19.14 Processing Metal-matrix and Ceramic-matrix Composites

Metal-matrix composites can be made into near-net shaped parts by the following processes:

- **Liquid-phase processing** basically consists of casting together the liquid-matrix material (such as aluminum or titanium) and the solid reinforcement (such as graphite, aluminum oxide, or silicon carbide) by conventional casting processes or by pressure-infiltration casting. In the latter process, pressurized gas forces the liquid-metal matrix into a preform, usually shaped out of wire or sheet and made of reinforcing fibers.
- **Solid-phase processing** utilizes powder metallurgy techniques (Chapter 17), including cold and hot isostatic pressing. Proper mixing is important for homogeneous distribution of the fibers throughout the part. An example is the production of tungsten-carbide tools and dies, with cobalt as the matrix material.
- **Two-phase (liquid–solid) processing** involves technologies that consist of rheocasting (Section 11.4.7) and the techniques of *spray atomization* and *deposition*. In the latter two processes, the reinforcing fibers are mixed with a matrix that contains both liquid and solid phases of the metal.

In making complex metal-matrix composite parts with whisker or fiber reinforcement, die geometry and control of process variables are very important, for ensuring the proper distribution and orientation of the fibers within the part. MMC parts made by powder metallurgy techniques generally are heat treated for optimum properties.

CASE STUDY 19.3 Metal-matrix Composite Brake Rotors and Cylinder Liners

Some brake rotors are made of composites consisting of an aluminum-based matrix, reinforced with 20% silicon-carbide particles. First, the particles are stirred into molten aluminum alloys, and the mixture is cast into ingots. The ingots are then remelted and cast into shapes, by such casting processes as green-sand, bonded-sand, investment, permanent-mold, and squeeze casting. These rotors (a) are about one-half the weight of those made of gray cast iron, (b) conduct heat three times faster, (c) add stiffness

(*continued*)

and wear-resistance characteristics of ceramics, and (d) reduce noise and vibration, because of internal damping in the rotors.

To improve the wear- and heat-resistance of cast-iron cylinder liners in aluminum engine blocks, aluminum-matrix liners are also available. The metal-matrix layer consists of 12% aluminum-oxide fiber and 9% graphite fiber, and has a thickness that ranges from 1.5 to 2.5 mm.

19.14.1 Processing Ceramic-matrix Composites

Several processes, including techniques such as melt infiltration, controlled oxidation, and hot-press sintering, are used to make ceramic-matrix composites; other processes are:

- **Slurry infiltration** is the most common process for making ceramic-matrix composites. It involves the preparation of a fiber preform, which is first hot pressed and then impregnated with a combination of slurry (containing the matrix powder), a carrier liquid, and an organic binder. High strength, toughness, and uniform structure are obtained by this process, but the product has limited high-temperature properties. A further improvement on the process is *reaction bonding* or *reaction sintering* of the slurry.
- **Chemical-synthesis** processes involve the sol-gel and the polymer-precursor techniques. In the *sol-gel process*, a *sol* (a colloidal fluid having the liquid as its continuous phase) that contains fibers is converted to a *gel*, which is then subjected to heat treatment to produce a ceramic-matrix composite. The *polymer-precursor method* is analogous to the process used in making ceramic fibers with aluminum oxide, silicon nitride, and silicon carbide.
- In **chemical-vapor infiltration**, a porous fiber preform is infiltrated with the matrix phase, using the chemical vapor deposition technique (Section 34.6). The product has very good high-temperature properties, but the process is time consuming and costly.