19.2 Extrusion

In *extrusion*, which produces the largest volume of plastics, raw materials in the form of thermoplastic pellets, granules, or powder are placed into a *hopper* and fed into the barrel of a *screw extruder* (Fig. 19.2). The barrel is equipped with a helical screw, which builds up pressure in the barrel, blends the pellets, and conveys them down the barrel toward the die. The barrel heaters and the internal friction from the mechanical action of the screw heat the pellets and liquify them.

Screws have three distinct sections:

1. *Feed section*: Conveys the material from the hopper into the central region of the barrel

2. *Melt section*, also called *compression* or *transition section*: Where the heat generated by the viscous shearing of the plastic pellets and by the external heaters around the barrel cause melting to begin
3. *Metering* or *pumping section*: Where additional shearing and melting occur, with pressure building up at the die entrance

The lengths of these individual sections can be changed to accommodate the melting characteristics of different types of plastics. A metal-wire filter screen (Fig. 19.2a) usually is placed just before the die, to filter out unmelted or congealed resin. This screen, which is replaced periodically, also causes back pressure in the barrel, which needs to be overcome by the extruder screw. Between the screen and the die is a *breaker plate*, which has several small holes in it and helps improve mixing of the polymer prior to its entering the die. The extruded product is cooled, generally by exposing it to blowing air or by passing it through a water-filled channel (trough).

Controlling the rate and uniformity of cooling is important in extruding, in order to minimize product shrinkage and distortion. In addition to single-screw extruders, other designs include *twin* (two parallel screws side by side) and *multiple screws*, for polymers that are difficult to extrude (see also *reciprocating screw*, Section 19.3).

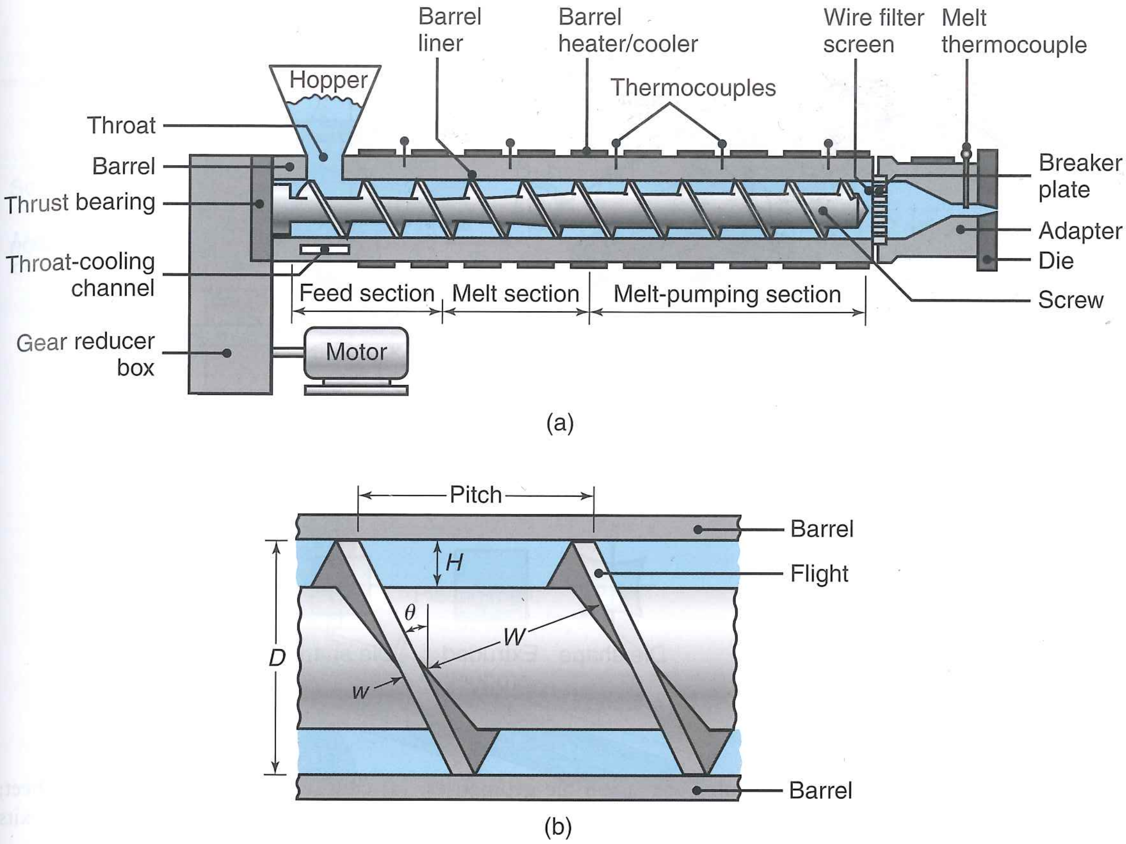

FIGURE 19.2 (a) Schematic illustration of a typical screw extruder. (b) Geometry of an extruder screw. Complex shapes can be extruded with relatively simple and inexpensive dies.

A typical helical screw is shown in Fig. 19.2b, indicating the important parameters that affect the mechanics of polymer extrusion. At any point in time, the molten plastic is in the shape of a helical ribbon, with thickness H and width W, and is conveyed toward the extruder outlet by the rotating screw *flights*. The shape, pitch, and flight angle of the helical screw are important parameters, as they affect the flow of the polymer through the extruder. The ratio of the barrel length, L, to its diameter, D, is also important. In typical commercial extruders, the L/D ratio ranges from 5 to 30, and barrel diameters generally are in the range from 25 to 200 mm.

Process Characteristics. Because there is a continuous supply of raw material from the hopper, long products such as solid rods, sections, channels, sheet, tubing, pipe, and architectural components can be extruded continuously by extrusion. Complex shapes with constant cross-sections also can be extruded with relatively inexpensive tooling. Some common die profiles are shown in Fig. 19.3b. Polymers usually undergo much greater and uneven shape recovery than is encountered in metal extrusion. Since the polymer will *swell* at the exit of the die, the openings shown in Figs. 19.3b and c are smaller than the extruded cross-sections. After it has cooled, the extruded product may subsequently be drawn (*sized*) by a puller and coiled or cut into desired lengths.

The control of processing parameters, such as extruder-screw rotational speed, barrel-wall temperatures, die design, and rate of cooling, and drawing speeds are all important, in order to ensure product integrity and uniform dimensional accuracy. *Defects* observed in extruding plastics are similar to those observed in metal

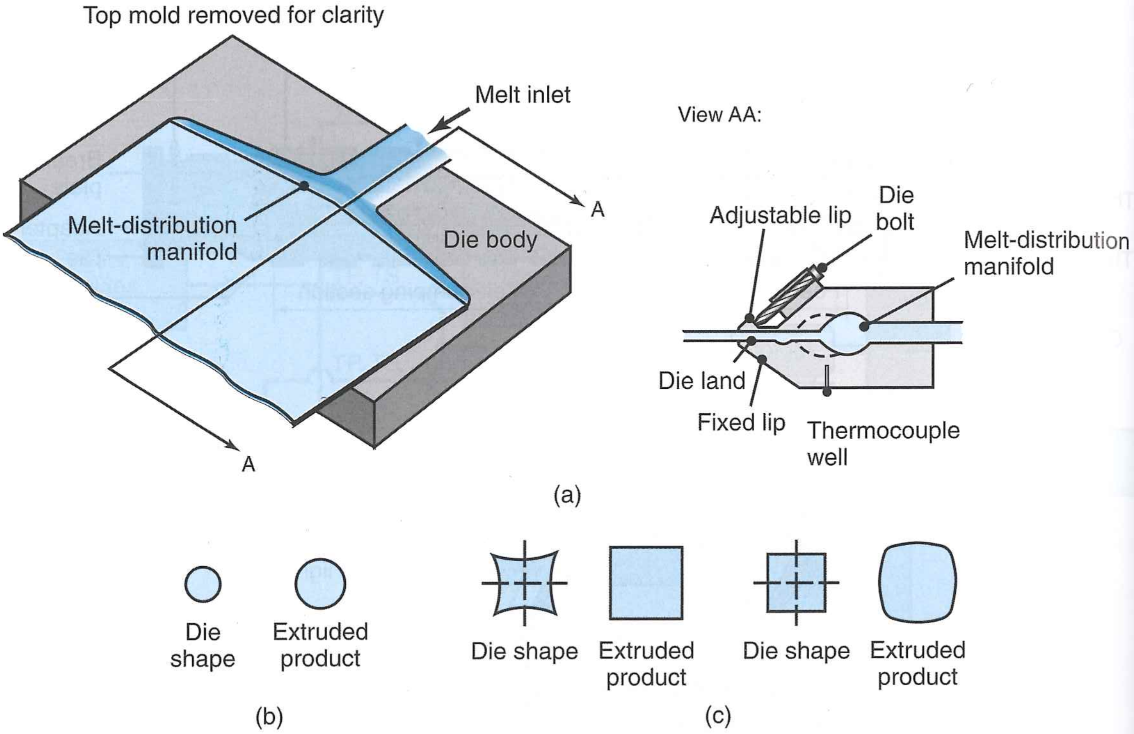

FIGURE 19.3 Common extrusion die geometries: (a) coat-hanger die for extruding sheet; (b) round die for producing rods; and (c) and (d) nonuniform recovery of the part after it exits the die.

extrusion, described in Section 15.5. Die shape is important, as it can induce high stresses in the product, causing it to develop surface fractures, as also occur with metals. Other surface defects are *bambooing* and *sharkskin defects*, due to a combination of friction at the die–polymer interfaces, elastic recovery, and nonuniform deformation of the outer layers of the product with respect to its bulk during extrusion.

Extruders generally are rated by the diameter, D, of the barrel and the length-to-diameter (L/D) ratio of the barrel. Machinery costs can be on the order of \$300,000, including the cost for the equipment for downstream cooling and winding of the extruded product.

19.2.1 Miscellaneous Extrusion Processes

There are several variations of the basic extrusion process for producing a number of different polymer products.

Plastic Tubes and Pipes. These are produced in an extruder with a *spider die*, as shown in Fig. 19.4a (see also Fig. 15.8 for details). Woven fiber or wire reinforcements also may be fed through specially designed dies in this operation, for the production of reinforced products to withstand higher pressures, such as garden hose. The extrusion of tubes is also a first step for related processes, such as extrusion blow molding and blown film.

Rigid Plastic Tubing. Extruded by a process in which the die is *rotated*, rigid plastic tubing causes the polymer to be sheared and biaxially oriented during extrusion. As a result, the tube has a higher crushing strength and a higher strength-to-weight ratio than conventionally extruded tubing.

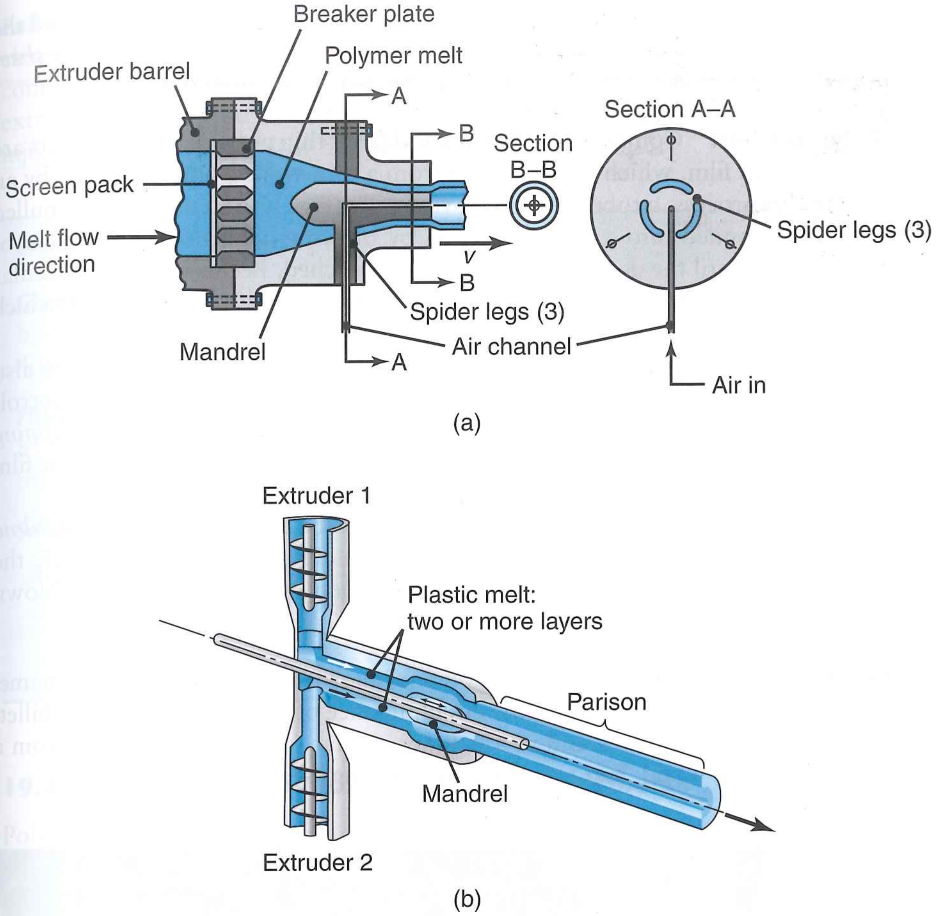

FIGURE 19.4 Extrusion of tubes. (a) Extrusion using a spider die (see also Fig. 15.8) and pressurized air. (b) Coextrusion for producing a parison for a plastic bottle.

Coextrusion. Shown in Fig. 19.4b, coextrusion involves simultaneous extrusion of two or more polymers through a single die; the product cross-section thus contains different polymers, each with its own characteristics and function. Coextrusion is commonly performed in shapes such as flat sheets, films, and tubes, and used especially in food packaging where different layers of polymers have different functions. These are: (a) providing inertness for food, (b) serving as barriers to fluids, such as water or oil, and (c) labeling of the product.

Plastic-coated Electrical Wire. Electrical wire, cable, and strips are simultaneously extruded and coated with plastic. The wire is fed into the die opening, at a controlled rate with the extruded plastic, in order to have a uniform coating on the wire. To ensure proper insulation, extruded electrical wires are checked continuously for their electrical resistance as they exit the die; the wire is also marked with ink using a roller to identify the specific type of wire. Plastic-coated wire *paper clips* also are made by this coating process.

Polymer Sheets and Films. Sheet and film can be produced by using a specially designed flat extrusion die, such as that shown in Fig. 19.3a. Also known as a *coat-hanger die*, it is designed to distribute the polymer melt evenly throughout the width of the die opening. The polymer is extruded by forcing it through the die, after which the extruded sheet is taken up by rolls, first on water-cooled rolls (to cool the sheets), and then by a pair of rubber-covered pull-off rolls. Generally, polymer *sheet* is considered to be thicker than 0.5 mm, and *film* is thinner than 0.5 mm.