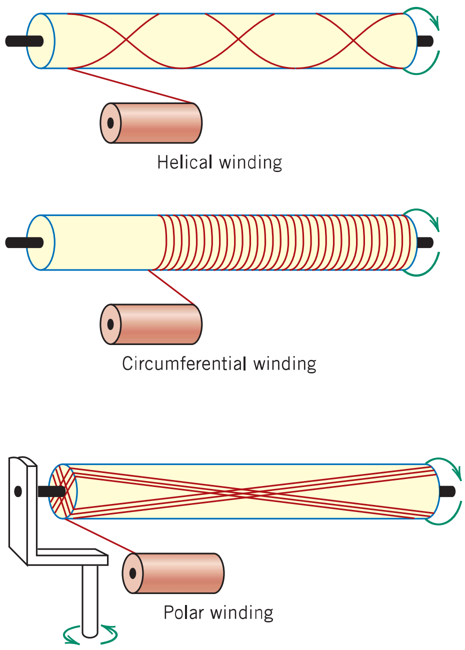

Figure 16.15 Schematic representations of helical, circumferential, and polar filament winding techniques. [From N. L. Hancox, (Editor), *Fibre Composite Hybrid Materials,* The Macmillan Company, New York, 1981.]

and orientation is afforded with this technique. Furthermore, when automated, the process is most economically attractive. Common filament-wound structures include rocket motor casings, storage tanks and pipes, and pressure vessels.

Manufacturing techniques are now being used to produce a wide variety of structural shapes that are not necessarily limited to surfaces of revolution (e.g., I-beams). This technology is advancing very rapidly because it is very cost effective.

Structural Composites

structural composite

A **structural composite** is normally composed of both homogeneous and composite materials, the properties of which depend not only on the properties of the constituent materials but also on the geometrical design of the various structural elements. Laminar composites and sandwich panels are two of the most common structural composites; only a relatively superficial examination is offered here for them.

16.14 LAMINAR COMPOSITES

laminar composite

A **laminar composite** is composed of two-dimensional sheets or panels that have a preferred high-strength direction, such as is found in wood and continuous and aligned fiber–reinforced plastics. The layers are stacked and subsequently cemented together such that the orientation of the high-strength direction varies with each successive layer (Figure 16.16). For example, adjacent wood sheets in plywood are aligned with the grain direction at right angles to each other. Laminations may also be constructed using fabric material such as cotton, paper, or woven glass fibers embedded in a plastic matrix. Thus a laminar composite has relatively high strength in a number of directions in the two-dimensional plane; however, the strength in any given direction is, of course, lower than it would be if all the fibers were oriented in that direction. One example of a relatively complex laminated structure is the modern ski (see the chapter-opening illustration for this chapter).

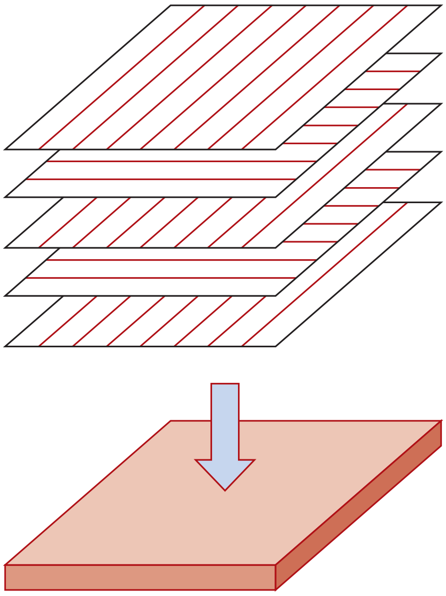

Figure 16.16 The stacking of successive oriented fiber–reinforced layers for a laminar composite.

16.15 SANDWICH PANELS

sandwich panel

Sandwich panels, considered to be a class of structural composites, are designed to be lightweight beams or panels having relatively high stiffnesses and strengths. A sandwich panel consists of two outer sheets, or faces, that are separated by and adhesively bonded to a thicker core (Figure 16.17). The outer sheets are made of a relatively stiff and strong material, typically aluminum alloys, fiber-reinforced plastics, titanium, steel, or plywood; they impart high stiffness and strength to the structure and must be thick enough to withstand tensile and compressive stresses that result from loading. The core material is lightweight and normally has a low modulus of elasticity. Core materials typically fall within three categories: rigid polymeric foams (i.e., phenolics, epoxy, polyurethanes), wood (i.e., balsa wood), and honeycombs (discussed shortly).

Structurally, the core serves several functions. First of all, it provides continuous support for the faces. In addition, it must have sufficient shear strength to withstand transverse shear stresses and also be thick enough to provide high shear stiffness (to resist buckling of the panel). (Tensile and compressive stresses on the core are much lower than on the faces.)

Another popular core consists of a "honeycomb" structure—thin foils that have been formed into interlocking hexagonal cells, with axes oriented perpendicular to

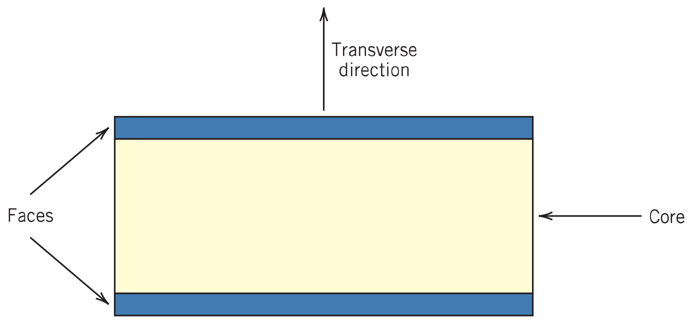

Figure 16.17 Schematic diagram showing the cross section of a sandwich panel.

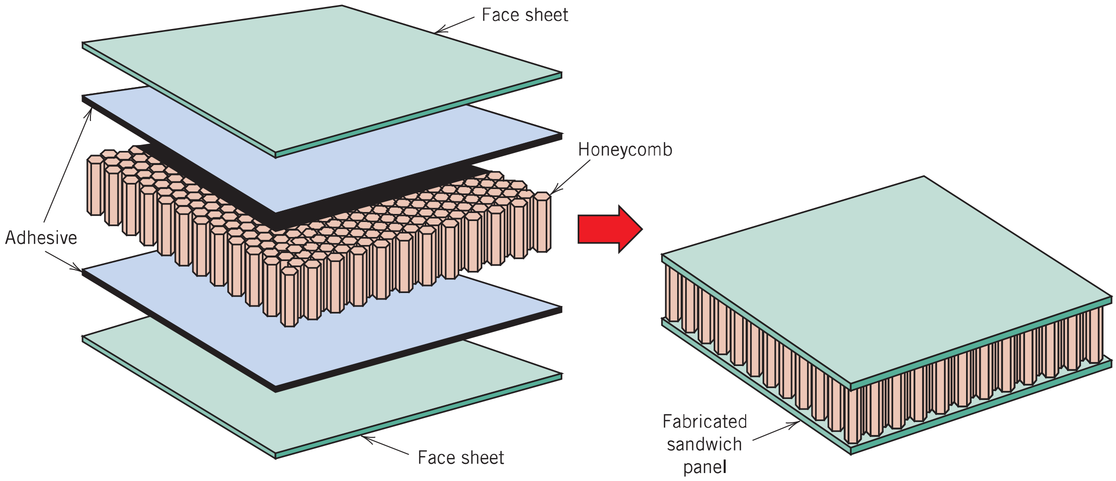

Figure 16.18 Schematic diagram showing the construction of a honeycomb core sandwich panel. (Reprinted with permission from *Engineered Materials Handbook,* Vol. 1, *Composites,* ASM International, Metals Park, OH, 1987.)

the face planes; Figure 16.18 shows a cutaway view of a honeycomb core sandwich panel. The honeycomb material is normally either an aluminum alloy or aramid polymer. Strength and stiffness of honeycomb structures depend on cell size, cell wall thickness, and the material from which the honeycomb is made.

Sandwich panels are used in a wide variety of applications including roofs, floors, and walls of buildings and in aerospace and aircraft (i.e., for wings, fuselage, and tailplane skins).

MATERIALS OF IMPORTANCE

Nanocomposites in Tennis Balls

Nanocomposites—composites that consist of nanosized particles embedded in some type of matrix—are a group of promising new materials that will undoubtedly become infused with some of our modern technologies. In fact, one type of nanocomposite is currently being used in high-performance tennis balls. These balls retain their original pressure and bounce twice as long as conventional ones. Air permeation through the walls of the ball is inhibited by a factor of two due to the presence of a flexible and very thin (10 to 50 μm) nanocomposite barrier coating that covers the inner core;[5] a schematic diagram of the cross-section of one of these tennis balls is shown in Figure 16.19. Because of their outstanding characteristics, these Double Core balls have recently been selected as the official balls for some of the major tennis tournaments.

This nanocomposite coating consists of a matrix of butyl rubber, within which is embedded thin platelets of vermiculite,[6] a natural clay mineral. The vermiculite platelets exist as single-molecule thin sheets—on the order of a nanometer thick—that have a very large aspect ratio (of about 10,000); *aspect ratio* is the ratio of the lateral dimensions of a platelet to its thickness. Furthermore, the vermiculite platelets are *exfoliated*—that is,

[5] This coating was developed by InMat Inc., and is called Air D-Fense. Wilson Sporting Goods has incorporated this coating in its Double Core tennis balls.

[6] Vermiculite is one member of the layered silicates group that is discussed in Section 12.3.

they remain separated from one another. Also, within the butyl rubber, the vermiculite platelets are aligned such that all their lateral axes lie in the same plane; and throughout this barrier coating are multiple layers of these platelets (per the inset of Figure 16.19).

The presence of the vermiculite platelets accounts for the ability of the nanocomposite coating to more effectively retain air pressure within the tennis balls. These platelets act as multilayer barriers to the diffusion of air molecules and slow down the diffusion rate; that is, the diffusion path length of air molecules is enhanced significantly because the air molecules must bypass these particles as they diffuse through the coating. Also, the addition of the particles to the butyl rubber does not diminish its flexibility.

It is anticipated that this type of coating can also be applied to other kinds of sporting equipment (i.e., soccer balls, footballs, bicycle tires), as well as to automobile tires (which would be lighter in weight and more recyclable).

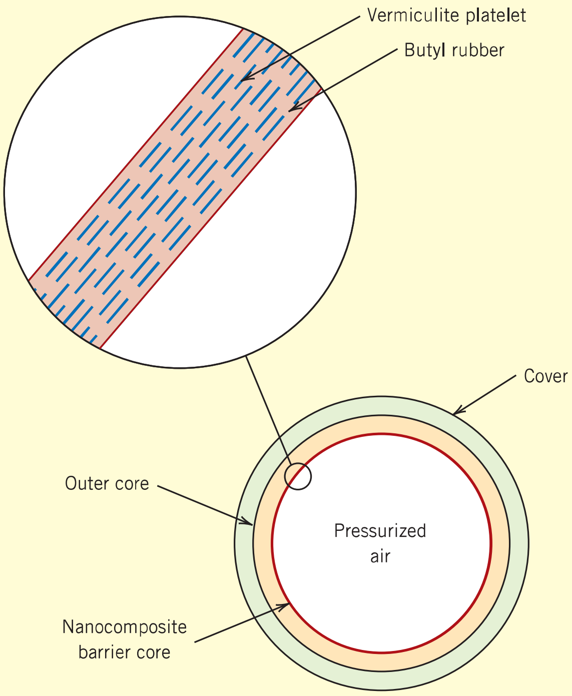

Figure 16.19 Schematic diagram showing the cross-section of a high-performance Double Core tennis ball. The inset drawing presents a detailed view of the nanocomposite coating that acts as a barrier to air permeation.

Photograph of a can of Double Core tennis balls and an individual ball. (Photograph courtesy of Wilson Sporting Goods Company.)

SUMMARY

Introduction

- Composites are artificially produced multiphase materials having desirable combinations of the best properties of the constituent phases.
- Usually, one phase (the matrix) is continuous and completely surrounds the other (the dispersed phase).
- In this discussion, composites were classified as particle-reinforced, fiber-reinforced, and structural.