Lecture 6

6-1 Manufacturing Fibers and Composite

Producing a fiber-reinforced composite involves several steps, including producing the fibers, arranging the fibers into bundles or fabrics, and introducing the fibers into the matrix.

Making the Fiber Metallic fibers, glass fibers, and many polymer fibers (including nylon, aramid, and polyacrylonitrile) can be formed by drawing processes, as described in Chapter 8 (wire drawing of metal) and Chapter 16 (using the spinnerette for polymer fibers). Boron, carbon, and ceramics are too brittle and reactive to be worked by conventional drawing processes. Boron fiber is produced by chemical vapor deposition (CVD) **[Figure 17-17(a)].** A very fine, heated tungsten filament is used as a substrate, passing through a seal into a heated chamber. Vaporized boron compounds such as BCl3 are introduced into the chamber, decompose, and permit boron to precipitate onto the tungsten wire (Figure 17-18). SiC fibers are made in a similar manner, with carbon fibers as the substrate for the vapor deposition of silicon carbide.

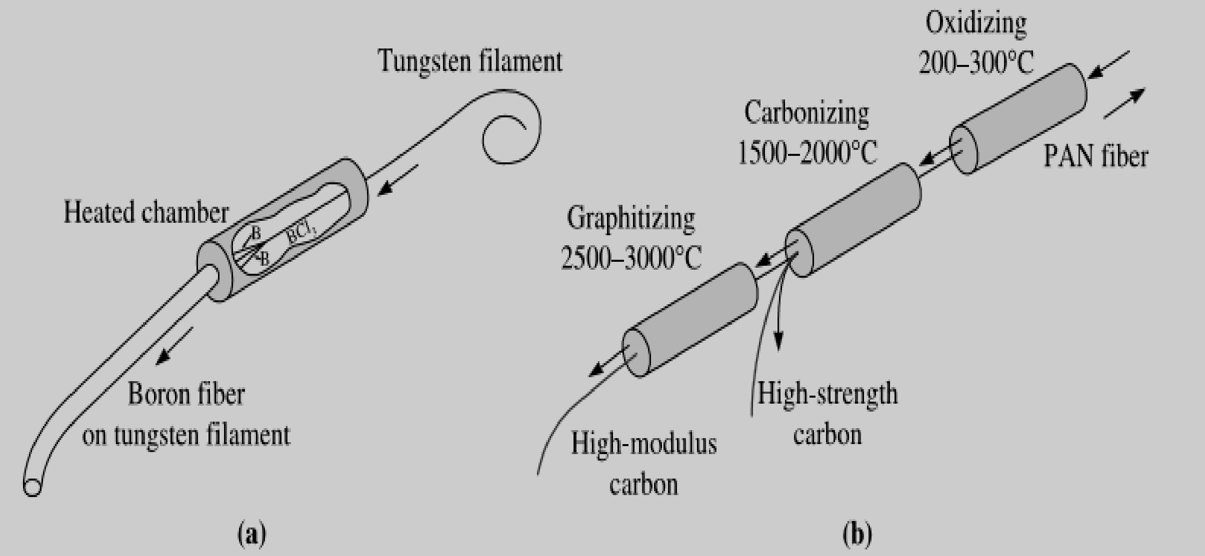
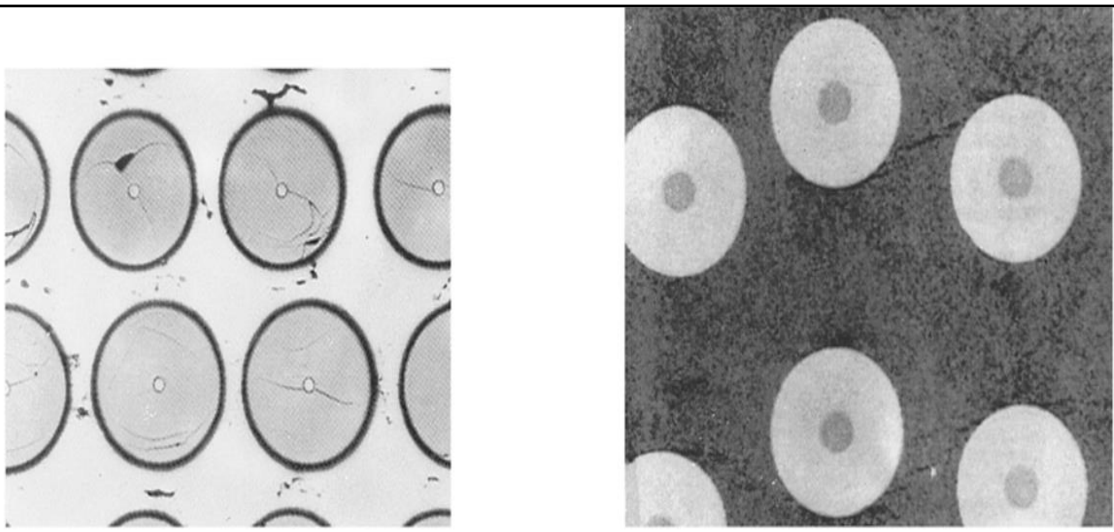


Figure 17-17 Methods for producing (a) boron and (b) carbon fibers.

Carbon fibers are made by carbonizing, or pyrolizing, an organic filament, which is more easily drawn or spun into thin, continuous lengths [Figure 17-17(b)]. The organic filament, known as a precursor, is often rayon (a cellulosic polymer), polyacrylonitrile (PAN), or pitch (various aromatic organic compounds). High temperatures decompose the organic polymer, driving o¤ all of the elements but carbon. As the carbonizing temperature increases from 1000 C to 3000 C, the tensile strength decreases while the modulus of elasticity increases (Figure 17-19 on the next page). Drawing the carbon filaments at critical times during carbonizing may produce desirable preferred orientations in the final carbon filament.

Whiskers are single crystals with aspect ratios of 20 to 1000. Because the whiskers contain no mobile dislocations, slip cannot occur and they have exceptionally high strengths. Because of the complex processing required to produce whiskers, their cost may be quite high.



(a) (b)

Figure 17-18 Photomicrographs of two fiber-reinforced composites: (a) In Borsic fiber-reinforced aluminum, the fibers are composed of a thick layer of boron deposited on a small-diameter tungsten filament (×1000). (*From* Metals Handbook, *American Society for Metals, Vol. 9, 9th Ed., 1985.*) (b) In this microstructure of a ceramic-fiber–ceramic-matrix composite, silicon carbide fibers are used to reinforce a silicon nitride matrix. The SiC fiber is vapor-deposited on a small carbon precursor filament (×125). (*Courtesy of Dr. R.T. Bhatt, NASA*

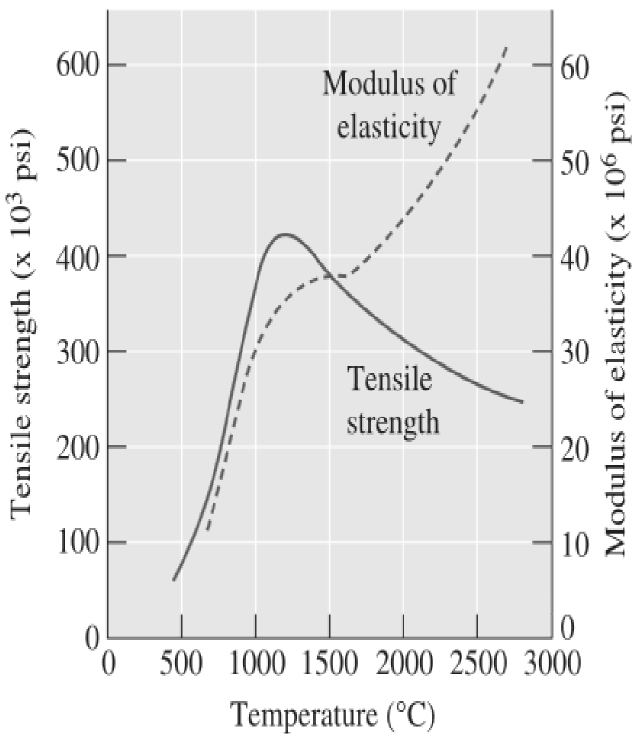


Figure 17-19
The effect of heat-treatment temperature on the strength and modulus of elasticity of carbon fibers.

Arranging the Fibers Exceptionally fine filaments are bundled together as rovings, yarns, or tows. In yarns, as many as 10,000 filaments are twisted together to produce the fiber. A tow contains a few hundred to more than 100,000 untwisted filaments (Figure 17-20).

Rovings are untwisted bundles of filaments, yarns, or tows. Often, fibers are chopped into short lengths of 1 cm or less. These fibers, also called staples, are easily incorporated into the matrix and are typical of the sheet-molding and bulk-molding compounds for polymer-matrix composites. The fibers often are present in the composite in a random orientation.

Long or continuous fibers for polymer-matrix composites can be processed into mats or fabrics. Mats contain non-woven, randomly oriented fibers loosely held together by a polymer resin. The fibers can also be woven, braided, or knitted into two dimensional or three-dimensional fabrics. The fabrics are then impregnated with a polymer resin. The resins at this point in the processing have not yet been completely polymerized; these mats or fabrics are called prepregs.

When unidirectionally aligned fibers are to be introduced into a polymer matrix, tapes may be produced. Individual fibers can be unwound from spools onto a mandrel, which determines the spacing of the individual fibers, and prepregged with a polymer resin. These tapes, only one fiber diameter thick, may be up to 48 in. wide. **Figure 17-21** illustrates that **tapes** can also be produced by covering the fibers with upper and lower layers of metal foil that are then joined by diffusion bonding.

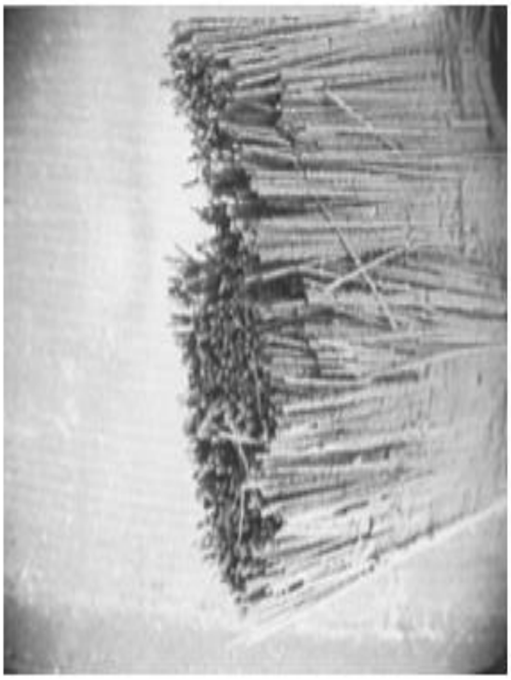


Figure 17-20
A scanning electron micrograph of a carbon tow containing many individual carbon filaments (×200).

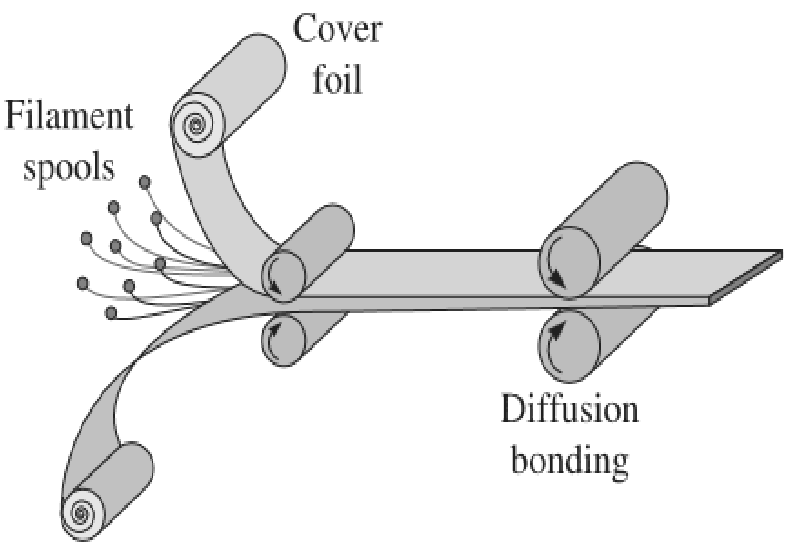


Figure 17-21
Production of fiber tapes by encasing fibers between metal cover sheets by diffusion bonding.

Producing the Composite A variety of methods for producing composite parts are used, depending on the application and materials. Short fiber-reinforced composites are normally formed by mixing the fibers with a liquid or plastic matrix, then using relatively conventional techniques such as injection molding for polymer-base composites or casting for metal-matrix composites. Polymer matrix composites can also be produced by a spray-up method, in which short fibers mixed with a resin are sprayed against a form and cured. Special techniques, however, have been devised for producing composites using continuous fibers, either in unidirectionally aligned, mat, or fabric form (Figure 17-22). In hand lay-up techniques, the tapes, mats, or fabrics are placed against a form, saturated with a polymer resin, rolled to assure good contact and freedom from porosity, and finally cured. Fiberglass car and truck bodies might be made in this manner, which is generally slow and labor intensive.

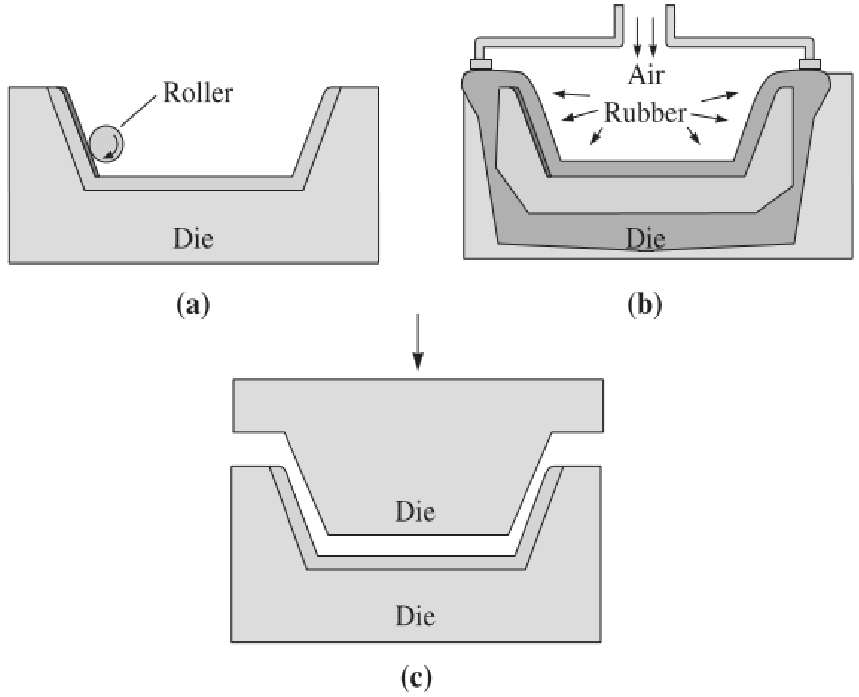


Figure 17-22 Producing composite shapes in dies by (a) hand lay-up, (b) pressure bag molding, and (c) matched die molding.

Tapes and fabrics can also be placed in a die and formed by bag molding. Highpressure gases or a vacuum are introduced to force the individual plies together so that good bonding is achieved during curing. Large polymer matrix components for the skins of military aircraft have been produced by these techniques. In matched die molding, short fibers or mats are placed into a two-part die; when the die is closed, the composite shape is formed.

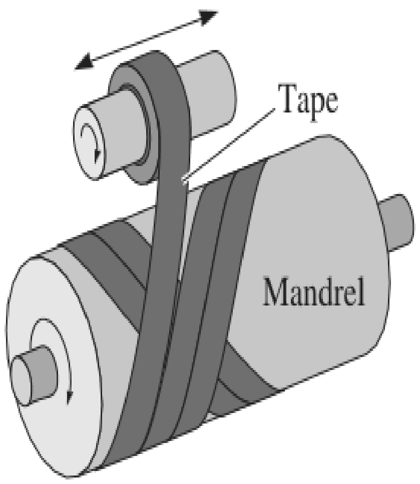


Figure 17-23
Producing composite shapes by filament winding.

Filament winding

Filament winding is used to produce products such as pressure tanks and rocket motor castings (Figure 17-23). Fibers are wrapped around a form or mandrel to gradually build up a hollow shape that may be even several feet in thickness. The filament can be dipped in the polymer-matrix resin prior to winding, or the resin can be impregnated around the fiber during or after winding. Curing completes the production of the composite part.

Pultrusion

Pultrusion is used to form a simple-shaped product with a constant cross section, such as round, rectangular, pipe, plate, or sheet shapes (Figure 17-24). Fibers or mats are drawn from spools, passed through a polymer resin bath for impregnation, and gathered together to produce a particular shape before entering a heated die for curing. Curing of the resin is accomplished almost immediately, so a continuous product is produced. The pultruded stock can subsequently be formed into somewhat more complicated shapes, such as fishing poles, golf club shafts, and ski poles.

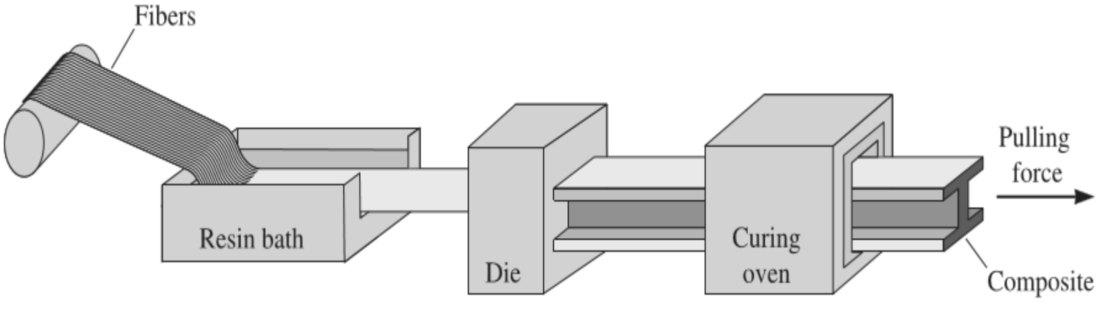


Figure 17-24 Producing composite shapes by pultrusion.

Metal-matrix composites with continuous fibers are more di‰cult to produce than are the polymer-matrix composites. Casting processes that force liquid around the fibers using capillary rise, pressure casting, vacuum infiltration, or continuous casting are used. Various solid-state compaction processes can also be used.