Engineering Materials

Engineering Materials

Generally, engineering materials may be classified into the **following five categories:**

1) **Metals and alloys**

2) **Ceramics**

3) **Polymers**

4) **Composites**

5) **Advanced materials**: such as semiconductors, biomaterials, smart materials, and nano-engineered materials.

1.) Metals and alloys

Metals

- **Metals are elements** which have free valence electrons which are responsible for their **good thermal and electrical conductivity.**

- **Metals readily loose their electrons** to form positive ions.

- The metallic bond is held by electrostatic force between **delocalized electrons** and positive ions.

Classification of metals and alloys

1.) Metals and alloys:

Classification of metals and alloys:

Ferrous Metals: are those which **have the iron as their main constituent,** such as **cast iron, wrought iron and steel.**

Nonferrous: are those **which have a metal other than iron as their main constituent,** such as **copper, aluminum, brass, tin, zinc,** etc.

Principal iron ores

The **principal iron ores** with their metallic contents are shown in the following table :

Iron ore	Chemical formula	Color	Iron content (%)
Magnetite	Fe_2O_3	Black	72
Hematite	Fe_3O_4	Red	70
Limonite	$FeCO_3$	Brown	60-65
Siderite	Fe_2O_3	Brown	48

General properties of metals and alloys

1.) Metals and alloys: General properties:

- High electrical conductivity
- High thermal conductivity
- Ductile and relatively high stiffness
- Toughness and strength

- **Metals and alloys are suitable for** machining, casting, forming, stamping and welding.
- Nevertheless, they are **susceptible to corrosion**.

Applications of metals and alloys

1.) Metals and alloys: Applications

- **Structures:** buildings, bridges, etc.
- **Automobiles:** body, springs, engine block, etc.
- **Airplanes:** engine components, fuselage, landing gear assembly
- **Trains:** rails, engine components, body, wheels
- **Machine tools**: drill bits, hammers, screwdrivers, saw blades
- **Electrical wiring** and Magnets.

Ferrous Alloys - Cast Iron

Ferrous Alloys: in which **iron is the main constituent**

- **1.Cast Iron**

  The cast iron is **obtained** by re-melting **pig iron with coke and limestone in a furnace** known as cupola.

- It is **primarily an alloy of iron and carbon**. The **carbon contents** in cast iron **varies from 1.7 per cent to 4.5 per cent.**

- Since the **cast iron is a brittle material**, therefore, it cannot be used in those parts of machines which are subjected to shocks.

- **Carbon = 1.7 to 4.5%;** and the remaining is iron (100 – 4.5 %= 95.5%)

Ferrous Alloys - Various Cast Iron

2.Grey cast iron.

Carbon = 3 to 3.5%; Silicon = 1 to 2.75%; Manganese = 0.40 to 1.0%; Phosphorous = 0.15 to 1% ; Sulphur = 0.02 to 0.15% ; and the remaining is iron (100 - 8.4 = 91.6%)

3. White cast iron.

Carbon = 1.75 to 2.3% ; Silicon = 0.85 to 1.2% ; Manganese = less than 0.4% ; Phosphorus = less than 0.2%; Sulphur = less than 0.12%, and the remaining is iron (100 – 4.2 = 95.8%)

4. Chilled cast iron.

It is a white cast iron produced by **quick cooling of molten iron**.

Ferrous Alloys-Wrought Iron

Ferrous Alloys: in which **iron is the main constituent**

- **5. Wrought Iron**
  It is the purest iron which **contains at least 99.5% iron** but may contain up to 99.9% iron.
- The **typical composition of a wrought iron** is
- **Carbon = 0.020%,** Silicon = 0.120%, Sulphur = 0.018%, Phosphorus = 0.020%, Slag = 0.070%, and the **remaining is iron (100 – 2.48 = 99.752%).**

Wrought iron **can be easily forged or welded.**

It is **used for** chains, crane hooks, railway couplings, water and steam pipes.

Ferrous Alloys- Steel

Ferrous Alloys: in which **iron is the main constituent**

- **6. Steel**

  It is **an alloy of iron and carbon**, with **carbon content up to a maximum of 1.5%.**

- Types of carbon steel

  1. Dead mild steel — up to 0.15% carbon

  2. Low carbon or mild steel — 0.15% to 0.45% carbon

  3. Medium carbon steel — 0.45% to 0.8% carbon

  4. **High carbon steel — 0.8% to 1.5% carbon**

Ferrous Alloys-**Alloy Steel**

7. Alloy Steel

An alloy steel may be **defined as a steel** to which **elements other than carbon are added in sufficient amount** to produce an improvement in properties.

Nickel. It increases the strength and toughness of the steel. These steels **contain 2 to 5% nickel and from 0.1 to 0.5% carbon**.

- **A nickel steel alloy** containing 36% of nickel is known as invar.
- It has nearly zero coefficient of expansion.
- So it is in great demand **for measuring instruments and standards of lengths** for everyday use.

Chrome steels and tungsten steels

Alloy steels:

- ***Chromium* (chrome steels)**
  The most common **chrome steels** contains from 0.5 to 2% chromium and 0.1 to 1.5% carbon. The chrome steel is **used for balls, rollers and races for bearings.**
  Chrome nickel steel is extensively used for motor car crankshafts, axles and gears requiring great strength and hardness.
- ***Tungsten*. (tungsten steels)**
  Steel containing 3 to 18% tungsten and 0.2 to 1.5% carbon is **used for cutting tools**. The **principal uses of tungsten steels** are for cutting tools, dies, valves, taps and permanent magnets

Ferrous Alloys: *Vanadium* **and** ***Manganese*** **alloy steel**

- ***Vanadium* alloy steel**

  It aids in obtaining a fine grain structure in **tool steel**. The addition of a very small amount of vanadium (less than 0.2%) produces a marked increase in tensile strength and elastic limit in low and medium carbon steels without a loss of ductility.

- ***Manganese* alloy steel**

  The manganese alloy steels containing over 1.5% manganese with a carbon range of 0.40 to 0.55% are **used extensively in gears, axles, shafts** and other parts where high strength combined with fair ductility is required.

Ferrous Alloys: other alloy steels

- ***Silicon* alloy steel**

  Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4% carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springs and corrosion resisting materials.

  Si = **1 to 2 %, C** = 0.1 to 0.4% and rest iron

  ***Cobalt* alloy steel**

  It gives red hardness by retention of hard carbides at high temperatures.

- ***Molybdenum* alloy steel**

  A very small quantity (0.15 to 0.30%) of molybdenum is generally used with chromium and manganese (0.5 to 0.8%) to make **molybdenum steel**. **Mo= 0.15 to 0.30% and Cr & Mn = 0.5 to 0.8%, and rest iron**

  These steels possess extra tensile strength and are used for air-plane fuselage and automobile parts. It can replace tungsten in high speed steels.

Ferrous Alloys: Stainless Steel

- **8. Stainless Steel**

  Stainless Steel is defined as that steel which when correctly heat treated and finished, **resists oxidation and corrosive attack** from most corrosive media.

- The different types of stainless steels are discussed below :

  1. *Martensitic stainless steel*.

  The **chromium steels** **containing 12 to 14 per cent chromium** and 0.12 to 0.35 per cent carbon are the first stainless steels developed. Cr = **12 to 14 %, C** = 0.12 to 0.35% and rest iron

Ferrous Alloys: Steels and stainless steel

- **Ferritic stainless steel.** The steels containing greater amount of chromium (from 16 to 18 per cent) and about 0.12 per cent carbon are called **ferritic stainless steels.**
- **Cr = 16 to 18 %, C = 0.12 %** and rest iron
  Austenitic stainless steel. The steel containing high content of both chromium and nickel are called **austenitic stainless**
- **Steels.** There are many variations in chemical composition of these steels.
- The **most widely used steel** contain 18 per cent chromium and 8 per cent nickel with carbon content as low as possible.
- Such a steel is commonly known as **18/8 steel.**
- **SS = Cr = 18 % + Ni = 8 % + C = very low %+ iron**

Non-ferrous Metals - Al and Al alloy

- **Non-ferrous Metals** are those **which have a metal other than iron as their main constituent,** such as **copper, aluminum, brass, tin, zinc,** etc.

  1. Aluminium

  It is white metal produced by electrical processes from its **oxide (alumina),** which is prepared from a clayey mineral called ***bauxite*.**
- It is a light metal having specific gravity 2.7 and melting point 658°C. The tensile strength of the metal varies from 90 MPa to 150 MPa.

Aluminum Alloys

***Duralumin*.** Its composition is as follows:

Copper = 3.5 – 4.5%; Manganese = 0.4 – 0.7%; Magnesium = 0.4 – 0.7%, and **the remainder is aluminum**.

Non-ferrous Metals - Cu and Cu alloy Brass

2. Copper

- It is one of the most widely used non-ferrous metals in industry
- It is a **soft, malleable and ductile material** with a reddish-brown appearance.
- Its specific gravity is 8.9 and melting point is 1083°C.
- The tensile strength varies from 150 MPa to 400 MPa under different conditions.

- Copper Alloys
- ***Copper-zinc alloys* (*Brass*).** The most widely used **copper-zinc alloy is brass.** There are various types of brasses, depending upon the proportions of copper and zinc.
- **Brass** is fundamentally **a binary alloy of** copper with zinc each 50%.

Non-ferrous Metals - Cu and Cu alloy Bronze

- **Copper-tin alloys (Bronze).** The alloys of copper and tin are usually termed as bronzes.

- The useful range of **composition of Bronze is** 75 to 95% copper and 5 to 25% tin.

- **Gun Metal**
  It is **an alloy of copper, tin and zinc.**
- It usually contains 88% copper, 10% tin and 2% zinc.

Non-ferrous Metals - Pb and Tin alloy

- **3. Lead:** The lead base alloys are employed where a cheap and corrosion resistant material is required.
- An alloy containing 83% lead, 15% antimony, 1.5% tin and 0.5% copper is **used for large bearings** subjected to light service.
- **4. Tin**
  It is brightly shining white metal.
- It is soft, malleable and ductile.
- It can be rolled into very thin sheets.
- It is used for making important alloys, fine solder, as a protective coating for iron and steel sheets and for making tin foil used as moisture proof packing.
- A tin base alloy containing 88% tin, 8% antimony and 4% copper is called **babbit metal.**

Non-ferrous Metals – Ni base alloy

- **5. Nickel Base Alloys**
- **Monel metal.** It is an important alloy of nickel and copper.
- It contains 68% nickel, 29% copper and 3% other constituents like iron, manganese, silicon and carbon.
- **Inconel.** It consists of 80% nickel, 14% chromium, and 6% iron.
- **Nichrome.** It consists of 65% nickel, 15% chromium and 20% iron.
- **Nimonic.** It consists of 80% nickel and 20% chromium.

Ceramics Materials

2.) Ceramics:

Inorganic, **non-metallic** crystalline compounds, usually oxides (SiO_2, Al_2O_3, MgO, TiO_2, BaO), Carbides (SiC), Nitrides (Si_3N_4), Borides (TiB_2), Silicide (WSi_2, $MoSi_2$).

Some literature includes glasses in the same category, however; **glasses are amorphous (nano crystalline) compounds** i.e. they possess "short range" order of atoms.

Ceramics as Engineering Materials

2.) Ceramics: Classification

Two principal categories:

- ✔ Application base system or
- ✔ composition base system.

Application based ceramic materials are:

i. Traditional Ceramics: Includes pottery, china, porcelain products…etc., these products utilizes **natural ceramic ores.**

ii. Advanced Ceramics: Alumina, magnesia, Carbides, Nitrides, Borides, Silicide …etc., they are **synthetic materials,** usually of better mechanical properties. Electronic ceramics falls in the same category.

General properties of Ceramics Materials

2.) Ceramics: General properties

- Light weight
- Hard
- High strength
- Stronger in compression than tension
- Tend to be brittle
- Low electrical conductivity
- High temperature resistance
- Corrosion resistance

Applications of Ceramics Materials

2.) Ceramics: Applications

- Electrical insulators
- Thermal insulation, coatings and windows
- Television screens
- Optical fibers (glass) and corrosion resistant
- Electrical devices: capacitors, resistors, transducers, etc.
- **Highways and roads (concrete) and Building blocks (bricks)**
- Building binders (cement, gypsum)
- Biocompatible coatings (fusion to bone)
- Magnetic materials (audio/video tapes, hard disks, etc.)

Polymer as Engineering Materials

3.) Polymers:

- A polymer is long chain molecule made up many repeating units, called monomers.
- Polymers can be natural (organic) or synthetic.
- The properties of polymers are linked directly to their structure, which is dictated mostly by intermolecular bonds.

Examples:

- Polymers are everywhere: in plastics (bottles, toys, packaging),
- cosmetics, shampoos and other hair care products,
- **contact lenses**, nature (crab shells, amber),
- food (proteins, starches, gelatin, gum, gluten),
- fabric, balls, sneakers, and even in your DNA!

General properties of Polymers

3.) Polymers: General properties

- **Compared with metals**:

❖ Polymers have lower density, lower stiffness and tend to creep.

❖ High thermal expansion and corrosion resistance.

❖ Low electrical and thermal conductivities.

❖ The prime weakness is that polymers do not withstand high temperatures.

Classification of Polymers

3.) Polymers: Classification according to their properties

i.) **Plastics:** **(Hard),** they can be semi-crystalline or amorphous (glassy).

1. **Thermoplastics:** such as Polyethylene (PE) and Poly methyl methacrylate (Acrylic and PMMA) are composed of "linear" polymer chains.

   They flow under shear when heated. They can be compression- or injection- molded.

2. **Thermosets:** such as Polystyrene (PS) and Bakelite are composed of "branched" polymer chains. They do not flow when heated. The monomers are 'cured' in a mold.

ii.) **Elastomers:** **Rubbery (Soft)** cross-linked solids that will deform elastically under stress, e.g. natural rubber

iii.) **Solutions:** Viscosity modifiers, lubricants.

Polymers: Applications and Examples

3.) Polymers: Applications and Examples

- Adhesives and glues
- Containers
- Moldable products (computer casings, telephone handsets, disposable razors)
- Clothing and upholstery material (vinyl's, polyesters, nylon)
- Water-resistant coatings (latex)
- Biomaterials (organic/inorganic interfaces)
- Liquid crystals
- Low-friction materials (Teflon)
- Synthetic oils and greases
- Soaps and surfactants

Composite Materials

4.) Composite:

- A combination of two or more materials to achieve better properties than that of the original materials.
- These materials are usually composed of a “Matrix” and one or more of “Filler” material.
- The **primary objective of engineering composites** is to increase strength to weight ratio.
- Composite material properties depends on type of filler materials and the method of fabrication.

Engineering Materials

4.) Composite:

Matrix material serves several functions in the composite :

- Provides the bulk form of the part or product
- Holds the embedded phase in place
- Shares the load with the secondary phase

Engineering Materials

4.) Composite:

The embedded phase is most commonly one of the following shapes:

- Fibers, particles, flakes

Orientation of fibers:

- **One-dimensional**: maximum strength and stiffness are obtained in the direction of the fiber
- **Planar:** in the form of two-dimensional woven fabric
- **Random or three-dimensional:** the composite material tends to posses isotropic properties

Composite: General properties

4.) Composite: General properties

- Low weight
- **High stiffness.**
- Brittle
- **Low thermal conductivity**
- High fatigue resistance

Their **properties can be tailored** according to the component materials.

Classification of Composites

4.) Composite: Classification

i.) Particulate composites (small particles embedded in a different material): e.g. Cermet (Ceramic particle embedded in metal matrix) and filled polymers.

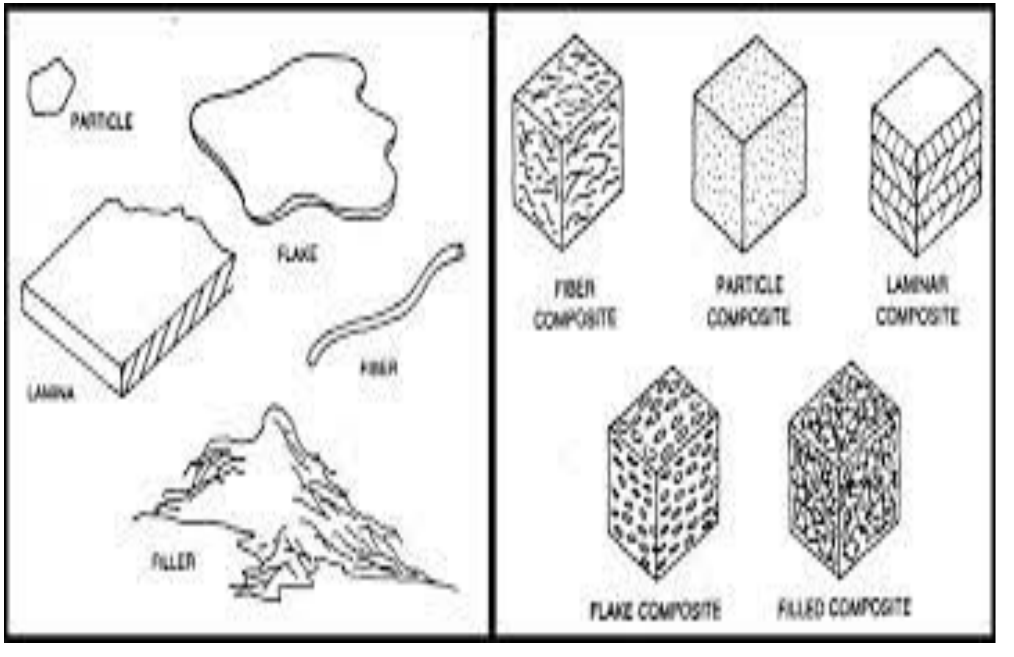
ii.) Laminate composites: e.g. (golf club shafts, tennis rackets).

iii.) Fiber reinforced composites: e.g. Glass Fiber (GFRP) and Carbon fiber reinforced polymers (CFRP).

Engineering Materials

4.) Five basic types of composite materials:

- Fiber,
- **particle,**
- flake,
- **laminar or layered and**
- filled composites.



Engineering Materials

4.) Composite: Classification:

- **Metal Matrix Composites (MMCs)**
  - Mixtures of carbides and metals, such as Al-MMC and other
  - Aluminum or magnesium reinforced by strong, high stiffness fibers
- **Ceramic Matrix Composites (CMCs)**
  - Least common composite matrix
  - Aluminum oxide and silicon carbide are materials that can be embedded with fibers for improved properties, especially in high temperature applications
- **Polymer Matrix Composites (PMCs)**
  - Thermosetting resins are the most widely used polymers in PMCs.
- Epoxy and polyester are commonly mixed with fiber reinforcement

Applications of Composite

4.) **Composite:** Applications

- Sports equipment (golf club shafts, tennis rackets, bicycle frames)
- **Aerospace materials**
- Thermal insulation
- **Concrete**
- "Smart" materials (sensing and responding)
- **Brake materials**

Applications of Composite

4.) Composite: Applications

Examples of composite material applications

- Reinforced cement concrete (RCC), 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, thick steel fibers.

- Wood is a natural composite of cellulose fibers in a matrix of polymer called lignin.

Advanced Engineering Materials

5.) Advanced Materials:

- Materials that are utilized in high-technology (or high-tech) applications are sometimes termed advanced materials.
- High technology mean a device or product that operates or functions **using relatively intricate and sophisticated principles;** examples include electronic equipment (camcorders, CD/DVD players, etc.), computers, fiber-optic systems, spacecraft, aircraft, and military rocketry.
- These **advanced materials are typically traditional materials whose properties have been enhanced,** and also newly developed, high-performance materials.
- They may be of all material types (e.g., metals, ceramics, polymers), and are normally expensive.

Engineering Materials

5.) Advanced Materials: include:

- **Semiconductors-**having electrical conductivities intermediate between conductors and insulators.
- **Biomaterials-**which must be compatible with body tissues.
- **Smart materials** - those that **sense and respond to changes** in their environments in predetermined manners.
- **Nano materials -**those that have structural features of the **order of a nanometer,** some of which may be designed on the atomic/molecular level.

Mechanical Properties of advanced Materials

Mechanical Properties :

- **Strength**
- Stiffness
- **Elasticity**
- Plasticity
- **Ductility**
- Brittleness
- **Malleability**
- Toughness
- **Machinability**
- Resilience
- **Creep**
- Fatigue
- **Hardness**

Definition of Properties

- **Strength.** It is the **ability of a material to resist the externally applied forces without breaking** or yielding. The internal resistance offered by a part to an externally applied force is called stress.
- **Stiffness.** It is the **ability of a material to resist deformation** under stress. The modulus of elasticity is the measure of stiffness. Steel deflects more in comparison of cast iron.
- **Elasticity.** It is the **property of a material to regain its original shape after deformation** when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.

Plasticity and ductility

- ***Plasticity*.** It is property of a material which **retains the deformation produced under load permanently.**
- This property of the material is **necessary for forgings**, in stamping images on coins and in ornamental work.

- ***Ductility*.** It is the **property of a material enabling it to be drawn into wire** with the application of a tensile force.
- A ductile material must be both strong and plastic.
- The ductility is usually measured by the terms, percentage elongation and percentage reduction in area.
- The ductile material commonly used in engineering practice (in order of diminishing ductility) are **mild steel, copper, aluminum, nickel, zinc, tin and lead.**

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- **Brittleness.** It is the **property of a material opposite to ductility.**
- It is the **property of breaking of a material with little permanent distortion**.
- Brittle materials **when subjected to tensile loads, snap off without giving any sensible elongation**. Cast iron is a brittle material.
- **Malleability.** It is a special case of ductility which **permits materials to be rolled or hammered into thin sheets. An ability of a material to undergo plastic deformation without rupture when subjected to compressive force.** A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are **gold , silver, lead.**

Engineering Materials

- **Toughness.**
- It is the **property of a material to resist against fracture.**
- The toughness of the material decreases when it is heated.
- It is property of a material which enables it to absorb energy and deform plastically before fracture.
- This property is depends on strength and ductility of the material.
- A material having high tensile strength coupled with good ductility is said to be a tough material.
- The toughness of a material can be enhanced by alloying.

Engineering Materials

- **Machinability.**
- It is the **property of a material which refers to a relative ease with which a material can be cut.**
- The machinability of a material can **be measured** in a number of ways such as comparing the tool life for cutting different materials or
- thrust required to remove the material at some given rate or
- the energy required to remove a unit volume of the material.
- It may be noted that brass can be easily machined than steel.

Engineering Materials

- **Resilience.** It is the **property of a material to absorb energy and to resist shock and impact loads.**
- It is measured by the amount of energy absorbed per unit volume within elastic limit.
- This property is **essential for spring materials.**
- **Creep.** When a part undergo permanent deformation under a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called **creep.**
- This property is considered in designing **internal combustion engines, boilers and turbines.**

Engineering Materials

- **Fatigue.**
- When a **material is subjected to repeated stresses**, it fails at much lower stresses as compared to its tensile strength.
- Such type of failure of a material is known as **Fatigue**.
- The **failure is caused** by means of a progressive crack formation which are usually fine and of microscopic size.
- This property is considered in **designing shafts, connecting rods, springs, gears, etc.**

Engineering Materials

- **Hardness.**
- It is a **very important property of the metals** and has a wide variety of meanings.
- It embraces many different properties such as **resistance to abrasion,wear,** scratching, deformation and machining etc.
- Hardness of a material can be enhanced considerably by heat treatment or cold working.
- Hardness of a material decrease with increase in temperature.

Factors affecting the selection of materials

An engineer must be in a position to choose (1) the optimum combination of **properties in a material (2)** at the lowest possible cost (3) without compromising the quality. Factors affecting the selection of materials

(i) Component shape

(ii) Dimensional tolerance

(iii) Mechanical properties

(iv) Fabrication (Manufacturing) requirements

(v) Service requirements

(vi) Cost

(vii) Availability of the material

What are the criteria and factors for material selection?

Q: What are the criteria of material selection?

A: Some of the important characteristics of materials are strength, durability, flexibility, weight, resistance to heat and corrosion, ability to cast, welded or hardened, machinability, electrical conductivity, etc. is the best indicator.

Material selection is the act of choosing the material best suited to achieve the requirements of a given application.

Q: Many different factors go into determining the selection requirements, such as mechanical properties, chemical properties, physical properties, electrical properties and cost.

These **different criteria must be weighed** during the material selection process.

What are the criteria and factors for material selection?

Q: What are the criteria of material selection?

A: Selecting Materials

- Identify product design requirements.
- Identify product element design requirements.
- Identify potential materials.
- Evaluate different materials.
- Determine whether any of the materials meet the selection criteria.

Q: **What are the 4 factors for engineering material selection?**

A: Factors affecting the selection of materials:

(i) Component shape:

(ii) Dimensional tolerance:

(iii) Mechanical properties:

(iv) Fabrication (Manufacturing) requirements:

What are the basic criteria for material selection?

Material selection is an essential aspect of product design and development. An appropriate material should meet many basic criteria including **efficient manufacturability, performance, reliability non-degradability and recyclability**.

Other important factors in material selection are

- Life
- Environment stability or response to exposure
- Cost
- Availability
- Related health issues

Engineering Materials

Procedure for materials selection:

- ✔ The selection of an appropriate material and its subsequent conversion into a useful product with desired shape and properties can be a rather complex process.
- ✔ Nearly every engineered item goes through a sequence of activities that includes: design material selection, process selection, production evaluation, and possible redesign or modification.
- ✔ The **selection of a specific mat**erial for a particular use is a very complex process.
- ✔ However, one can simplify the choice if the details about:

(i) operating parameters, (ii) manufacturing processes, (iii) functional requirements (iv) cost considerations are known.