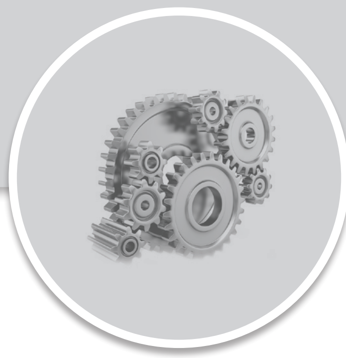
# MECHANICAL ENGINEERING

## Material Science



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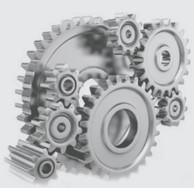



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# Material Science

CHAPTER

1

# Introduction to Engineering Materials

## 1.1 INTRODUCTION

Why do we study materials?

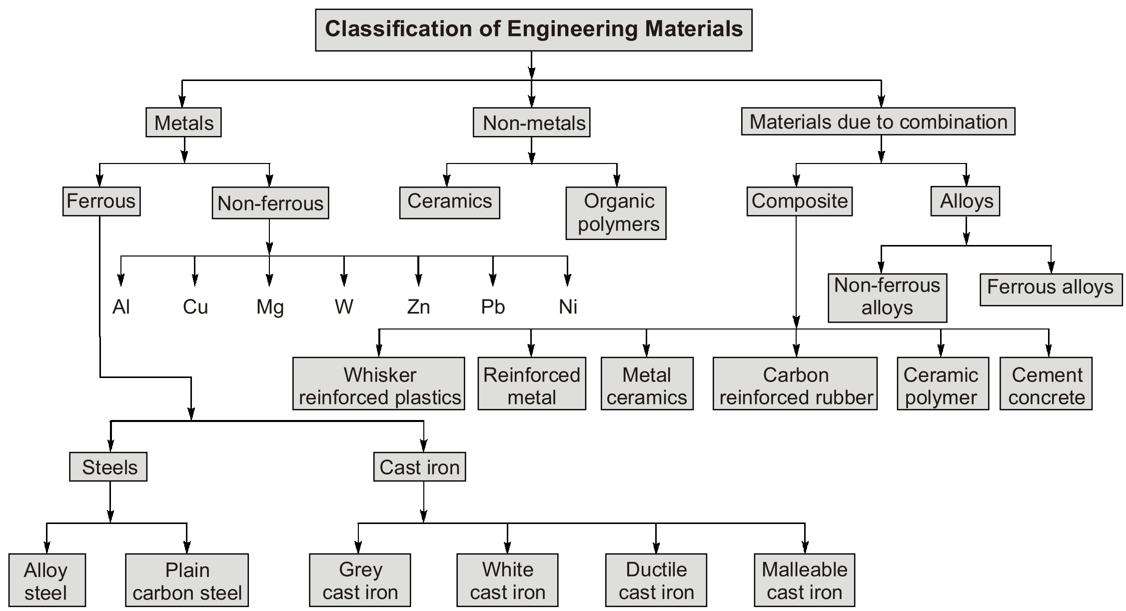
Many times an applied scientist or engineer, whether mechanical, civil, chemical, or electrical, is at one time or another exposed to a design problem involving materials, such as a transmission gear, the superstructure for a building, an oil refinery component, or an integrated circuit chip. Of course, materials scientists and engineers are specialists who are totally involved in the investigation and design of materials.

Many times, a materials problem is one of selecting the right material from the thousands available. The final decision is normally based on several criteria. First of all, the **in-service conditions** must be characterized, for these dictate the properties required of the material. On only rare occasions does a material possess the maximum or ideal combination of properties. Thus, it may be necessary to trade one characteristic for another. The classic example involves strength and ductility; normally, a material having a high strength has only a limited ductility. In such cases, a reasonable compromise between two or more properties may be necessary. A second selection consideration is any **deterioration of material properties** that may occur during service operation. For example, significant reductions in mechanical strength may result from exposure to elevated temperatures or corrosive environments.

Finally, probably the overriding consideration is that of economics: What will the finished product cost? A material may be found that has the ideal set of properties but is prohibitively expensive. Here again, some compromise is needed. The cost of a finished piece also includes any expense incurred during fabrication to produce the desired shape. The more familiar an engineer or scientist is with the various characteristics and structure property relationships, as well as the processing techniques of materials, the more proficient and confident he or she will be in making judicious materials choices based on these criteria.

## 1.2 MATERIAL CLASSIFICATION

Most engineering materials may be classed into one of the following types:




### 1.2.1 Metals

Metals are the ones which have **free electrons**. They are capable of changing shape upon machining and gives good finish. At room temperature they are usually solid (except mercury) and to some extent they are malleable and ductile. Atoms in metals and their alloys are arranged in a very orderly manner and relatively dense in comparison to ceramics and polymers. Metals are good conductors of heat and electricity. Example Copper, Silver and Gold etc.

**General Characteristics of Metals**

- Luster
- Hardness
- Low specific heat
- Plastic deformability
- Good thermal and electrical conductivity
- Relatively high melting point
- Strength
- Ductility
- Malleability
- Opaque
- Stiffness
- Rigidity
- Formability
- Machinability
- Weldability
- Castability
- Dimensional stability.

**Examples of commonly employed metals are :**

Iron, Aluminium, Copper, Zinc, Magnesium, etc.

### 1.2.2 Ceramic Materials

- Ceramics usually consist of oxides, nitrides, carbides, silicates of various metals.
- Ceramics are any inorganic, non-metallic solids (or super-cooled liquids) processed or used at high temperatures.

- Ceramic materials are rock or clay mineral materials.
- Ceramic materials contain compounds of metallic and non-metallic elements, such as MgO, $SiO_2$, SiC, $BaTiO_3$, glass, etc. Such compounds contain both ionic and covalent bonds.
- In addition, they are typically very hard. Historically, ceramics have exhibited extreme brittleness (lack of ductility) and are high susceptibility to fracture. However, newer ceramics are being engineered to have improved resistance to fracture.

**Important characteristics of ceramics are :**

- Brittleness
- Resistance to high temperatures
- Abrasiveness
- Corrosion resistance
- High temperature strength
- Rock-like appearance
- Hardness
- Insulation (to flow of electric current)
- Opaque to light

**Examples of ceramic materials are :**

Sand, Glass, Brick, Cement, Concrete, Insulators, Silicon Carbide, Tungsten Carbide, Boron Nitride, Refractories, Abrasives, Plaster, etc.

### 1.2.3 Organic Polymers

Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen and other non-metallic elements; 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 Poly ethelene (PE), Nylon, Polyvinyl chloride (PVC) and Silicon rubber. These materials typically have low densities and may be extremely flexible.

**Important characteristics of organic materials are:**

- Lightweight
- Combustible
- Soft
- Ductile
- Not dimensionally stable
- Poor conductors of heat and electricity
- Poor resistance to temperature.

**Examples of organic materials are:**

Rubber, Plastics, Paper, Fuels, Wood, Lubricants, Textiles, Paints, Adhesives, Explosives, etc.

**Organic materials find its place in:**

1. Electric Insulation
2. Improving appearance
3. Fuels
4. As Vitamins and Medicines
5. Protection against corrosion, high temperature, extreme weather conditions, etc.

6. Refrigerants
7. Adhesives
8. Lubricants
9. Detergents
10. Explosives

### 1.2.4 Composites

A composite is composed of two (or more) individual materials that come from the categories previously discussed—metals, ceramics, and polymers. The design goal of a composite is to achieve a combination of properties that is not displayed by any single material and also to incorporate the best characteristics of each of the component materials. A large number of composite types are represented by different combinations of metals, ceramics, and polymers. Furthermore, some naturally occurring materials are composites—for example, wood and bone. However, most of those which we consider in our discussions are synthetic (or human-made) composites.

One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material (normally an epoxy or polyester). The glass fibers are relatively strong and stiff (but also brittle), whereas the polymer is more flexible. Thus, fiberglass is relatively stiff, strong and flexible. In addition, it has a low density. Another technologically important material is the Carbon Fiber–Reinforced Polymer (CFRP) composite-carbon fibers that are embedded within a polymer. These materials are stiffer and stronger than glass fiber-reinforced materials but more expensive. CFRP composites are used in some aircraft and aerospace applications, as well as in high-tech sporting equipment (e.g., bicycles, golf clubs, tennis rackets, skis/ snowboards) and recently in automobile bumpers.

### 1.2.5 Semiconductors

Semiconductors have electrical properties that are intermediate between the electrical conductors and insulators. Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms for which the concentrations may be controlled over very small spatial regions. The semiconductors have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries.

### 1.2.6 Nano Materials

One new material class that has fascinating properties and tremendous technological promise is the nanomaterials, which may be any one of the four basic types-metals, ceramics, polymers, or composites. However, unlike these materials, they are not distinguished on the basis of their chemistry but rather their size; the nano prefix denotes that the dimensions of these structural entities are of the order of a nanometer ($10^{-9}$ m) as a rule, less than 100 nanometers (nm); (equivalent to approximately 500 atoms).

Prior to the advent of nanomaterials, the general procedure scientists used to understand the chemistry and physics of materials was to begin by studying large and complex structures and then investigate the fundamental building blocks of these structures that are smaller and simpler. This approach is sometimes termed as top-down science. However, with the development of scanning probe microscopes which permit observation of individual atoms and molecules, it has become possible to design and build new structures from their atomic-level constituents, one atom or molecule at a time (i.e., "materials by design"). This ability to arrange atoms carefully provides opportunities to develop mechanical, electrical, magnetic, and other properties that are not otherwise possible. We call this the bottom-up approach, and the study of the properties of these materials is termed as nanotechnology.

## 1.3 ENGINEERING REQUIREMENTS OF MATERIALS

- Engineering requirements of a material means what is expected from the material so that the same can be successfully used for making engineering components such a crankshaft, connecting rod, etc.
- When an engineer thinks of fabricating an engineering part, he goes in search of that material which possesses such properties that will permit the component part to perform its functions successfully while in use. For example, one may select high speed steel for making a milling cutter or a power hacksaw blade.
- The main engineering requirements of materials fall under three categories :
    1. Fabrication requirements
    2. Service requirements
    3. Economic requirements.

Fabrication requirements mean that the material should be able to get shaped (e.g., cast, forged, formed, machined, sintered etc.) and joined (e.g., welded, brazed, etc.) easily. Fabrication requirements relate themselves with materials' machinability, ductility, castability, heat-treatability, weldability, etc.

Service requirements imply that the material selected for the purpose must stand up to service demands, e.g., proper strength, wear resistance, corrosion resistance, etc.

Economic requirements demand that the engineering part should be made with minimum overall cost. Minimum overall cost may be achieved by proper selection of both technical and marketing variables.

## 1.4 TYPES OF BOND

Solid state exhibits a crystal structure which is having a definite geometry except amorphous state like glass. Various types of bonding forces in crystal structure:

1. **Ionic Bond :** Strong electrostatic attraction between cations and anions is called ionic bond. These bonds are permanent and atoms doesn't drift throughout the lattice structure.
2. **Covalent Bond :** In this type of bond there is a sharing of one or more electrons from the adjacent atoms.
3. **Metallic Bond :** Metallic bond is formed when material (metal) have one, two or three valence electrons. These electrons are not bound to any particular atom in the solid and drift through out the entire metal.
4. **Vander Waals Forces :** These are attractive forces that hold molecules close together. These attractive forces are more commonly referred to as intermolecular forces. The bond formation generally takes place in neutral atoms like inert gases.

■■■■

## OBJECTIVE BRAIN TEASERS

**Q.1** Which of the following methods of synthesis of nanomaterials has solid as starting phase?
1. Electro deposition 2. Sliding wear
3. Spark erosion 4. Ball milling
(a) 1, 2 and 3 (b) 1, 2, 3 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

**Q.2** Two important properties of nano substances are
(a) Pressure and friction
(b) Temperature and friction
(c) Sticking and temperature
(d) Sticking and friction

**Q.3** Match **List-I** (Materials) with **List-II** (Application) and select the correct answer using the codes given below the lists:

**List-I**
**A.** Fibre reinforced plastics
**B.** Acrylics
**C.** Phenolics
**D.** Butadiene rubber

**List-II**
**1.** Automobile tyre
**2.** Aircraft
**3.** Lenses
**4.** Electric switch cover

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 1 | 4 | 3 | 2 |
| (b) | 2 | 3 | 4 | 1 |
| (c) | 1 | 3 | 4 | 2 |
| (d) | 2 | 4 | 3 | 1 |

**Q.4** Nano composite materials are highly preferable in design consideration for their
(a) High resistance to crack propagation
(b) Vibration resistance
(c) Impact resistance
(d) High resilience

**Q.5** **Statement (I):** A short specimen elongates proportionally more during the same time period than does a long specimen.
**Statement (II):** The strain rate is a function of the specimen length.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

## ANSWERS KEY

**1.** (d) **2.** (d) **3.** (b) **4.** (b) **5.** (a)

## HINTS & EXPLANATIONS

**1. (d)**
Electro deposition has liquid as its starting phase, while rest three have solid as starting phase.

**2. (d)**
For Nano substances both sticking and friction are considerable properties.

**3. (b)**

| Materials | Their application |
|---|---|
| Acrylics | Lenses, drafting equipment |
| Phenolics | Motor housing, electrical fixtures |
| Butadiene rubber | Automobile tyres |
| Fibre reinforced plastic | Aircraft |

**5. (a)**
Shorter the specimen, more the strain rate if subjected to same deformation in a given time. Illustrated below is two rubber bands, one of 20 mm and the other of 100 mm gauge length. Both are elongated by 10 mm within a period of 1 sec. The strains rates are 0.5 $s^{-1}$ and 0.1 $s^{-1}$ respectively, which implies short band being subjected to a strain rate five times as high as that for the long band, although both are being stretched at the same deformation rate.

## CONVENTIONAL BRAIN TEASERS

**Q.1** Define nano materials. How are they classified? What are the different types of method used to manufacture nano-materials? Explain briefly arc discharge method.

**Sol.**

**Nano-materials :** The materials which have at least one external dimension or any internal structure (like grain size or any separated small structures in materials) is less than 100 nm are called nanomaterials.
In other words, these are those materials which contain an internal morphology less than 100 nm. The internal morphology may be in the form of sphere, clusters, fibres, tubes, etc.

**Nanomaterials are classified according to the internal morphology, as**

**(i)** Zero dimensional (spheres, clusters).
**(ii)** One dimensional (tubes, fibres and rods).
**(iii)** Two dimensional (films).
**(iv)** Three dimensional (particles).

**Methods used to manufacture nano-materials :**

**(i)** Top-down approach (bulk material to nanomaterial).
**(ii)** Bottom to top approach (atoms to nanomaterial).

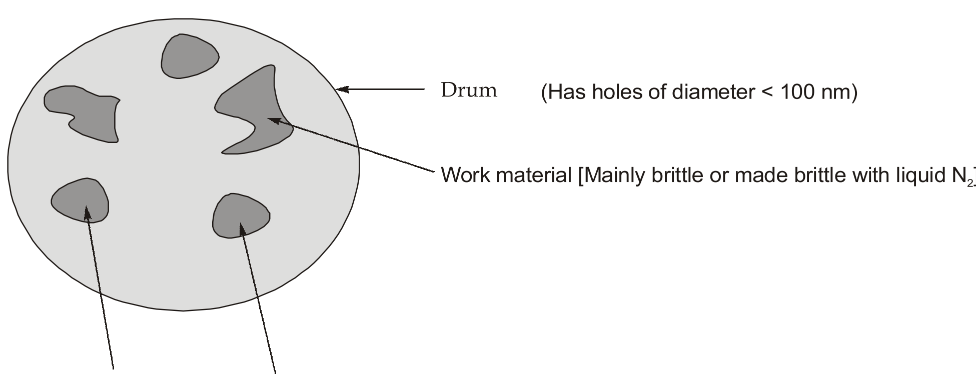
**Arc discharge method :** It is used to make carbon nano tubes (CNT).

**Q.2** Briefly explain the following methods to produce nano-materials

**(i)** Mechanical grinding **(ii)** Laser ablation

**Sol.**

**(i) Mechanical grinding :** It is one of the most popular method to produce nano-materials.




- Work materials alongwith hardened steel balls is placed inside a drum and then drum is rotated.
- When work material is hit repeatedly by hardened steel balls gradually it will convert into nano-material. But this nano-materials will have same contamination of steel. As the mixer of nano-material and steel coming out through the drum, we create a magnetic field in its path. Since, steel is having magnetic behaviour so will be attracted towards magnetic field. But when the nano-material is also having magnetic properties three extensive produces are involved to purify the nano-material.