19.2.2 Production of Polymer Reinforcing Fibers

Polymer fibers have numerous important applications. In addition to their use as reinforcement in composite materials, these fibers are used in a wide variety of consumer and industrial products, including clothing, carpeting, fabrics, rope, and packaging tape.

Most synthetic fibers used in reinforced plastics are polymers, extruded through tiny holes of a device called a *spinneret* (resembling a shower head), to form continuous filaments of semisolid polymer. The extruder forces the polymer through the spinneret, which may have from one to several hundred holes. If the polymers are thermoplastics, they first are melted in the extruder, as described in Section 19.2. Thermosetting polymers also can be formed into fibers, by first dissolving or chemically treating them so that they can be extruded. These operations are performed at high production rates and with very high reliability.

As the filaments emerge from the holes in the spinneret, the liquid polymer is first converted to a rubbery state, and then it solidifies. This process of extrusion and solidification of continuous filaments is called **spinning**, a term also used for the production of natural textiles, such as cotton or wool. There are four methods of spinning fibers: melt, wet, dry, and gel spinning.

1. In **melt spinning** (Fig. 19.6), the polymer melt is extruded through the spinneret and then solidified directly by cooling. A typical spinneret for this operation is around

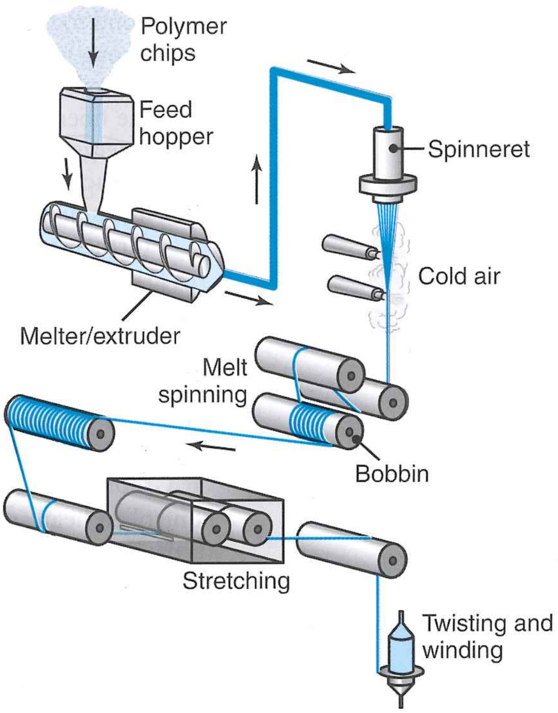

FIGURE 19.6 The melt-spinning process for producing polymer fibers, used in a variety of applications, including fabrics and as reinforcements for composite materials; in the stretching box, the right roll rotates faster than the left roll.

5 mm thick and has about 50 holes, about 0.25 mm in diameter. The fibers that emerge from the spinneret are cooled by forced-air convection, and are simultaneously pulled, so that their final diameter becomes much smaller than the spinneret opening. Polymers such as nylon, olefin, polyester, and PVC are produced in this manner.

Melt-spun fibers also can be extruded from the spinneret in various other cross-sections, such as trilobal (a triangle with curved sides), pentagonal, octagonal, and hollow shapes. Hollow fibers trap air, and thus provide additional thermal insulation.

2. **Wet spinning**, the oldest process for fiber production, is used for polymers that have been dissolved in a solvent, by submerging the spinnerets in a chemical bath. As the filaments emerge, they precipitate in the bath, producing a fiber that is then wound onto a *bobbin* (*spool*). The term "wet" refers to the use of a precipitating liquid bath, resulting in wet fibers, that require drying before they can be used. Acrylic, rayon, and aramid fibers are produced by this process.
3. **Dry spinning** is used for thermosets that are dissolved by a fluid. Instead of precipitating the polymer by dilution, as in wet spinning, solidification is achieved by evaporating the solvent fluid in a stream of air or inert gas. Thus, the filaments do not come in contact with a precipitating liquid, eliminating the need for drying. Dry spinning is used for the production of acetate, triacetate, polyether-based elastane, and acrylic fibers.
4. **Gel spinning** is a special process, used to obtain high strength or special fiber properties. Some polyethylene and aramid fibers are produced by gel spinning. The polymer is not melted completely, or dissolved in a liquid, but the molecules bond together at various points in liquid-crystal form. This operation produces strong interchain forces in the resulting filaments, that can significantly increase the tensile strength of the fibers. Moreover, the liquid crystals are aligned along the fiber axis, by the strain encountered during extrusion. Thus, the filaments emerge from the spinneret with an unusually high degree of orientation relative to each other, further enhancing their strength. This process is also called *dry wet spinning*, because the filaments first pass through air and are then cooled further in a liquid bath.

A necessary step in the production of most fibers is the application of significant *stretching*, to induce orientation of the polymer molecules in the fiber direction. This orientation is the main reason for the high strength of the fibers, as compared with the polymer in bulk form. The stretching can be done while the polymer is still pliable (just after extrusion from the spinneret) or it can be performed as a cold-drawing operation. The strain induced can be as high as 800%.

Graphite fibers are produced from polymer fibers by *pyrolysis*. In this operation, controlled heat, in the range from 1500° to 3000°C, is applied to the polymer fiber (typically polyacrylonitrile, PAN) to drive off all elements except the carbon. The fiber is under tension in order to develop a high degree of orientation in the resulting fiber structure. (See also Section 9.2.1 on the properties of graphite fibers and other details.)