# MATERIAL SCIENCE

1-Introduction to Materials

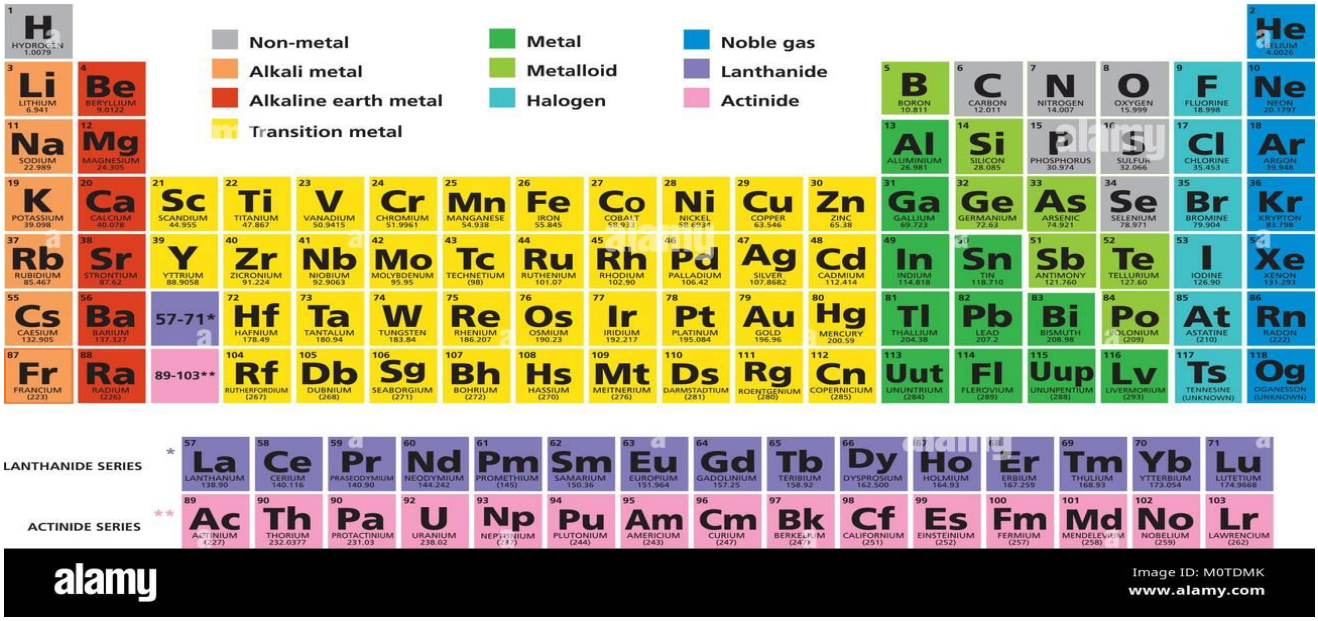
**SYNOPSIS** Engineering materials constitute the foundation of technology, whether the technology pertains to structural, electronic, thermal, electrochemical, environmental, biomedical, or other applications. The history of human civilization evolved from the Stone Age to the Bronze Age, the Iron Age, the Steel Age, and to the Space Age (contemporaneous with the Electronic Age). Each age is marked by the advent of certain materials. The Iron Age brought tools and utensils. The Steel Age brought rails and the Industrial Revolution. The Space Age brought structural materials (e.g., composite materials) that are both strong and lightweight. The Electronic Age brought semiconductors. Modern materials include metals, polymers, ceramics, semiconductors, and composite materials. This chapter provides an overview of the classes and applications of materials.

## 1.1 CLASSES OF MATERIALS

Metals, polymers, ceramics, semiconductors, and composite materials constitute the main classes of materials.

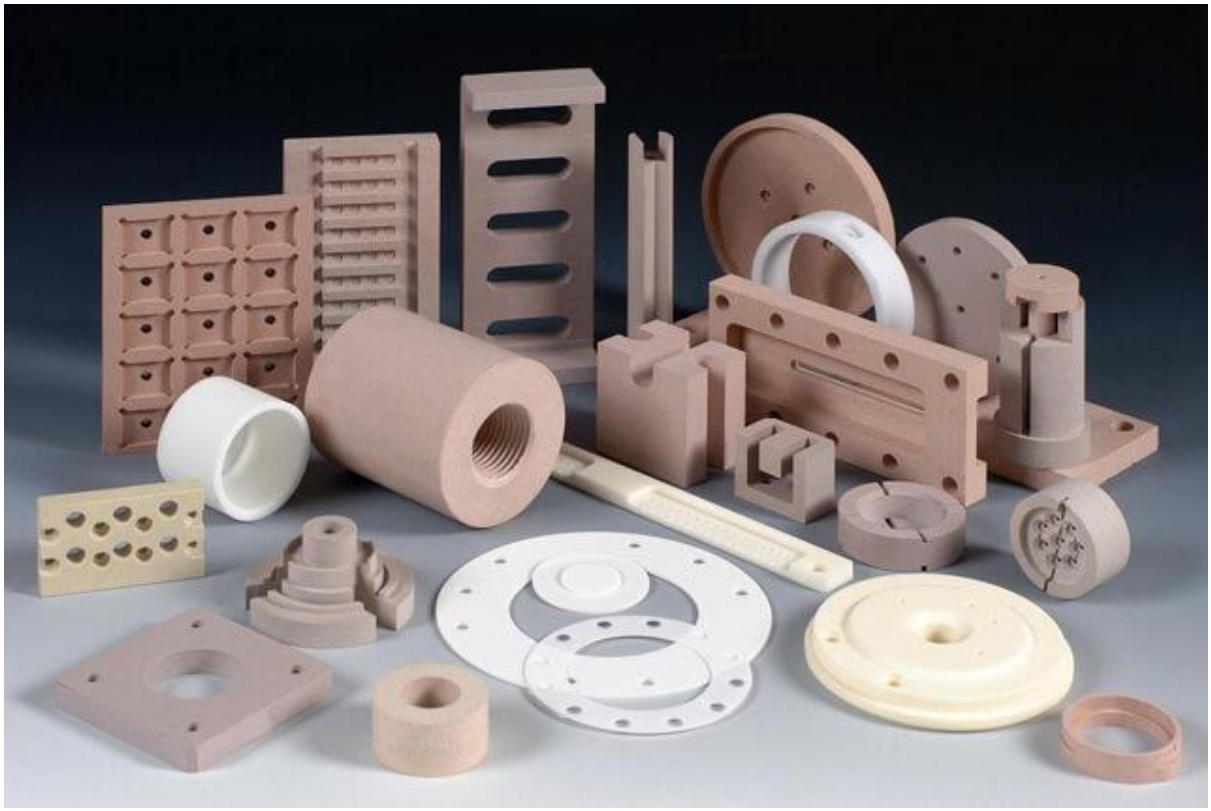
Metals (including alloys) consist of atoms and are characterized by metallic bonding (i.e., the valence electrons of each atom are delocalized and shared among all the atoms). Most of the elements in the Periodic Table are metals. Examples of alloys are Cu-Zn (brass), Fe-C (steel), and Sn-Pb (solder). Alloys are classified according to the majority element present. The main classes of alloys are iron-based alloys for structures; copper-based alloys for piping, utensils, thermal conduction, electrical conduction, etc.; and aluminum-based alloys for lightweight structures and metal-matrix composites. Alloys are almost always in the polycrystalline form.

# Periodic Table of the Elements






Ceramics are inorganic compounds such as $Al_2O_3$ (for spark plugs and for substrates for microelectronics), $SiO_2$ (for electrical insulation in microelectronics), $Fe_3O_4$ (ferrite for magnetic memories used in computers), silicates (clay, cement, glass, etc.), and SiC (an abrasive). The main classes of ceramics are oxides, carbides, nitrides, and silicates. Ceramics are typically partly crystalline and partly amorphous. They consist of ions (often atoms as well) and are characterized by ionic bonding and often covalent bonding.



Polymers in the form of thermoplastics (nylon, polyethylene, polyvinyl chloride, rubber, etc.) consist of molecules that have covalent bonding within each molecule and van der Waals' forces between them. Polymers in the form of thermosets (e.g., epoxy, phenolics, etc.) consist of a network of covalent bonds. Polymers are amorphous, except for a minority of thermoplastics. Due to the bonding, polymers are typically electrical and thermal insulators. However, conducting polymers can be obtained by doping, and conducting polymer-matrix composites can be obtained by the use of conducting fillers.

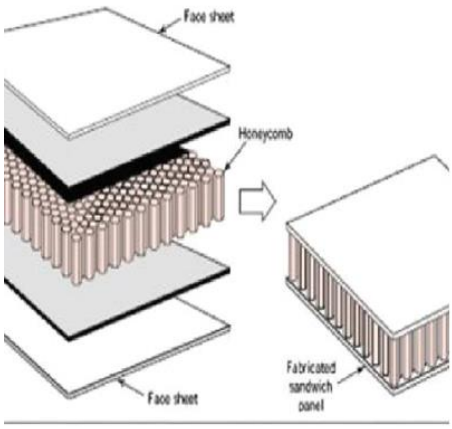


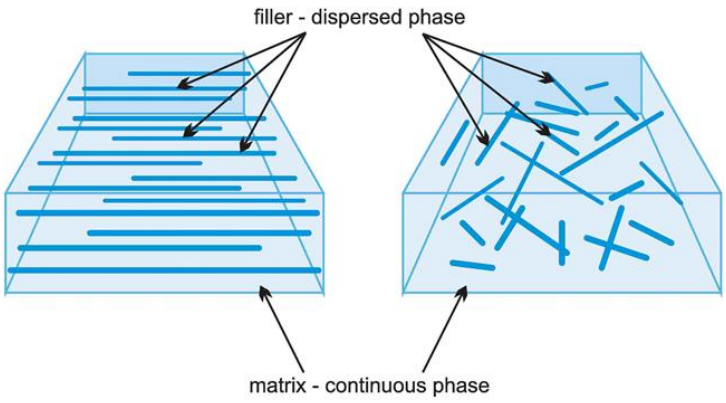


Polymeric Materials

9

Composite materials are multiphase materials obtained by artificial combination of different materials to attain properties that the individual components cannot attain. An example is a lightweight structural composite obtained by embedding continuous carbon fibers in one or more orientations in a polymer matrix. The fibers provide the strength and stiffness while the polymer serves as the binder. Another example is concrete, a structural composite obtained by combining cement (the matrix, i.e., the binder, obtained by a reaction known as hydration, between cement and water), sand (fine aggregate), gravel (coarse aggregate), and, optionally, other ingredients known as admixtures. Short fibers and silica fume (a fine $SiO_2$ particulate) are examples of admixtures. In general, composites are classified according to their matrix materials. The main classes of composites are polymer-matrix, cement-matrix, metal-matrix, carbon-matrix, and ceramic-matrix.




Composite Materials

11

Polymer-matrix and cement-matrix composites are the most common due to the low cost of fabrication. Polymer-matrix composites are used for lightweight structures (aircraft, sporting goods, wheelchairs, etc.) in addition to vibration damping,