

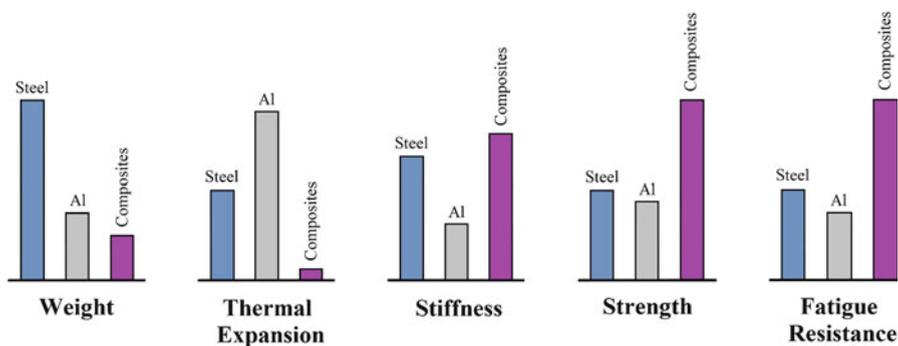
# Chapter 1

## Introduction

It is a truism that technological development depends on advances in the field of materials. One does not have to be an expert to realize that the most advanced turbine or aircraft design is of no use if adequate materials to bear the service loads and conditions are not available. Whatever the field may be, the final limitation on advancement depends on materials. Composite materials in this regard represent nothing but a giant step in the ever-constant endeavor of optimization in materials.

Strictly speaking, the idea of composite materials is not a new or recent one. Nature is full of examples wherein the idea of composite materials is used. The coconut palm leaf, for example, is essentially a cantilever using the concept of fiber reinforcement. Wood is a fibrous composite: cellulose fibers in a lignin matrix. The cellulose fibers have high tensile strength but are very flexible (i.e., low stiffness), while the lignin matrix joins the fibers and furnishes the stiffness. Bone is yet another example of a natural composite that supports the weight of various members of the body. It consists of short and soft collagen fibers embedded in a mineral matrix called apatite. Weiner and Wagner (1998) give a good description of structure and properties of bone. For descriptions of the structure–function relationships in the plant and animal kingdoms, the reader is referred to Elices (2000) and Wainwright et al. (1982). In addition to these naturally occurring composites, there are many other engineering materials that are composites in a very general way and that have been in use for a very long time. The carbon black in rubber, Portland cement or asphalt mixed with sand, and glass fibers in resin are common examples. Thus, we see that the idea of composite materials is not that recent. Nevertheless, one can safely mark the origin of the distinct discipline of composite materials as the beginning of the 1960s. It would not be too much off the mark to say that a concerted research and development effort in composite materials began in 1965. Since the early 1960s, there has been an increasing demand for materials that are stiffer and stronger yet lighter in fields as diverse as aerospace, energy, and civil construction. The demands made on materials for better overall performance are so great and diverse that no one material can satisfy them. This naturally led to a resurgence of the ancient concept of combining different materials in an integral-composite material to satisfy the user requirements.

Such composite material systems result in a performance unattainable by the individual constituents, and they offer the great advantage of a flexible design; that is, one can, in principle, tailor-make the material as per specifications of an optimum design. This is a much more powerful statement than it might appear at first sight. It implies that, given the most efficient design of, say, an aerospace structure, an automobile, a boat, or an electric motor, we can make a composite material that meets the need. Schier and Juergens (1983) surveyed the design impact of composites on fighter aircraft. According to these authors, “composites have introduced an extraordinary fluidity to design engineering, in effect forcing the designer-analyst to create a different material for each application as he pursues savings in weight and cost.”



**Fig. 1.1** Comparison between conventional monolithic materials and composite materials [from Deutsch (1978), used with permission]

Yet another conspicuous development has been the integration of the materials science and engineering input with the manufacturing and design inputs at all levels, from conception to commissioning of an item, through the inspection during the lifetime, as well as failure analysis. More down-to-earth, however, is the fact that our society has become very energy conscious. This has led to an increasing demand for lightweight yet strong and stiff structures in all walks of life. And composite materials are increasingly providing the answers. Figure 1.1 makes a comparison, admittedly for illustrative purposes, between conventional monolithic materials, such as aluminum and steel, and composite materials (Deutsch 1978). This figure indicates the possibilities of improvements that one can obtain over conventional materials by the use of composite materials. As such, it describes vividly the driving force behind the large effort in the field of composite materials. Glass fiber reinforced resins have been in use since the early twentieth century. Glass fiber reinforced resins are very light and strong materials, although their stiffness (modulus) is not very high, mainly because the glass fiber itself is not very stiff. The third quarter of the twentieth century saw the emergence of the so-called advanced fibers of extremely high modulus, for example, boron, carbon, silicon

carbide, and alumina (Chawla 1998, 2005). These fibers have been used for reinforcement of resin, metal, and ceramic matrices. Fiber reinforced composites have been more prominent than other types of composites for the simple reason that most materials are stronger and stiffer in the fibrous form than in any other form. By the same token, it must be recognized that a fibrous form results in reinforcement mainly in fiber direction. Transverse to the fiber direction, there is little or no reinforcement. Of course, one can arrange fibers in two-dimensional or even three-dimensional arrays, but this still does not gainsay the fact that one is not getting the full reinforcement effect in directions other than the fiber axis. Thus, if a less anisotropic behavior is the objective, then perhaps laminate or sandwich composites made of, say, two different materials would be more effective. A particle reinforced composite will also be reasonably isotropic. There may also be specific nonmechanical objectives for making a fibrous composite. For example, an abrasion- or corrosion-resistant surface would require the use of a laminate (sandwich) form, while in superconductors the problem of flux-pinning requires the use of extremely fine filaments embedded in a conductive matrix. In what follows, we discuss the various aspects of composites, mostly fiber reinforced composites, in greater detail, but first let us agree on an acceptable definition of a composite material. Practically everything in this world is a composite material. Thus, a common piece of metal is a composite (polycrystal) of many grains (or single crystals). Such a definition would make things quite unwieldy. Therefore, we must agree on an operational definition of *composite material* for our purposes in this text. We shall call a material that satisfies the following conditions a composite material:

1. It is manufactured (i.e., naturally occurring composites, such as wood, are excluded).
2. It consists of two or more physically and/or chemically distinct, suitably arranged or distributed phases with an interface separating them.
3. It has characteristics that are not depicted by any of the components in isolation.

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## Problems

- 1.1. Describe the structure and properties of some fiber reinforced composites that occur in nature.
- 1.2. Many ceramic-based composite materials are used in the electronics industry. Describe some of these electroceramic composites.
- 1.3. Describe the use of composite materials in the Voyager airplane that circled the globe for the first time without refueling in flight.
- 1.4. Nail is a fibrous composite. Describe its components, microstructure, and properties.
- 1.5. Discuss the use of composite materials in civilian aircraft, with special attention to Boeing 787 and Airbus A380 aircraft.