Class: 1st
Subject: Engineering Materials
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Materials Science and Engineering

Materials Science and Engineering (MSE) is an interdisciplinary field concerned with inventing new materials and improving previously known materials by developing a deeper understanding of the (microstructure-composition-synthesis-processing) relationships. The term **composition** means the chemical make-up of a material. The term **structure** means a description of the arrangement of atoms, as seen at different levels of detail. The term ''**synthesis**'' refers to how materials are made from naturally occurring or man-made chemicals. The term ''**processing**'' means how materials are shaped into useful components.

One of the most fascinating aspects of materials science involves the investigation into the **structure** of a material. The structure of materials has a deep influence on many properties of materials, even if the general composition does not change! For example, if you take a pure copper wire and bend it repeatedly, the wire not only becomes harder but also becomes increasingly brittle. Finally, the pure copper wire becomes so hard and brittle that it will break rather easily. The electrical resistivity of wire will also increase as we bend it repeatedly. In this simple example, note that we did not change the material's composition (i.e., its chemical makeup). The changes in the material's properties are often due to a change in its internal structure. If you examine the wire after bending using an optical microscope, it will look the same as before (other than the bends, of course). However, its structure has been changed at a very small or microscopic scale. The structure at this microscopic scale is known as **microstructure**. If we can understand what has changed at a micrometer level, we can begin to discover ways to control the material's properties.

Classification of Materials

There are different ways of classifying materials. One way is to describe four groups (Table.1):

1. Metals and alloys.
2. Ceramics (glasses, and glass-ceramics).
3. Polymers.
4. Composite materials.

Materials in each of these groups have different structures and properties. The differences in strength, illustrate the wide range of properties, engineers can select from. Since metallic materials are extensively used for load-bearing applications, their mechanical properties are of great practical interest. The term ''**Stress**'' refers to load or force per unit area. ''**Strain**'' refers to elongation or change in dimension divided by original dimension. If the strain goes away after the load or applied stress is removed, the strain is said to be **elastic**. If the strain remains after the stress is removed, the strain is said to be **plastic.** When the deformation is elastic, stress and strain are linearly related, the slope of the stress-strain diagram is known as the **elastic** or **Young's modulus**. A level of stress needed to initiate plastic deformation is known as **yield stress.** The maximum percent deformation we can get is a measure of the ductility of a metallic material.

Metals and Alloys: These include steels, aluminum, magnesium, zinc, cast iron, titanium, copper, and nickel. In general, metals have good electrical and thermal conductivity. Metals and alloys have relatively high strength, high stiffness, ductility or formability (i.e., capable of large amounts of deformation without fracture),, and shock resistance. They are particularly useful for structural or loadbearing applications. Although pure metals are occasionally used, combinations of metals called **alloys** provide improvement in a particular desirable property or permit better combinations of properties. Atoms in metals and their alloys are arranged in a very orderly way, and in comparison to the ceramics and polymers, are relatively dense. Some of the metals (viz., Fe, Co, and Ni) have desirable magnetic properties.

Ceramics: Ceramics can be defined as inorganic materials, compounds between metallic and nonmetallic elements; they are most commonly oxides, nitrides, and carbides. For example, some of the common ceramic materials include aluminum oxide (or alumina,Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, 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 respect to mechanical behavior, ceramic materials are relatively stiff and strong stiffness and strengths are comparable to those of the metals. In addition, ceramics are typically very hard. On the other hand, they are extremely brittle (lack ductility) due to the presence of porosity (small holes), and are highly susceptible to fracture. Therefore, we normally prepare fine powders of ceramics and convert these into different shapes. These materials are typically insulates to the passage of heat and electricity (i.e., have low electrical conductivities, and are more resistant to high temperatures and harsh environments than metals and polymers.

Polymers: Polymers are typically organic materials produced using a process known as **polymerization**. Polymeric materials include rubber (elastomers), polyethylene (PE), nylon, poly(vinyl chloride) (PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber. Many polymers have very good electrical resistivity. They can also provide good thermal insulation. Although they have lower strength, polymers have a very good strength-to-weight ratio. They are typically not suitable for use at high temperatures. Many polymers have very good resistance to corrosive chemicals. Polymers have thousands of applications ranging from bulletproof vests, compact disks (CDs), ropes, and coffee cups. **Thermoplastic polymers**, in which the long molecular chains are not rigidly connected, have good ductility and formability; **thermosetting polymers** are stronger but more brittle because the molecular chains are tightly linked. Polymers are used in many applications, including electronic devices. **Thermoplastics** are made by shaping their molten form. **Thermosets** are typically cast into molds.

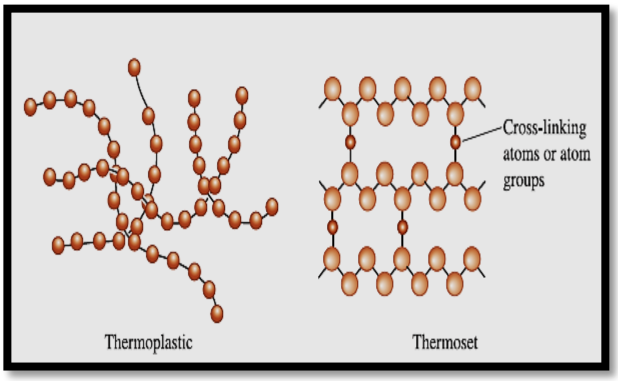

Figure 1. Polymerization occurs when small molecules, represented by the circles, combine to produce larger molecules, or polymers. The polymer molecules can have a structure that consists of many chains that are entangled but not connected (thermoplastics) or can form three-dimensional networks in which chains are cross-linked (thermosets).

Composite Materials: The main idea in developing composites is to blend the properties of different materials. The composites are formed from two or more materials, producing properties not found in any single material. **Concrete**, **plywood**, and **fiberglass** are examples of composite materials. **Fiberglass** is made by dispersing glass fibers in a polymer matrix. The glass fibers make the polymer matrix stiffer, without significantly increasing its density. With composites we can produce lightweight, strong, ductile, high temperature-resistant materials or we can produce hard, yet shock-resistant, cutting tools that would otherwise shatter. Advanced aircraft and aerospace vehicles rely heavily on composites such as carbon-fiber-reinforced polymers. Sports equipment such as bicycles, golf clubs, tennis rackets, and the like also make use of different kinds of composite materials that are light and stiff.

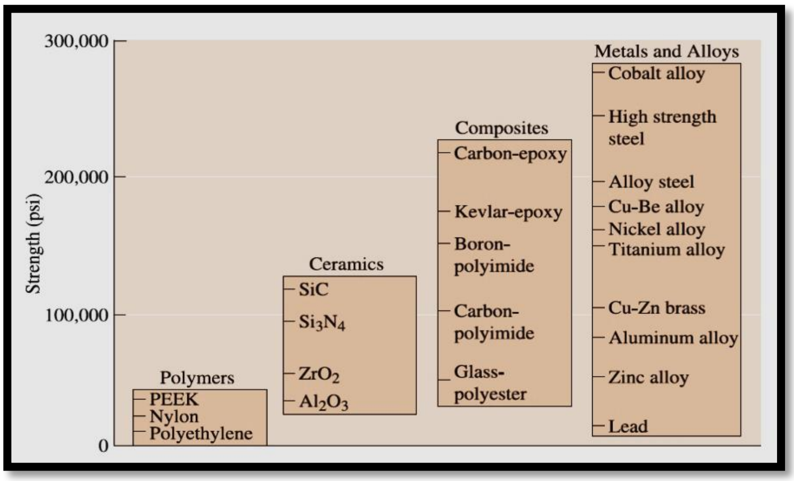

Figure 2. Representative strengths of various categories of materials. The strength of ceramics is under a compressive stress.

Table 1. Representative examples, applications, and properties for each category of materials.

Materials	Examples of Applications	Properties
Metals and Alloys **1.** Copper	Electrical conductor wire	High electrical conductivity, good formability
2. Gray cast iron	Automobile engine blocks	Castable, machinable, vibration damping
3. Alloy steels	Wrenches, automobile chassis	Significantly strengthened by heat treatment
Ceramics and Glasses **1.** SiO_2-Na_2O-CaO	Window glass or soda-lime glass	Optically transparent, thermally insulating
2. Al_2O_3, MgO, SiO_2	Refractories (i.e., heat-resistant lining of furnaces) for containing molten metal	Thermally insulating, withstand high temperatures, relatively inert to molten metal
3. Barium titanate	Capacitors for microelectronics	High ability to store charge
4. Silica	Optical fibers for information technology	Refractive index, low optical losses
Polymers **1.** Polyethylene	Food packaging	Easily formed into thin, flexible, airtight film

2. Epoxy	Encapsulation of integrated circuits	Electrically insulating and moisture-resistant
3. Phenolic	Adhesives for joining plies in plywood	Strong, moisture resistant
Semiconductors **1.** Silicon (Si)	Transistors and integrated circuits	Unique electrical behavior
2. GaAs	Optoelectronic systems	Converts electrical signals to light, lasers, laser diodes, etc.
Composites **1.** Graphite-epoxy	Aircraft components	High strength-to-weight ratio
2. Tungsten carbide-cobalt (WC-Co)	Carbide cutting tools for machining	High hardness, yet good shock resistance