

MODULE 3

ENGINEERING MATERIALS

The materials which have applications in engineering in making an article of utility are called as engineering materials.

Classification of engineering materials: Engineering materials are classified into following four types.

1) Metals and Alloys 2) Polymers 3) Ceramics 4) Composites.

Metals: A metal is a material that is typically hard, opaque, shiny, and features good electrical and thermal conductivity. Metals are generally malleable: they can be hammered or pressed permanently out of shape without breaking or cracking well as fusible and ductile

Metals can be either ferrous or non-ferrous. Ferrous metals contain iron while non-ferrous metals do not. Both ferrous and non-ferrous metals are divided into pure metals and alloys.

A pure metal is an element – Ex: iron, copper, gold - unalloyed (not mixed) with another substance. An alloy is a mixture of two or more elements (Ex: iron and carbon) to make another metal with particular properties (Ex: steel).

MECHANICAL PROPERTIES OF ENGINEERING MATERIALS

1. Strength: It is the property of a material which opposes the deformation or breakdown of material in presence of external forces or load.

2. Toughness: It is the ability of a material to absorb the energy and gets plastically deformed without fracturing

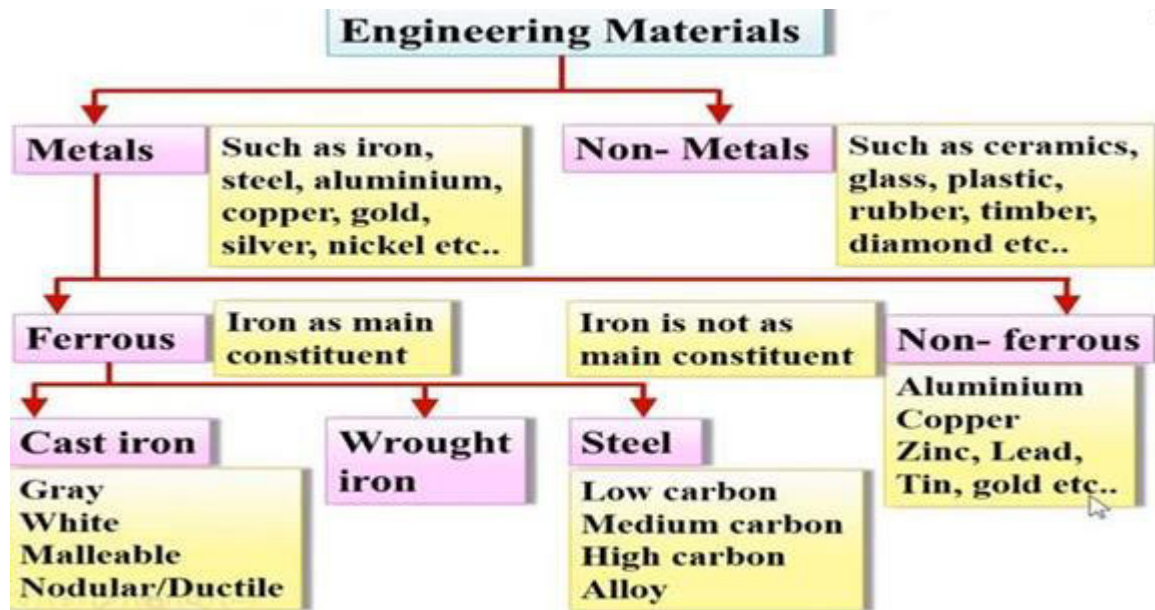
3. Hardness: It is the ability of a material to resist to permanent shape change due to external stress.

4. Brittleness: Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load. When a brittle material is subjected to a stress it observes very less energy and gets fractures without significant strain.

5. Ductility: Ductility is a property of a solid material which indicates that how easily a material gets deformed under tensile stress.

6. Malleability: Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress.

CLASSIFICATION OF ENGINEERING MATERIALS:



FERROUS METALS

Ferrous metals contain iron. Examples are cast iron, mild steel, medium carbon steel, high carbon steel, stainless steel, and high speed steel.

➤ Types of Ferrous metal

1. Cast iron

Composition: Alloy of iron and 2-5% carbon, 1-3% silicon and traces of magnesium, Sulphur and phosphorus

Properties and characteristics: it is very strong but brittle. Cast iron has relatively low melting point, is wear resistant, possesses good fluidity, has admirable machinability and is resistant to deformation

Application: It is used to manufacture machine frames, columns, beds and plates, housing flywheel, manhole cover, automotive parts such as engine block, cylinder head, gear box case and machine parts which are not subjected to tension and shocks.

2. Steel

Steel is an alloy of iron and carbon which is produced either by basic oxygen steelmaking process or by electric arc furnace.

Steels are broadly classified into

- a) Carbon Steels
- b) Alloy Steels
- c) Tool Steels

a) Carbon steels: Carbon steels are types of steel containing primarily iron and carbon. Other elements present in small proportions are sulphur, phosphorous, manganese and magnesium. The following types of carbon steel are.

- **Mild steel or Low carbon steel:**

Composition: It has a carbon content of 0.05 to 0.3%. The balance is iron. The most popularly used carbon steel is mild steel.

Properties and characteristics: Tough, ductile and malleable. Good tensile strength, poor resistance to corrosion

Application: General-purpose engineering material like rivets, bolts, keys plain washer boiler plate's shaft, camshafts and gear.

- **Medium carbon steel**

Composition: It has a carbon content of 0.3 - 0.6% carbon. The remainder is iron content.

Properties and characteristics: Strong, hard and tough, with a high tensile strength, but less ductile than mild steel.

Application: It finds application in transmission shafts, springs, spring washers, crane hooks and hand tools etc.

- **High carbon steel**

Composition: It has a carbon content of 0.6 - 1.5%. It has an iron content of 96% to 97%

Properties and characteristics: Even harder than medium carbon steel, and more brittle. Can be heat treated to make it harder and tougher

Application: Cutting tools, hammers, chisels, screw, punches, drills lathe tools, leaf springs and milling cutter

b) Alloy Steels

Alloy steel is an iron-based material, which, in addition to carbon, contains one or more intentionally added elements. Some of the common additions to alloy steel include: chromium, cobalt, columbium, molybdenum, manganese, nickel, titanium, tungsten, silicon, and vanadium. The alloying elements are added to the steel to improve one or more of its physical and/or mechanical properties, such as: hardness, strength, toughness, high-temperature performance, corrosion resistance, and wear resistance.

➤ **Stainless steel**

Stainless steel is the name of a family of iron-based alloys known for their corrosion and heat resistance. One of the main characteristics of stainless steel is its minimum chromium content of

10.5%, which gives it its superior resistance to corrosion in comparison to other types of steels.

Properties and characteristics: Hard and tough, resists wear and corrosion

Application: Cutlery, kitchen equipment, surgical equipment, chemical handling equipment and cutlery etc.,

➤ **Tool steel**

Tool steels are a family carbon and alloy steels having distinct characteristics such as hardness, wear resistance, toughness, and resistance to softening at elevated temperatures. Tool steels comprise carbide-forming elements such as chromium, vanadium, molybdenum and tungsten in different combinations.

The primary properties of tool steels are listed below:

- Toughness
- Wear resistance
- Hardness
- Heat resistance

The major applications of tool steels are in the following processes:

- Forming, stamping, cutting and shearing of plastics and metals
- Extrusion of plastic sections e.g vinyl window frames and pipes
- Stamping of computer parts from metal sheets
- Slitting of steel coils into strips
- Dies for compacting of powder metal into forms such as gears.

Application of ferrous Metals and alloys:

1. Structural area: Steel is used as reinforcement in building construction, and in fabrication of Grills, Gates etc.
2. Automobile: In the manufacture of automobile parts like Engine Blocks, Gear Box, Gears, Chassis etc.
3. Bearings: Used for Bearing Housing, Bushes, Ball OR Roller Bearings etc.
4. Decorative Items: Stair case, Doors and Windows, Fittings for residence, Office, Hotels, multiplexes etc.
5. Power generation: For the fabrication of Towers for the electricity Transmission Lines, Shafts for generators etc.
6. Household applications: For Stainless Steel utensils, Toys,
7. application: For the machine parts like Base, guide beds, Tool holders etc.
8. Tools, Jigs and Fixtures: For tools like cutting tools, hacksaw blade, chisels, vice, and

clamping devices etc

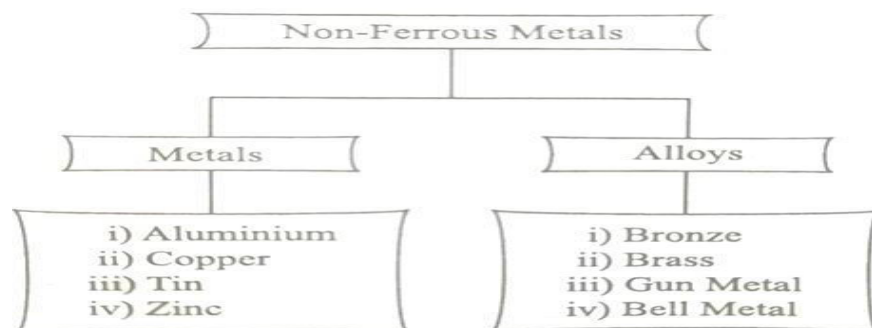
9. Transportation: For manufacturing of Hooks for crane, Crane OR Lift Wires etc. Railway Tracks,

10. Defense: for manufacture of Fighter Tanks, Weapons etc.

NON-FERROUS METALS & ALLOYS:

Metals containing elements other than iron as their chief constituents are usually referred to as non-ferrous metals.

Generally non-ferrous metals are costlier when compared to ferrous metals, but they are used for desirable properties. These desirable properties could be high conductivity, low weight, resistance to corrosion or non-magnetic property etc.



➤ **Types of Non-Ferrous metal**

1. Aluminium: It is one of the widely used metal in recent years which has replaced iron and steel because of its special properties like light weight and non-corrosiveness.

It is a white color metal extracted from bauxite. Their mechanical properties can be improved by mixing aluminium with other elements like silica, copper, zinc etc. These are called alloys of aluminium.

Properties and characteristics: Good strength-to-weight ratio, light, soft, ductile, good conductor of heat and electricity

Application: Kitchen equipment, window frames, general cast components.

1. Copper

Composition: Pure copper (an element)

Properties and characteristics: Malleable and ductile, good conductor of heat and electricity, good corrosion resistance and light weight.

Application: copper tubes used in refrigerator and air conditioners and radiators due to high thermal conductivity, electrical wires and cables, used to make door knobs.

3. Zinc: It is very resistant to corrosion from moisture. However, zinc is a very weak metal and is used mainly for coating steel.

Applications: used as a coating on screws, steel buckets etc. It is also used to galvanize iron based metals.

4. Lead: It is soft, malleable metal. It is also counted as one of the heavy metals. Lead has a bluish-white color after being freshly cut, but it soon tarnishes to a dull grayish color when exposed to air.

Applications: used for roof flashing, also used for batteries & for X-ray protection.

5. Tin: it is very ductile and very malleable material. It is resistant to corrosion from moisture. It is bright silver in appearance.

➤ **NON-FERROUS ALLOYS:**

When two or more metals are mixed together in different proportions to get a homogenous mixture is called as an alloy.

They have better properties than metals and have wide applications.

1. Brass: 60% Copper, 40% Zinc
2. Bronze: 90% Copper, 10% Zinc
3. Gun Metal: 60% Copper, 38% Zinc, 2% Tin
4. Bell Metal: 80% Copper, 20% Tin.

1. Brass: It is an alloy of copper and zinc in equal proportions. It is soft, ductile, gives a good surface finish and good tensile strength. It is non-corrosive to air and water but a poor conductor of electricity. This is widely used in hydraulic fittings, pump lining, bushes and bearings.
2. Bronze: It is an alloy of copper and tin. It is comparatively hard, wear resistant and can be cast or rolled into sheet, rods etc.
3. Gun metal: It is a special alloy which contains 10% tin, 88% Cu and 2% Zinc. It is very hard and resistant to corrosion by water and atmosphere. It is used in boiler fittings, bushes, bearing glands etc.
4. Bell metal: This contains 20% tin and rest copper. It is very hard and resistant to surface wear. It is used to make bell, utensils etc.

Application of Non-ferrous Metals and Alloys:

1. Structural area: Stair case, Windows, Doors, Pipe Fittings, Electrical Wires, galvanized Pipes etc.
2. Automobile: Engine Blocks, Body parts and automobile parts.

3. Bearings: Bushes OR Bearings for rotating parts for both industrial and domestic application.
4. Decorative Items: Interior items like Show lamps, Idols, Bells, Jewelry items, door and window fittings.
5. Power generation: Turbine blades and castings, Electrical bus bars etc.
6. House hold applications: Home appliances and Toys.
7. Aerospace: Structural parts like aircraft wings, electrical fittings and connectors etc.
Refrigeration: For refrigerator tubing (Condensers and evaporators), Heat Exchangers, solar water heaters etc.
8. Defense: Marine shaft and Turbine blades.

COMPOSITE MATERIALS

COMPOSITES

A material that is created from two or more constituent materials is called a composite material. A composite material can increase stiffness and strength. They are preferred over conventional materials because they enhance the underlying material's qualities and can be used in various contexts.

Definition:

Composite material is a material composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different from those of any of the constituents.

Matrix phase: The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

Dispersed (reinforcing) phase: The second phase (or phases) is embedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

CLASSIFICATION OF COMPOSITE MATERIALS:

Composite materials are classified as follows.

- Based on Matrix Material
- Based on Reinforcement



➤ **Based on Matrix:**

a) Metal Matrix Composites (MMC'S): The materials like Aluminum Copper etc. when mixed with other materials like Tungsten, Chromium, Titanium, Molybdenum Oxides and carbides are added as reinforcement materials to develop better hardness, strength in composite form these can be machined also.

Ex: Engine blocks and other parts of Automobiles, front and main landing gears and other parts of Aircraft.

b) Polymer Matrix Composites (PMC'S): The Polymer materials like resin, polyurethane and epoxy are reinforced with fibers (Glass fibers, Carbon Fiber), develop better hardness and strength properties.

Ex: Automobiles Bumpers, Air craft seats etc. use Fiber reinforced plastic (FRP).

c) Ceramic Matrix Composites (CMC'S): These are composed of ceramic materials reinforced with other ceramic materials. these composites can withstand high temperatures.

Ex: Exhaust Nozzles for Rockets to withstand high Temperatures. Aluminum oxide wheel mixed with silicon carbide gives better strength than Aluminum wheel.

➤ **Based on Reinforcement:**

a) Particulates: Particulates are the small irregular shaped reinforcement materials. These reinforcements have more or less equal size.

Fiber reinforced composite materials:

b) Continuous fiber: The reinforcement material is continuous and runs throughout the length of Matrix.

c) Discontinuous fiber: The reinforcement is in discontinuous form. The ratio of l/d is more.

Advantages of Composite Material

Composites have a lot of advantages. Strength, lightness, resistance to corrosion, design flexibility, and durability are essential attributes among them.

1. Strength: Composites outperform traditional materials like steel in terms of strength per kilogram. Composites' two main ingredients, fibers and resins, both contribute to their tensile strength. The weight is carried by the fibers, and the resins distribute it appropriately throughout the composite part.

2. Lightweight: Compared to most woods and metals, composite materials are lightweight. In both automobiles and aircraft, lighter weight improves fuel efficiency. Furthermore, lighter materials, from bridge decks to utility poles, are simpler to carry and assemble.

3. Durable: Composite-built structures are durable and require little care. Boats and other items built of composites have been in use for more than 50 years.

4. Flexible: Composites have a broad range of material combinations that can be used, which promotes design flexibility. The materials can be specially made to meet the particular requirements of each application. Additionally, composites are simple to mould into complex designs.

5. Resistant: Unlike other materials, composites are resistant to weather damage and corrosive substances. Because of this, they are suitable for situations where salt water, hazardous chemicals, temperature changes, and other harsh conditions are present constantly.

Application of composite materials in aerospace and automobiles:

Aerospace application:

1. Aerospace application needs materials with lesser weight and more strength.
2. Aircraft Wing and other structure parts are made of composites.
3. Main landing Gear and Doors.
4. Front landing Gear and Doors,
5. Helicopter blades.
6. Rocket Nozzles which require high temperature are made of Composites,'
7. Air craft passenger seats are made of FRP
8. The parts like Dash board, interiors, etc. are made of composites.

Application in automobiles:

Most of the parts of automobile parts which are made of steel are replaced by Composite materials, so that they can travel at faster speed and better fuel consumption. The followings are few applications.

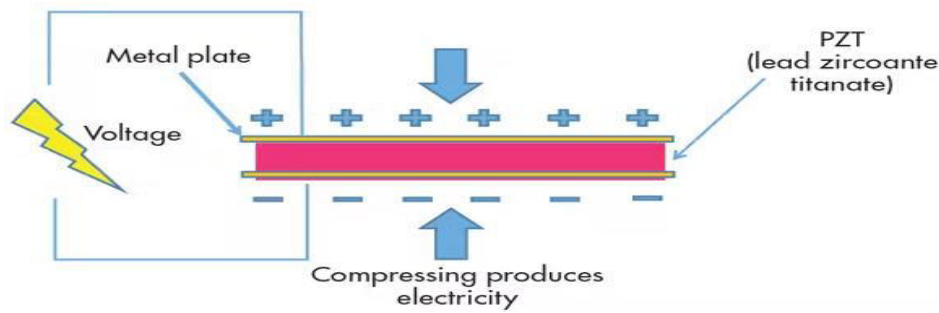
1. Automobile body parts including Doors etc. are made of composites.
2. The body parts like front Bumper and Rear bumpers are made of Composites.
3. The other parts like radiator grill, steering wheels, Dash board, interiors are made of composites.
4. Nylon reinforced rubber composites are used for automobile Tires.
5. Aluminum based MMC'S are used in Engine and other parts.
6. Housing for Lubricating oils, Brake oils, Water containers for cooling etc. are made of composites

SMART MATERIALS:

- Smart materials are a group of new and state-of-the-art materials developed in recent times and which have a tremendous influence on many of our latest technologies.
- The word "smart" implies that these materials are able to sense changes in their environment and then respond to these changes in a pre-determined manner.
- Smart materials, also called intelligent materials, are a concept that extends to both newer and traditional materials which form a part of modern sophisticated systems.
- Two major categories of smart materials are discussed they are:
 1. Piezo-electric materials
 2. Shape memory alloys

1. PIEZO-ELECTRIC EFFECT:

- Piezoelectric materials are a special class of materials that can **convert mechanical energy into electrical energy** and vice versa.
- They exhibit the **piezoelectric effect**, which is the generation of an electric charge in response to applied mechanical stress.
- Similarly, they can deform mechanically when an electric field is applied (reverse piezoelectric effect).
- Piezoelectric materials allow conversion of energy from the mechanical domain to the electrical domain and *vice versa*.



Examples:

1. Ignition in Lighters and Gas Stoves-

- When you press a lighter button, a piezoelectric crystal (usually **quartz**) is struck.
- The mechanical stress generates a **high voltage** that produces a spark to ignite gas.

2. Microphones- Piezoelectric microphones convert sound vibrations into electrical signals.

3. Sensors in Cars-

- Airbag sensors: Piezoelectric sensors detect sudden pressure changes during a collision.
- Knock sensors: Detect engine vibrations to adjust ignition timing.

Advantages:

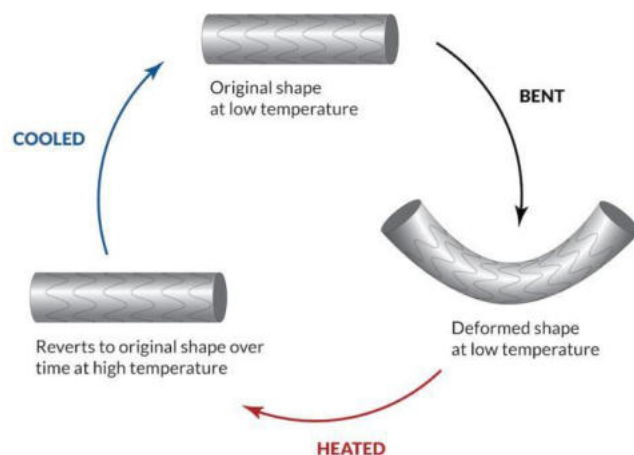
1. **High sensitivity:** Can detect very small changes in pressure, force, or vibration.
2. **Fast response:** Produces an almost instantaneous electrical signal when mechanical stress is applied.
3. **No external power needed:** Generates electricity directly from mechanical stress.
4. **Compact and durable:** Piezoelectric materials can be small and robust, suitable for various sensors and actuators.
5. **Wide applications:** Used in sensors, actuators, energy harvesting, and medical devices like ultrasound equipment.

Disadvantages:

1. **Brittle materials:** Most piezoelectric crystals are fragile and can break under high stress.
2. **Limited displacement:** The mechanical movement generated is very small, often requiring amplification for practical use.
3. **Temperature sensitivity:** Performance can degrade at high or very low temperatures.
4. **Voltage dependence:** Requires careful handling of generated voltage spikes to avoid circuit damage.
5. **Cost:** Some high-performance piezoelectric materials can be expensive.

2. SHAPE MEMORY ALLOYS:

- Shape memory alloys are those materials, even after being deformed, have the ability to remember and return to their original shape and size, upon appropriate heat treatment.
- Deformation is normally carried out at relatively low temperature, whereas, shape memory effect happens due to heating.
- Among materials that are capable of recovering significant amounts of deformation, the best known are Nickel-Titanium (NITINOL) alloys; and some Copper based alloys (Cu-Zn-Al and Cu-Al-Ni).



Examples:

- **Eyeglass frames** – Can return to original shape after bending.
- **Stents in medicine** – Expand in blood vessels at body temperature.
- **Surgical clamps** – Automatically regain shape when heated.

Advantages:

1. **Shape Recovery:** Can return to their original shape after deformation when heated (shape memory effect).
2. **Superelasticity:** Can undergo large strains and recover without permanent deformation.
3. **Compact and Lightweight:** Useful in actuators and robotics where space is limited.
4. **Durable:** Resistant to fatigue in certain applications.
5. **Versatile Applications:** Used in medical devices (stents, orthodontics), actuators, sensors, and aerospace components.

Disadvantages:

1. **High Cost:** Expensive compared to conventional metals.
2. **Limited Working Temperature:** Performance depends on specific temperature ranges.
3. **Low Mechanical Strength:** Can't bear heavy loads compared to traditional metals.
4. **Complex Processing:** Requires precise control in manufacturing and heat treatment.
5. **Slow Response:** Some applications require fast actuation, which may be limited by heating/cooling rates.

MR FLUIDS:

Magnetorheological (MR) Fluids are a type of smart fluid whose rheological (flow) properties change in response to an applied magnetic field. They are widely used in engineering applications for vibration control, braking systems, clutches, and damping systems. Here's a clear overview:

1. Composition of MR Fluids

MR fluids typically consist of three main components:

- **Carrier Fluid:** Usually oil (synthetic or mineral), water, or glycol.
- **Magnetic Particles:** Fine ferrous particles (like iron powder) suspended in the fluid.
- **Additives:** To prevent settling, oxidation, and improve stability (e.g., surfactants, stabilizers).

2. Working Principle

- When no magnetic field is applied → the fluid behaves like a **normal liquid** (low viscosity).
- When a magnetic field is applied → the magnetic particles **align along the field lines**, forming chain-like structures → fluid becomes **semi-solid**, increasing viscosity and yield stress.

Characteristics

- **Variable viscosity:** Can be adjusted by controlling the magnetic field strength.
- **Fast response:** Responds almost instantly to a magnetic field.
- **Controllable damping:** Provides precise control in mechanical systems.

Advantages

1. Fast and controllable response.
2. Simple design with fewer moving parts.
3. Can operate over a wide range of temperatures.

Limitations

1. Settling of particles over time → need additives or continuous agitation.
2. Relatively expensive.
3. Limited operating temperature (very high or very low can affect performance).
4. Possible corrosion if not properly stabilized.

Applications

1. **Automotive:** Adaptive shock absorbers, clutches, brakes.
2. **Robotics:** Haptic devices, actuators.
3. **Civil Engineering:** Vibration damping in buildings and bridges.
4. **Aerospace:** Controllable dampers in landing gears and seats.