Classification Of Engineering Materials, And Their Properties

A] Material classification:
There are different ways of classifying materials. One way is to describe five groups or families:
1. Metals and alloys;
2. Ceramics
3. glasses
4. Polymers (plastics);
5. Semiconductors
6. Composite materials

1- Metals and Alloys:
Metals include aluminum, magnesium, zinc, cast iron. An alloy is a metal that contains additions of one or more metals like steel, titanium alloy...etc. In general, metals have good electrical and thermal conductivity. Metals and alloys have relatively high strength, high stiffness, ductility or formability, and shock resistance. They are particularly useful for structural or load-bearing applications. Although pure metals are occasionally used, alloys provide improvement in a particular desirable property or permit better combinations of properties.

2- Ceramics:
Ceramics can be defined as inorganic crystalline materials. Sand and rocks are examples of naturally occurring ceramics. Advanced ceramics are materials made by refining naturally occurring ceramics and other special processes. Advanced ceramics are used in sensors and capacitors, wireless communications, inductors, and electrical insulation. Ceramics are also used in such consumer products as paints, and tires, and for industrial applications such as the tiles for the space shuttle.
Traditional ceramics are used to make bricks, tableware, toilets, bathroom sinks. In general, due to the presence of porosity (small holes), ceramics do not conduct heat well; they must be heated to very high temperatures before melting. Ceramics are strong and hard, but also very brittle. We normally prepare fine powders of ceramics and convert these into different shapes.

3- Glasses:
Glass is an amorphous material, (often, but not always), derived from a molten liquid. The term “amorphous” refers to materials that do not have a regular, periodic arrangement of atoms. The fiber optics industry is founded on optical fibers based on high purity silica glass. Glasses are also used in houses, cars,
computer and television screens, and hundreds of other applications. Glasses can be thermally treated (tempered) to make them stronger.

4- Polymers:

**Polymers are typically organic materials.** They are produced using a process known as polymerization. **Polymers include rubber (elastomers) and many types of adhesives.** Polymers typically are good electrical and thermal insulators. 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 liquid crystal displays (LCDs) to clothes 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 (Figure 1-1).

Figure 1-1 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).

5- Semiconductors:

Silicon, germanium, are semiconductors such as those used in computers and electronics are part of a broader class of materials known as **electronic materials.** The electrical conductivity of semiconducting materials is between that of ceramic insulators and metallic conductors. In some semiconductors, the level of conductivity can be controlled to enable electronic devices such as transistors, diodes, etc., that are used to build integrated circuits. In many applications, we need large single crystals of semiconductors. These are grown from molten materials. Often, thin films of semiconducting materials are also made using specialized processes.

6- Composite Materials:

The main idea in developing composites is to blend the properties of different materials. These are formed from two or more materials, producing properties not found in any single material. Concrete, plywood, and fiberglass are examples of composite materials. Advanced aircraft and aerospace vehicles rely heavily on composites such as carbon fiber-reinforced polymers (Figure 1-2). 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 1-2 The X-wing for advanced helicopters
Relies on a material composed of a carbon fiber reinforced polymer.

B] Material properties:
The various properties of materials are classified as follows:

1- Mechanical properties: there are many mechanical properties as in figure (1-3), below some of them:
   a) Strength :
      It is defined as resistance by which the material opposes the deformation. The maximum load withstood by a specimen of the metal before failure is called ultimate strength. The load acting per unit area of specimen is called stress and the deformation produced is called strain.
   b) Stiffness:
      Is defined as its resistance to elastic deformation or it’s the slope of the hooke’s law. A material which undergoes a slight deformation under the action of load is said to possess high degree of stiffness.
   c) Hardness:
      It is the property of which material resist the penetration of other bodies into it. Hardness measurement can be defined as macro-, micro- or nano-scale according to the forces applied and displacements obtained.
   d) Toughness:
      It is the ability of a material to resist fracture under impact load, or its yhe area under the stress-strain curve. Tough materials can withstand large deformation together with high stress without fracture.
2- Thermal properties

*Thermal property* refers to the response of a material to the application of heat. As a solid absorbs energy in the form of heat, its temperature rises and its dimensions increase. **Heat capacity, thermal expansion, and thermal conductivity** are properties that are often critical in the practical utilization of solids.

a) **Heat capacity**

A solid material, when heated, experiences an increase in temperature signifying that some energy has been absorbed. **Heat capacity** is a property that is indicative of a material’s ability to absorb heat from the external surroundings; it represents the amount of energy required to produce a unit temperature rise.

b) **Thermal expansion**

Most solid materials expand upon heating and contract when cooled. The change in length with temperature for a solid material may be expressed as follows:

\[
\frac{t_f - t_0}{l_0} = \alpha_l(T_f - T_0)
\]

\[
\frac{\Delta l}{l_0} = \alpha_t \Delta T
\]
Where \( l_0 \) and \( l_f \) represent, respectively, initial and final lengths with the temperature change from \( T_0 \) to \( T_f \). The parameter \( \alpha \) is called the **linear coefficient of thermal expansion**; it is a **material property that is indicative of the extent to which a material expands upon heating**.

\[ c) \quad \text{Thermal conductivity} \]

Thermal conduction is the phenomenon by which heat is transported from high- to low-temperature regions of a substance. **The property that characterizes the ability of a material to transfer heat is the thermal conductivity.**

**3- Electrical, Magnetic And Optical Properties**

We start with electrical conduction and insulation (Figure 1.4(a)). Without electrical conduction we would lack the easy access to light, heat, power, control and communication that today we take for granted. Metals conduct well **copper and aluminum** are the best of those that are affordable. But conduction is not always a good thing. Fuse boxes, switch casings, all require insulators. Here the property we want is **resistivity**, the inverse of electrical conductivity. **Most plastics and glass** have high resistivity (Figure 1.4(a)) they are used as insulators. Electricity and magnetism are closely linked. Electric currents induce magnetic fields; a moving magnet induces an electric current. Some metals called **ferromagnets** because have the capacity to trap a magnetic field permanently. These are called ‘hard’ magnetic materials because, once magnetized, they are hard to demagnetize. They are used as permanent magnets in headphones, motors and dynamos. Here the key property is the **remanence**, a measure of the intensity of the retained magnetism.
A few others soft Magnet materials are easy to magnetize and demagnetize. They are the materials of transformer cores. They have the capacity to conduct a magnetic field, but not retain it permanently (Figure 1.4(b)). For these a key property is the saturation magnetization, which measures how large a field the material can conduct. Materials that are opaque reflect light; those that are transparent refract it, and some have the ability to absorb some wavelengths (colors) while allowing others to pass freely (Figure 1.4(c)).