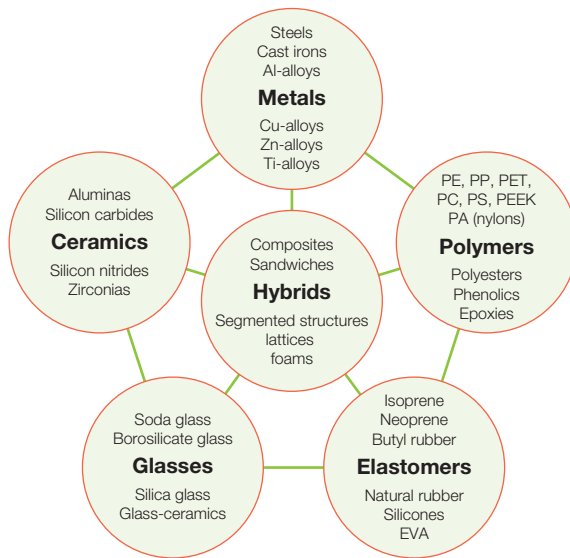


3.2 THE FAMILIES OF ENGINEERING MATERIALS

It is conventional to classify the materials of engineering into the six broad families shown in [Figure 3.1](#): metals, polymers, elastomers, ceramics, glasses, and hybrids. The members of a family have certain features in

**FIGURE 3.1**

The menu of engineering materials. The basic families of metals, ceramics, glasses, polymers, and elastomers can be combined in various geometries to create hybrids.

common: similar properties, similar processing routes, and, often, similar applications.

Metals are stiff. They have relatively high elastic moduli. Most, when pure, are soft and easily deformed. They can be made strong by alloying and by mechanical and heat treatment, but they remain ductile, allowing them to be formed by deformation processes. Certain high-strength alloys (spring steel, for instance) have ductilities as low as 1%, but even this is enough to ensure that the material yields before it fractures and that fracture, when it occurs, is of a tough, ductile type. Partly because of their ductility, metals are prey to fatigue and of all the classes of material, they are the least resistant to corrosion.

Ceramics, too, have high moduli, but unlike metal, they are brittle. Their “strength” in tension means the brittle fracture strength; in compression it is the brittle crushing strength, which is about 15 times greater. And because ceramics have no ductility, they have a low tolerance for stress concentrations (like holes or cracks) or for high-contact stresses (at clamping points, for instance). Ductile materials accommodate stress concentrations by deforming in a way that redistributes the load more evenly, and because of this, they can be used under static loads within a small margin of their yield strength. Ceramics cannot. Brittle materials always have a wide scatter in strength, and the strength itself depends on

the volume of material under load and the time over which it is applied. So ceramics are not as easy to design with as metals. Despite this, they have attractive features. They are stiff, hard, and abrasion-resistant (hence their use for bearings and cutting tools); they retain their strength to high temperatures; and they resist corrosion well.

Glasses are noncrystalline (“amorphous”) solids. The most common are the soda-lime and borosilicate glasses familiar as bottles and ovenware, but there are many more. Metals, too, can be made noncrystalline by cooling them sufficiently quickly. The lack of crystal structure suppresses plasticity, so, like ceramics, glasses are hard, brittle, and vulnerable to stress concentrations.

Polymers are at the other end of the spectrum. They have moduli that are low, roughly 50 times lower than those of metals, but they can be strong—nearly as strong as metals. A consequence of this is that elastic deflections can be large. They creep, even at room temperature, meaning that a polymer component under load may, with time, acquire a permanent set. And their properties depend on temperature so that a polymer that is tough and flexible at 20°C may be brittle at the 4°C of a household refrigerator, yet may creep rapidly at the 100°C of boiling water. Few have useful strength above 200°C. Some polymers are mainly crystalline, some are amorphous (noncrystalline), some are a mix of crystalline and amorphous—transparency goes with the amorphous structure. If these aspects are allowed for in the design, the advantages of polymers can be exploited. And there are many. When combinations of properties, such as strength per unit weight, are important, polymers can compete with metals. They are easy to shape. Complicated parts performing several functions can be molded from a polymer in a single operation. The large elastic deflections allow the design of polymer components that snap together, making assembly fast and cheap. And by accurately sizing the mold and precoloring the polymer, no finishing operations are needed. Polymers resist corrosion (paints, for instance, are polymers) and have low coefficients of friction. Good design exploits these properties.

Elastomers are long-chain polymers above their glass-transition temperature, T_g . The covalent bonds that link the units of the polymer chain remain intact, but the weaker Van der Waals and hydrogen bonds that, below T_g , bind the chains to each other, have melted. This gives elastomers unique properties: Young’s moduli as low as 10^{-3} GPa (10^5 times less than that typical of metals) increase with temperature (all other solids show a decrease), and have enormous elastic extension. Their properties differ so much from those of other solids that special tests have evolved to characterize them. This creates a problem: If we wish to select materials by prescribing a desired attribute profile, as we do later in this book, then a prerequisite is a set of attributes common to all materials.

To overcome this, we use a common set of properties in the early stages of design, estimating approximate values for anomalies like elastomers. Specialized attributes, representative of one family only, are stored separately; they are for use in the later stages.

Hybrids are combinations of two or more materials in a predetermined configuration and scale. They combine the attractive properties of the other families of materials while avoiding some of their drawbacks. Their design is the subject of Chapters 11 and 12. The family of hybrids includes fiber and particulate composites, sandwich structures, lattice structures, foams, cables, and laminates; almost all the materials of nature—wood, bone, skin, and leaf—are hybrids. Fiber-reinforced composites are, of course, the most familiar. Most of those at present available to the engineer have a polymer matrix reinforced by fibers of glass, carbon, or Kevlar (an aramid). They are light, stiff, and strong, and they can be tough. They, and other hybrids using a polymer as one component, cannot be used above 250°C because the polymer softens, but at room temperature their performance can be outstanding. Hybrid components are expensive, and they are relatively difficult to form and join. So, despite their attractive properties, the designer will use them only when the added performance justifies the added cost. Today's growing emphasis on high performance and fuel efficiency provides increasing drivers for their use.

These, then, are the material families. What do we need to know about them?