# Introduction

Sometimes it is useful to subdivide the discipline of materials science and engineering into materials science and materials engineering sub disciplines. **Materials science** involves investigating the relationships that exist between the structures and properties of materials. In contrast, **Materials engineering** involves designing the structure of a material to produce a predetermined set of properties. Virtually all important properties of the solid materials may be grouped into mechanical, electrical, thermal and magnetic properties.

**Mechanical properties** relate deformation to an applied load or force; examples include elastic modulus (stiffness), strength, and toughness. **Electrical properties**, such as electrical conductivity and dielectric constant. **Thermal properties** of solids can be represented in terms of heat capacity and thermal conductivity. The **Magnetic properties** demonstrate the response of a material to the application of a magnetic field.

In addition to the structure and properties, two other important components are involved in the science and engineering of materials, namely, **processing** and **performance**. The structure of a material will depend on how it is processed. Furthermore, a material’s performance will be a function of its properties. Thus, the interrelationship between processing, structure, properties, and performance is as depicted in the below schematic.



# Classification of Engineering Materials

Solid materials have been conveniently grouped into four basic categories: metals, ceramics, polymers and composites. Another category is advanced materials—those used in high-technology applications, such as Semiconductors, Biomaterials, Smart Materials, and Nano-Engineered Materials.

1. **Metals**

Materials in this group are composed of one or more metallic elements (e.g., iron, **aluminum**, **copper**, **titanium**, **gold**, and **nickel**), Atoms in metals and their alloys are arranged in a very orderly manner and are relatively dense in comparison to the ceramics and polymers. These materials are relatively **stiff** and **strong** yet are **ductile** (i.e., capable of large amounts of deformation without fracture) and are resistant to fracture, which accounts for their widespread use in structural applications. Metallic materials have large numbers of nonlocalized electrons. Many properties of metals are directly attributable to these electrons.

**Metals** can be classified into **ferrous** (Iron base) like (steel, cast iron) and **non-ferrous** like light metals (Al, Mg), heavy metals (Cu, Ni), refractories (Mo, W) and precious metals (Au, Ag).

**The main properties of metals:**

* 1. High density.
  2. Thermal and electrical conductivity.
  3. Good strength, ductility and toughness properties.
  4. Working at medium and high temperature.
  5. Low corrosion resistance.

1. **Ceramics**

**Ceramics** are compounds between metallic and nonmetallic elements; they are most frequently **oxides**, **nitrides**, and **carbides**. For example, common ceramic materials include aluminum oxide (alumina, Al2O3), silica (SiO2), silicon carbide (SiC), silicon nitride (Si3N4). In addition, what some refer to as the **traditional ceramics** those composed of clay minerals (i.e., porcelain), as well as cement and glass. With regard to mechanical behavior, ceramic materials are typically very hard and exhibited extreme brittleness (lack of ductility) and are highly susceptible to fracture. **Ceramic** can be classified into:

* 1. **Domestic Ceramics** (porcelain, china ware and cement).
  2. **Natural Ceramics** (stones and rocks).
  3. **Engineering Ceramics** (oxides, nitrides, and carbides).
  4. **Glasses** (glass and glass-ceramic).
  5. **Electronic Ceramics** (ferrites, semiconductor and ferroelectric).

**The main properties of ceramics:**

* 1. Medium density.
  2. Electrical and thermal insulation.
  3. Wear and corrosion resistance.
  4. Difficult to form (machine).
  5. Working at high temperature.

1. **Polymers**

Polymers include the familiar **plastic** and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements such as (O, N, and Si). Furthermore, they have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms. Some common and familiar polymers are polyethylene (PE), nylon, poly (vinyl chloride) (PVC), polycarbonate (PC). Polymers may be classified into three groups:

1. **Thermoplastic polymers:** this type, like nylon and polyethylene, soften when heated and become hard again when the heat is removed.

Also this polymer have linear or branch chains structure.

1. **Thermosetting polymers:** this type, like epoxy and polyester, don’t soften when heated, but char and decompose and have cross linked structure.

1. **Elastomer polymers:** this type, like rubber, have considerable extensions and reversible. Also have some degree of cross linking.

**The main properties of polymers:**

* 1. Low density.
  2. Easy to form.
  3. Working at low temperature.
  4. High corrosion resistance and low mechanical properties.
  5. Electrical and thermal insulation.

**4. Composites**

Often, the technical specifications for the properties of materials to be used in products exceed those that can be met by a single class of materials, such as polymers, metals, alloys, or ceramics. Sometimes, such limitations can be overcome by combining two or more classes of materials in a single material product, i.e., by making a **composite**.

**Composite materials** are mainly consist of two phases; one is named the **matrix**, which is continuous and surrounds the second phase, often termed the **dispersed phase**. Composite materials are classified according to the matrix phase including (PMCs), (CMCs) and (MMCs) or according to the dispersed phase including fiber reinforced composite (FRC), particles reinforced composite (PRC) and Structural composite.

**The main properties of composites:**

All types of properties enhanced in composite materials, but the important properties that recognize the composite materials is the **strength to the weight ratio**.

# Advanced materials

Materials that are utilized in high-technology (or high-tech) applications are sometimes termed advanced materials. By high technology we mean a device or product that operates or functions using relatively intricate and sophisticated principles; examples include electronic equipment, computers, fiber-optic systems, spacecraft, aircraft, and military rocketry. Advanced materials can be divided into:

1. **Semiconductors:**

Semiconductors have electrical properties that are **intermediate** between those of electrical conductors (i.e., metals and metal alloys) and insulators (i.e., ceramics and polymers). Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms. Semiconductors have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries.

1. **Biomaterials:**

**Biomaterials** are employed in components implanted into the human body to replace diseased or damaged body parts. These materials must not produce toxic substances and must be compatible with body tissues (i.e., must not cause adverse biological reactions). All of the preceding materials, metals, ceramics, polymers, composites, and semiconductors may be used as biomaterials.

1. **Smart Materials:**

Smart (or intelligent) materials are a group of new materials now being developed that will have a significant influence on many of our technologies. The adjective **smart** implies that these materials are able to sense changes in their environment and then respond to these changes in predetermined manners. The most important types of smart materials are (the **shape-memory alloys**) and **piezoelectric ceramics**. Shape memory alloys are metals that, after having been deformed, revert back to their original shape when temperature is changed. Piezoelectric ceramics expand and contract in response to an applied electric field (or voltage); conversely, they also generate an electric field when their dimensions are altered.

1. **Nanomaterials:**

A new class of advanced materials which has fascinating properties and tremendous technological application. Nanomaterials may be any one of the four basic types, metals, ceramics, polymers, and composites. However, they are not distinguished on the basis of their chemistry but **on the basis of their size**; the Nano prefix denotes that the dimensions of these structural entities are on **the order of a nanometer (10-9 m)**.

Some of physical and chemical characteristics of materials undergoes dramatic changes when the particle size approach to the atomic dimensions. For example, materials that are opaque in the macroscopic domain may become transparent on the nanoscale; some solids become liquids, chemically stable materials become combustible, and electrical insulators become conductors.

Because of these unique and unusual properties, nanomaterials are finding niches in electronic, biomedical, sporting, energy production, space and other industrial applications. Whenever a new material is developed, its potential for harmful and toxicological interactions with humans and animals must be considered.

Small nanoparticles have exceedingly l**arge surface area–to–volume ratios**, which can lead to high chemical reactivities. Although the safety of nanomaterials is relatively unexplored, there are concerns that they may be absorbed into the body through the skin, lungs, and digestive tract at relatively high rates, if present in sufficient concentrations, will pose health risks.