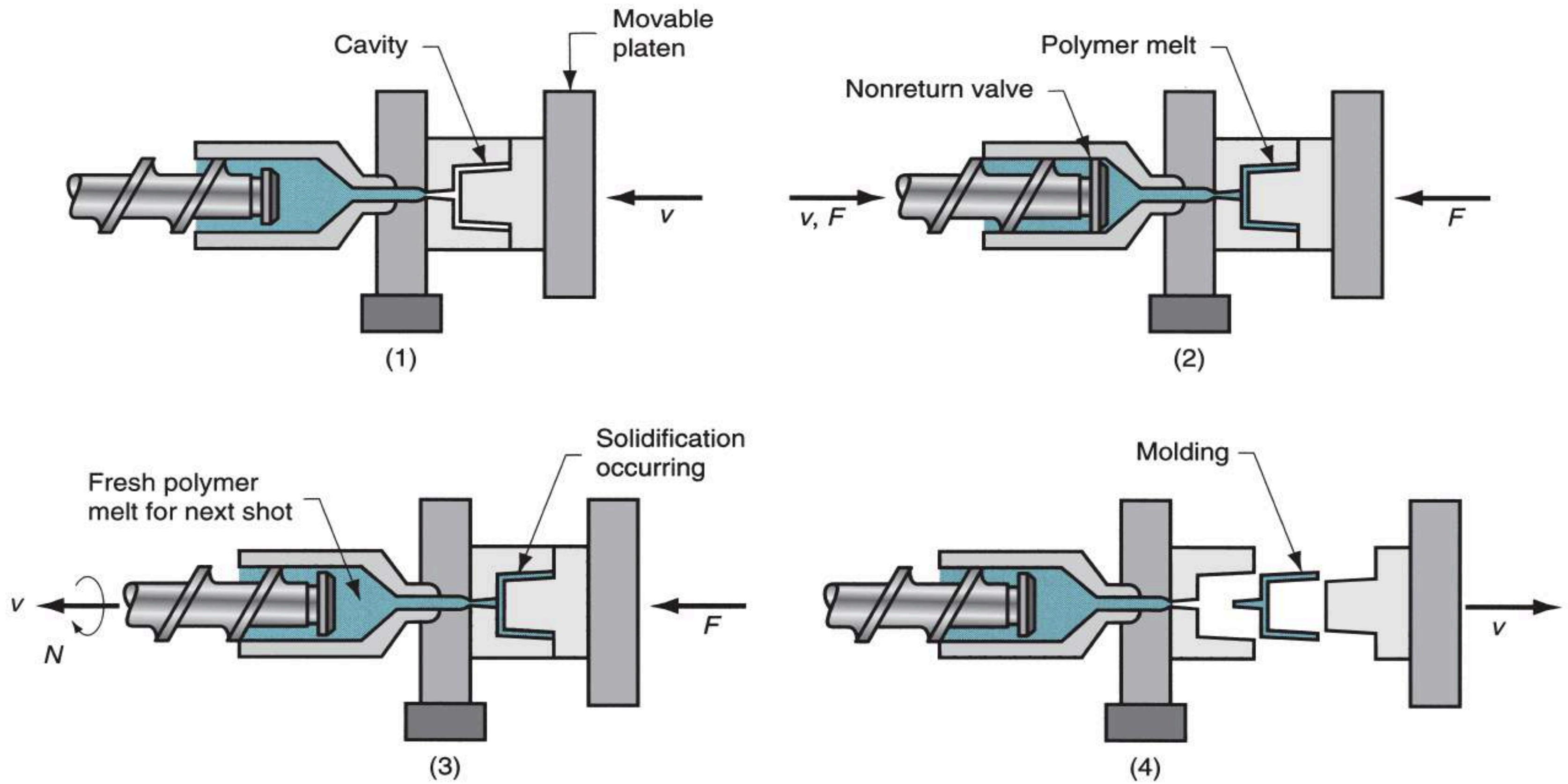


FIGURE 8.21 Typical molding cycle: (1) mold is closed, (2) melt is injected into cavity, (3) screw is retracted, and (4) mold opens, and part is ejected. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Compression Molding

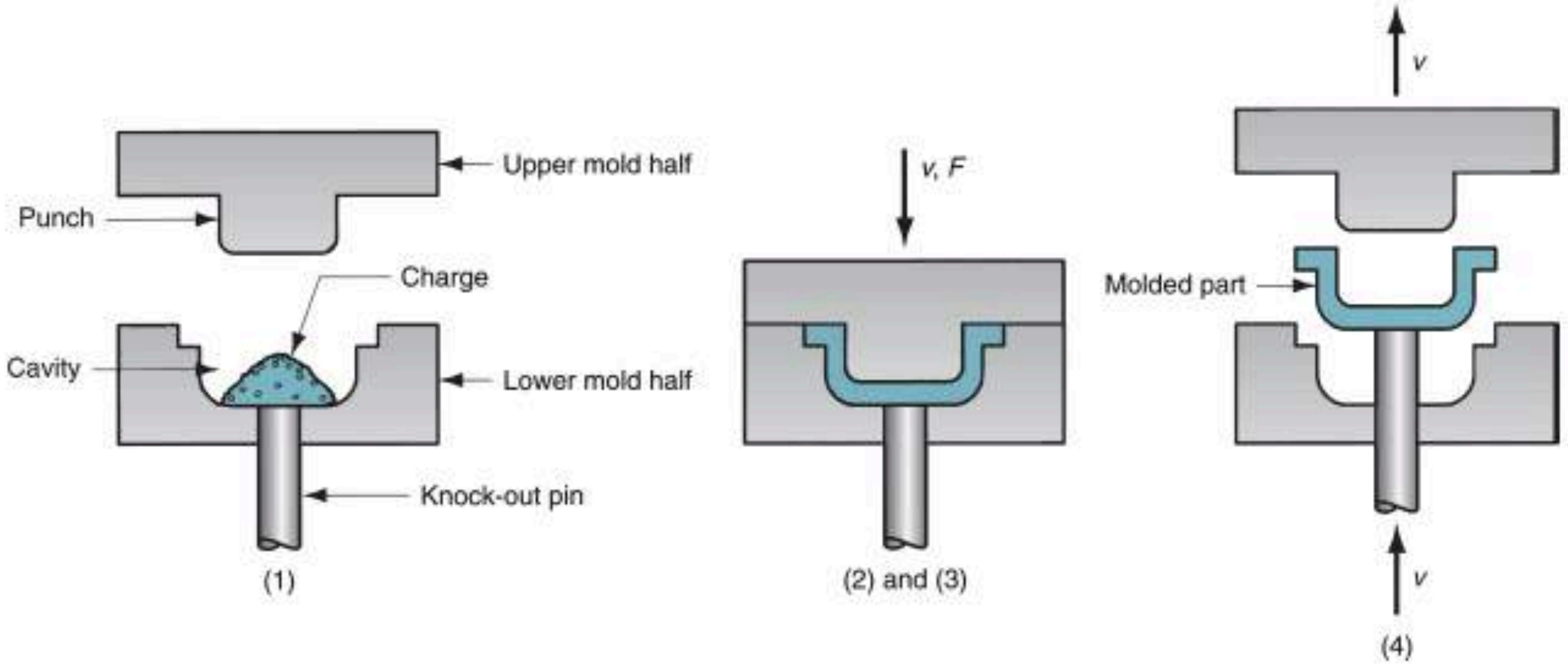


FIGURE 8.25 Compression molding for thermosetting plastics: (1) charge is loaded; (2) and (3) charge is compressed and cured; and (4) part is ejected and removed (some details omitted). (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Extrusion Blow Molding

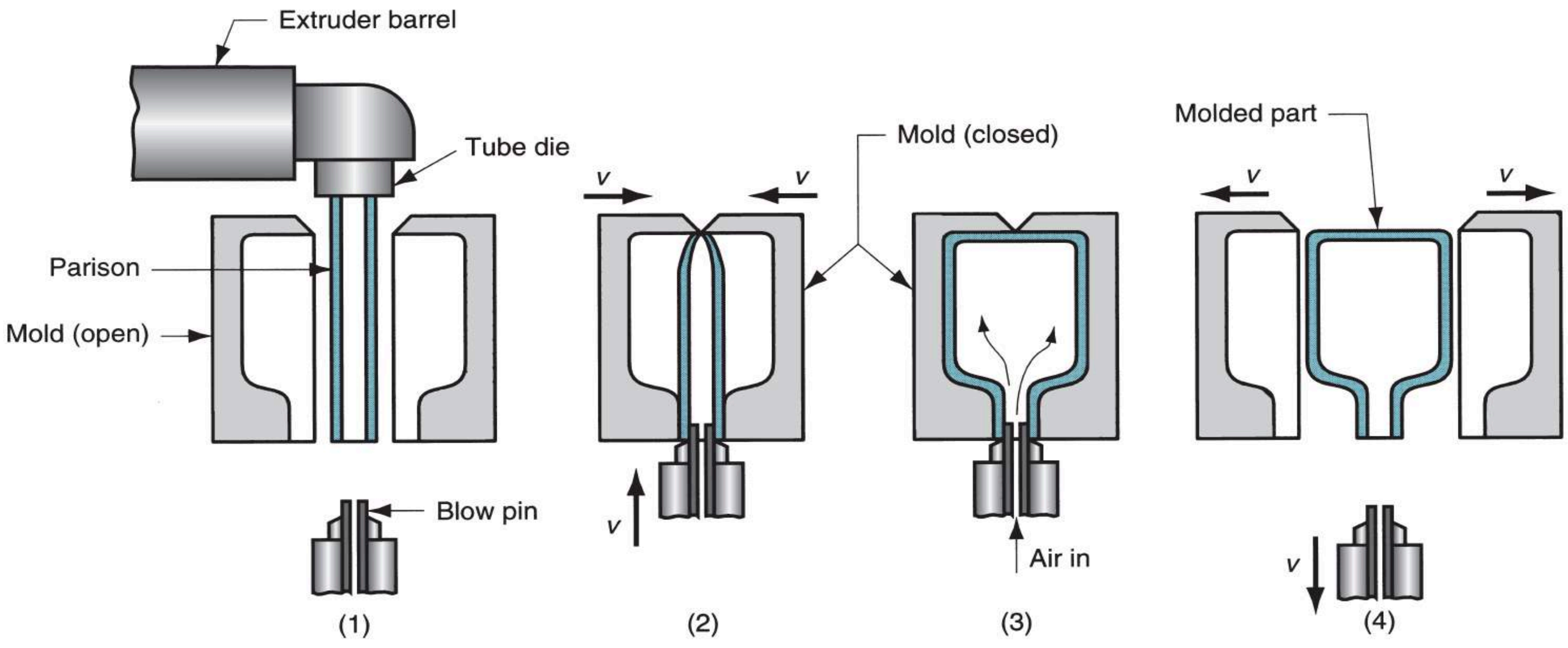


FIGURE 8.27 Extrusion blow molding: (1) extrusion of parison; (2) parison is pinched at the top and sealed at the bottom around a metal blow pin as the two halves of the mold come together; (3) the tube is inflated so that it takes the shape of the mold cavity; and (4) mold is opened to remove the solidified part. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Injection Blow Molding

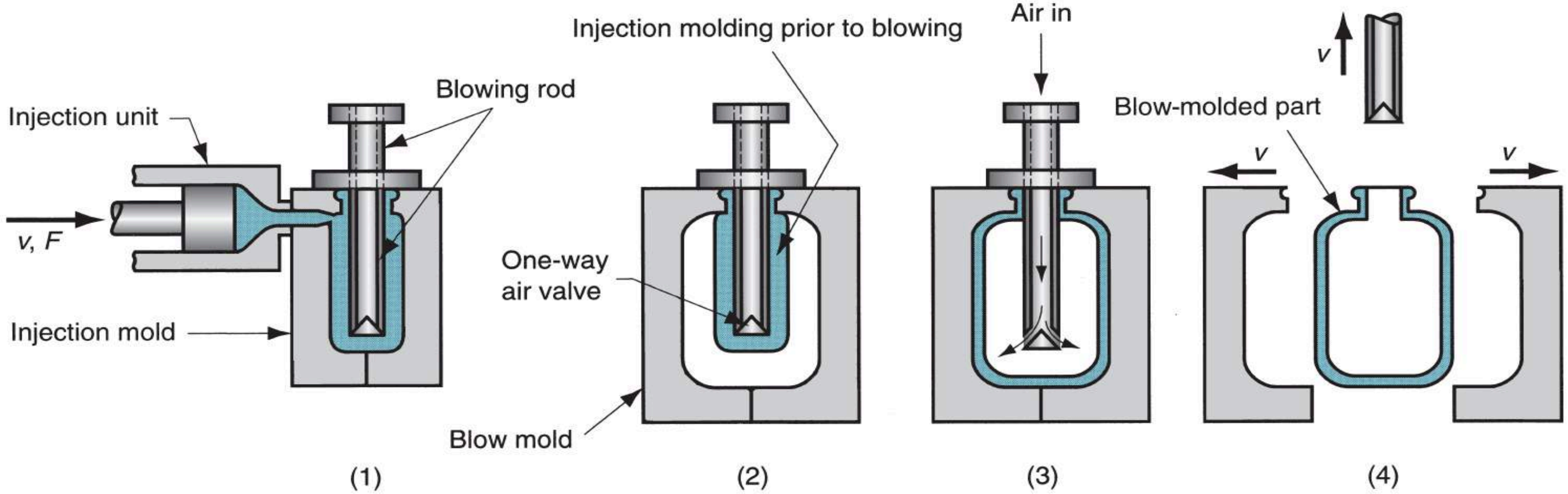


FIGURE 8.29 Injection blow molding: (1) parison is injected molded around a blowing rod; (2) injection mold is opened and parison is transferred to a blow mold; (3) soft polymer is inflated to conform to the blow mold; and (4) blow mold is opened, and blown product is removed. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

THERMOFORMING

(1) Vacuum thermoforming,
(2) pressure thermoforming, and
(3) mechanical thermoforming

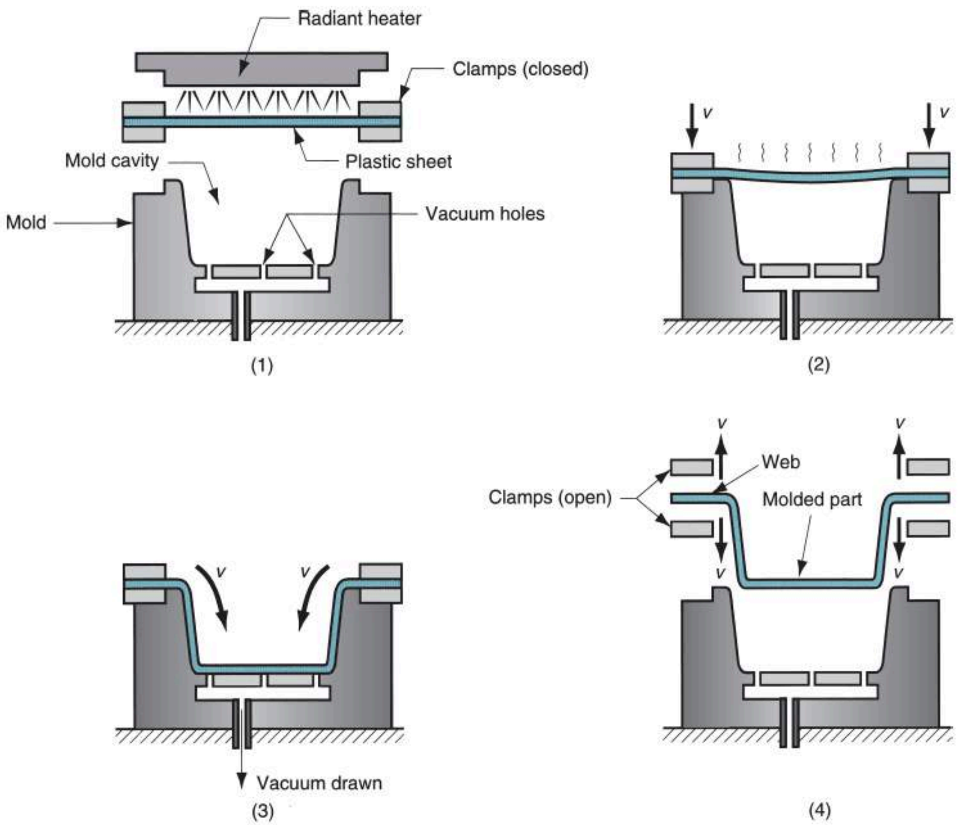


FIGURE 8.32 Vacuum thermoforming: (1) a flat plastic sheet is softened by heating; (2) the softened sheet is placed over a concave mold cavity; (3) a vacuum draws the sheet into the cavity; and (4) the plastic hardens on contact with the cold mold surface, and the part is removed and subsequently trimmed from the web. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

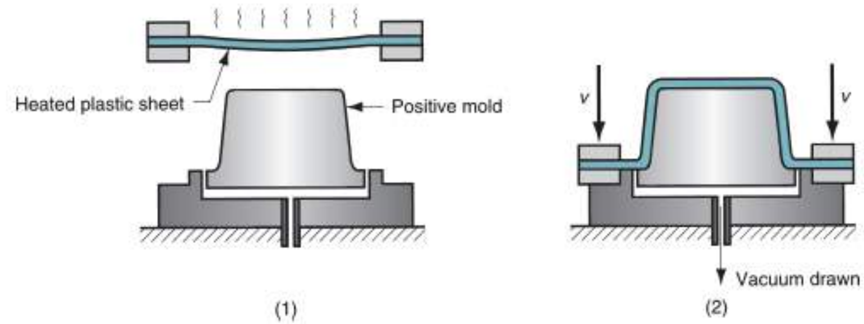


FIGURE 8.34 Use of a positive mold in vacuum thermoforming: (1) the heated plastic sheet is positioned above the convex mold and (2) the clamp is lowered into position, draping the sheet over the mold as a vacuum forces the sheet against the mold surface. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

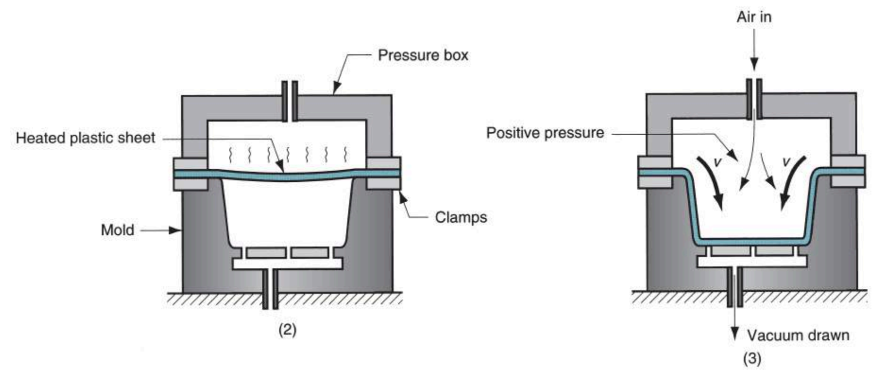
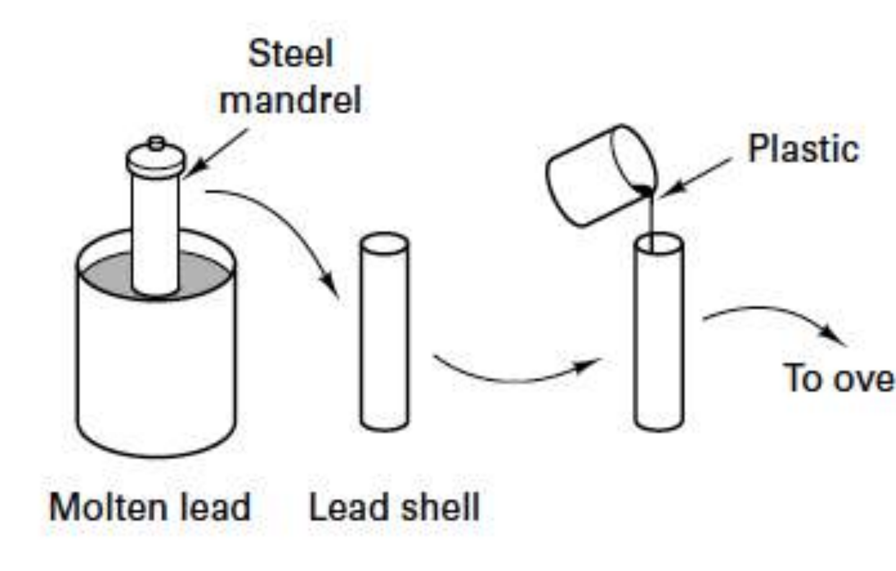


FIGURE 8.33 Pressure thermoforming. The sequence is similar to the previous figure, the difference being: (2) sheet is placed over a mold cavity; and (3) positive pressure forces the sheet into the cavity. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Casting Polymers



- Casting is the simplest of the shape forming processes because no fillers are used and no pressure is required.
- While not all plastics can be cast, there are a number of castable thermoplastics, including acrylics, nylons, urethanes, and PVC plastisols.
- The thermoplastic polymer is simply melted, and the liquid is poured into a container having the shape of the desired part.
- Some thermosets (such as phenolics, polyesters, epoxies, silicones, and urethanes) can also be cast, as well as any resin that will polymerize at low temperatures and atmospheric pressure. Because of the need for curing, the casting of thermoset resins usually involves additional processing, often some form of heating while in the mold.

Typical Tolerances of Molded Plastic Parts

TABLE 8.2 Typical tolerances on molded parts for selected plastics.

	Tolerances for:[a]			Tolerances for:[a]	
Plastic	**50-mm dimension**	**10-mm hole**	**Plastic**	**50-mm dimension**	**10-mm hole**
Thermoplastic:			Thermosetting:		
ABS	±0.2 mm (±0.007 in)	±0.08 mm (±0.003 in)	Epoxies	±0.15 mm (±0.006 in)	±0.05 mm (±0.002 in)
Polyethylene	±0.3 mm (±0.010 in)	±0.13 mm (±0.005 in)	Phenolics	±0.2 mm (±0.008 in)	±0.08 mm (±0.003 in)
Polystyrene	±0.15 mm (±0.006 in)	±0.1 mm (±0.004 in)			

Values represent typical commercial molding practice. Compiled from [3], [7], [14], and [19].
[a]For smaller sizes, tolerances can be reduced. For larger sizes, more generous tolerances are required.

PROCESSING OF RUBBER AND ELASTOMERS

DIPPING

Relatively thin parts with uniform wall thickness, such as boots, gloves, and fairings, are often made by some form of dipping.

1. Amaster form (metal) is first produced
2. The form is then immersed into a liquid preparation or compound (usually based on natural rubber or latex, neoprene, or silicone)
3. It is removed and allowed to dry. With each dip, a certain amount of the liquid adheres to the surface, with repeated dips being used to produce a final desired thickness.
4. Vulcanization, usually in steam
5. Products are stripped from the molds.

The dipping process can be accelerated by using electrostatic charges. The attraction and neutralization of the opposite charges causes the elastomeric particles to be deposited on the form at a faster rate and in thicker layers than the basic process. With electrostatic deposition, many products can be made in a single immersion.

Dipping Video

PROCESSING OF RUBBER AND ELASTOMERS

- When the parts are thicker or are complex in shape, the first step is the compounding of elastomeric resin, vulcanizers, fillers, antioxidants, accelerators, and pigments.
- This is usually done in some form of mixer, which blends the components to form a homogeneous mass. Adaptations of the processes previously discussed for plastics are frequently used to produce the desired shapes. Injection, compression, and transfer molding are used, along with special techniques for foaming. Urethanes and silicones can also be directly cast to shape.

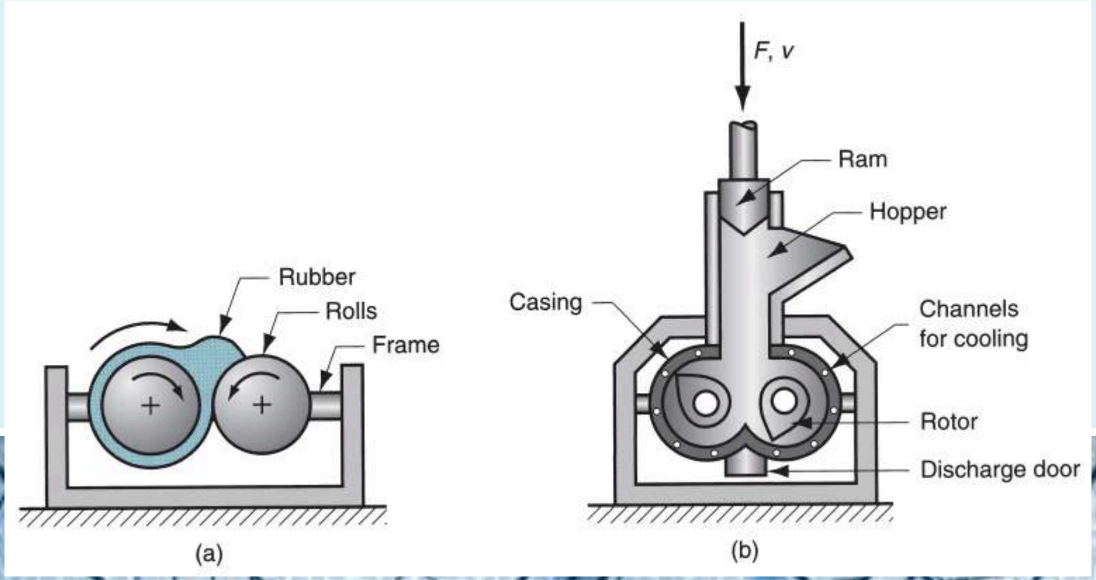


FIGURE 9.2 Roller die process: rubber extrusion followed by rolling. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

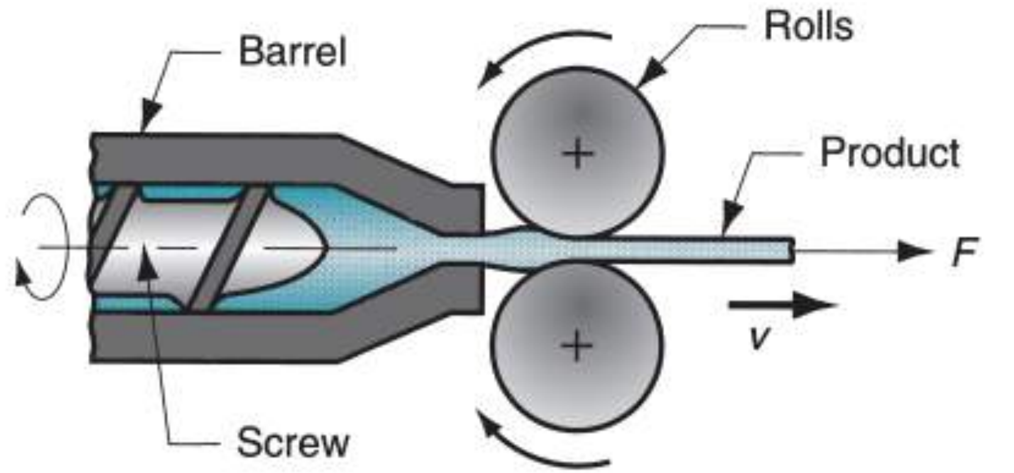
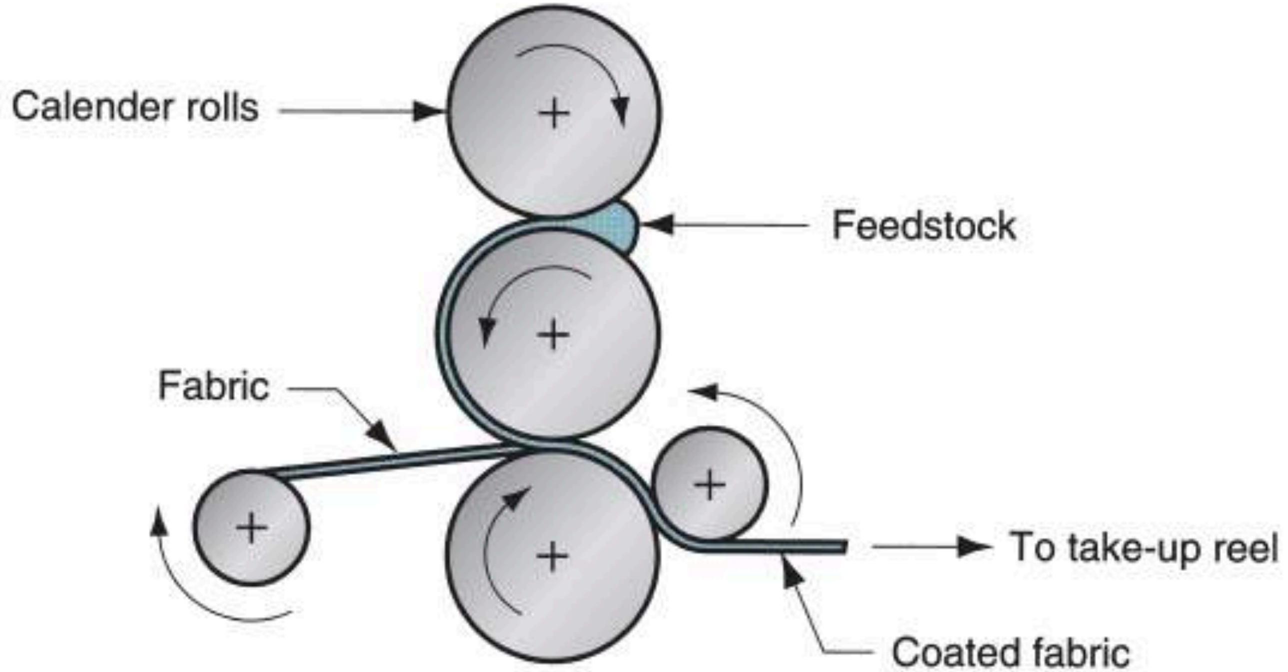


FIGURE 9.3 Coating of fabric with rubber using a calendering process. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



- https://www.youtube.com/watch?v=outx807C7QI

Home Work #3 – Fabrication of Plastics

- Answer questions from class #2 applied to Thermoplastic materials in group of 2 students. (x 26th August)
- Local Suppliers of Plastic (raw material) in your home country with cost per volume.