# BASIC MECHANICAL ENGINEERING

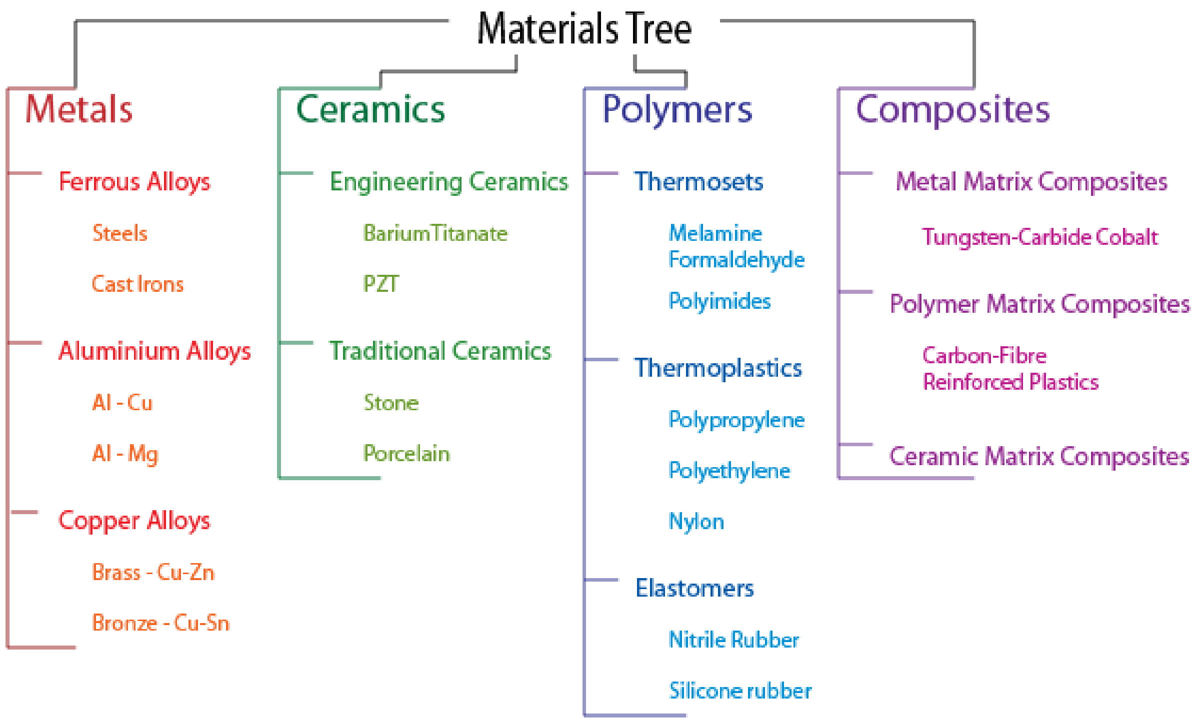
## UNIT - I

### Introduction of Mechanical Engineering:

Mechanical Engineering is defined as the branch of engineering that deals with the design, development, construction, and operation of mechanical systems and tools. It include machines, tools, and equipment used in various industries, such as transportation, manufacturing, power generation, and medical devices etc.

Mechanical engineers are involved in almost every aspect of human existence and welfare, including machines, cars and other vehicles, aircraft, power plants, automobile parts, and manufacturing plants etc. A Mechanical Engineer plays a significant role in designing, developing, and testing machines as well as thermal devices. It also includes systems that are essential to many aspects of modern society and Industries. They use their knowledge of mechanics, thermodynamics, materials science, and energy to create solutions that improve the quality of life of people.

### Classification of Materials:



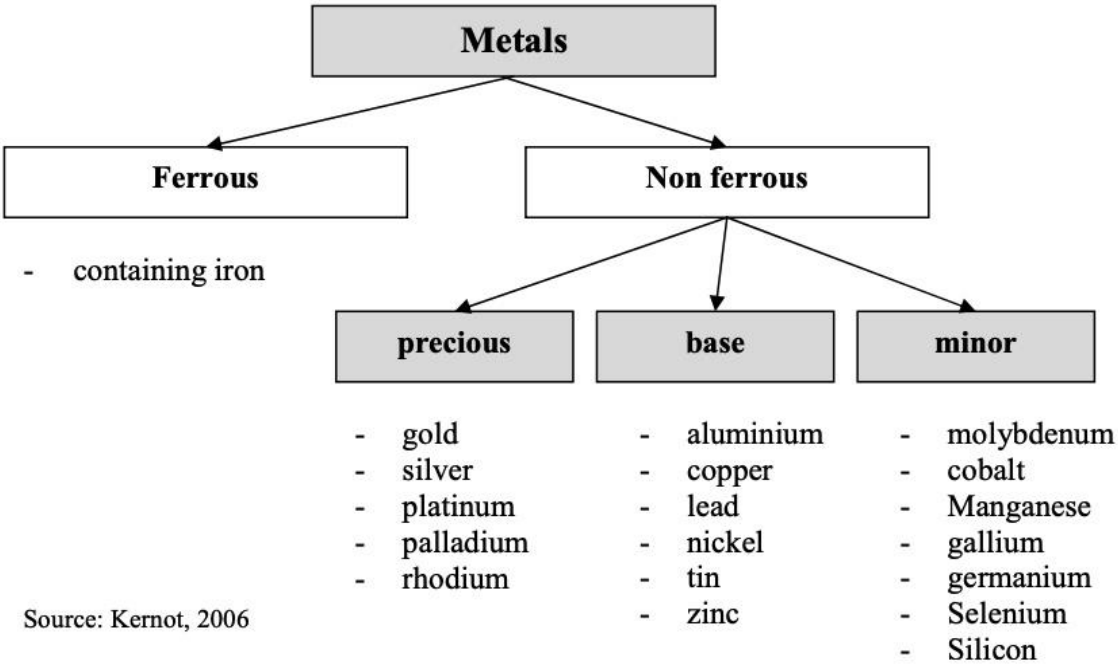

**METALS:**

Metals are substances that form naturally below the surface of the Earth. Most metals are lustrous or shiny. Metals are inorganic, which means they are made of substances that were never alive.

Metal is very strong and durable and therefore is used to make many things. These are used for making automobiles, satellites, cooking utensils, etc.

Most metals are hard but some are not. Sodium and potassium are such metals that can be cut by knife whereas mercury is a liquid metal at room temperature. Iron is solid in nature.

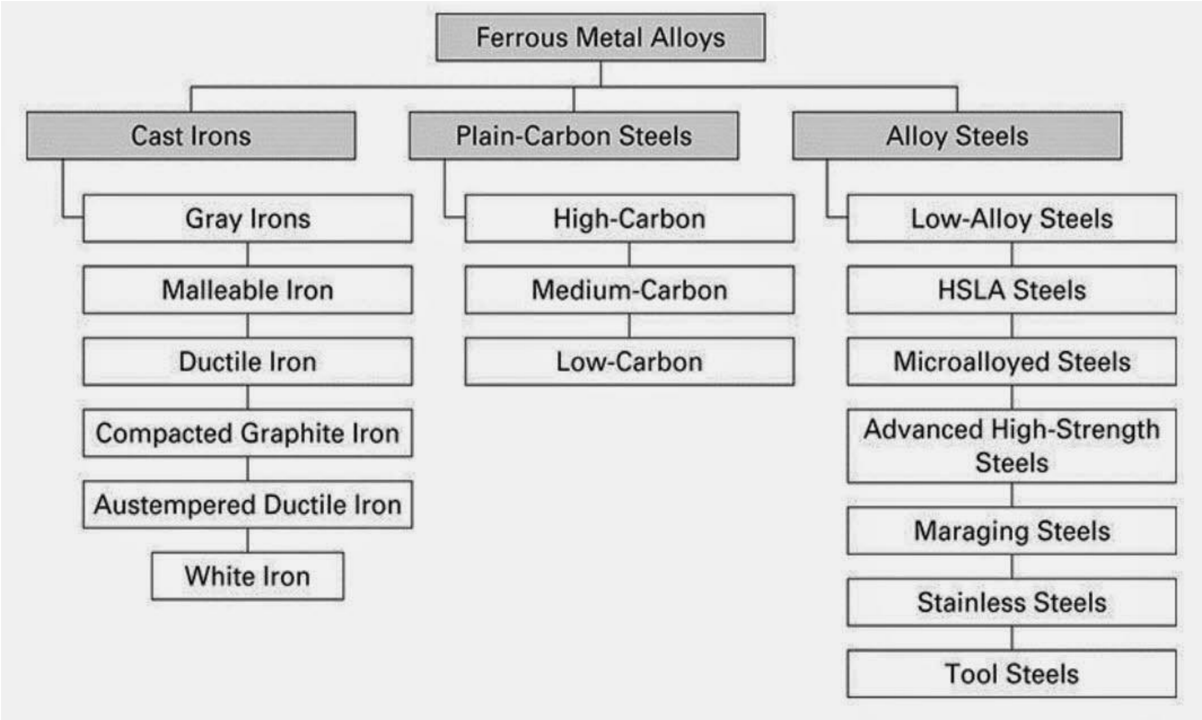
**Figure 1: Classification of Metals**




Source: Kernot, 2006

## Ferrous Metals:

Ferrous metals refer to any metal that contains iron. They are favoured for their tensile strength and durability, so are often utilised in housing construction, large-scale piping and industrial containers.




## CAST IRON:

**Cast iron**, an alloy of iron that contains 2 to 4 percent carbon, along with varying amounts of silicon and manganese and traces of impurities such as sulfur and phosphorus. It is made by reducing iron ore in a blast furnace.

➢ Very brittle, not amenable to deform

➢ Easy to cast (due to lower melting point) into complicated shapes and cheap.

➢ With alloying, good foundry practice and heat treatment, properties can be varied over wide range.

## Types of Cast Iron:

1. White Cast Iron

2. Malleable Cast Iron

3. Grey Cast Iron

4. Ductile Cast Iron / Nodular Cast Iron

## 1. White Cast Iron:

• A high cooling rate and a low carbon equivalent favors the formation of white cast iron.

• Hard and brittle

• Excellent wear resistance

• High compressive stress.

• Shows a white crystalline fractured surface.

## 2. Malleable Cast Iron:

• Malleable cast iron is essentially white cast iron which has been modified by heat treatment. It is formed when white cast iron is heated to around 920 deg C and then left to cool very slowly. Graphite separates out much more slowly in this case, so that surface tension has time to form it into spheroidal particles rather than flakes.

• The structure of malleable cast iron consists of ferrite, pearlite and tempered carbon as compared to the fracture inducing lamellar structure of gray cast iron.

• Malleable cast iron like ductile iron possesses considerable ductility and toughness because of its combination of nodular graphite and low carbon metallic matrix.

• It can be pierced, coined, or cold formed.

• Requiring maximum machinability.

• must retain good impact resistance at low temperatures.

• Wear resistance (martensitic malleable iron only).

## 3. Gray Cast Iron:

• Gray iron, or grey cast iron, is a type of cast iron that has a graphitic microstructure. It is named after the Gray colour of the fracture it forms, which is due to the presence of graphite.

• A low cooling rate or a high carbon equivalent promotes grey cast iron. The general characteristics of gray cast iron are:

- Cheap
- Low melting point
- Fluid – easy to cast, especially advantageous into large complex shapes
- Excellent machinability
- Excellent bearing properties
- Excellent damping properties
- Excellent wear resistance (hi C)
- Can be heat treated (surface hardenec
- Can be alloyed etc.

4. **Ductile Cast Iron / Nodular Cast Iron:**

- Nodular Cast Iron is an engineering material displaying high ductility, elastic modulus, mechanical strength and corrosion resistance.
- It has low cost and is easy to produce and machine and is thus widely used as a structural material.
- Additions of Ce / Mg poisons the easy growth direction and results change in graphite morphology from flakes to spheres which occurs due to isotropic growth.

- Gray iron composition for C and Si
- Impurity level control important as it will affect nodule formation
- Have nodule instead of flake if we add in 0.05% Mg and/or Ce
- As cast structure: graphite forms as nodules instead of flakes

**Steels:**

➢ Carbon steel is an iron-carbon alloy, which contains up to 2.1 wt.% carbon. For carbon steels, there is no minimum specified content of other alloying elements, however, they often contain manganese.

➢ The maximum manganese, silicon and copper content should be less than 1.65 wt.%, 0.6 wt.% and 0.6 wt.%, respectively.

➢ Carbon steel can be classified into three categories according to its carbon content: low-carbon steel (or mild-carbon steel), medium-carbon steel and high-carbon steel. Their carbon content, microstructure and properties compare as follows:

| Types of carbon steel | Carbon content (wt.%) | Properties |
|---|---|---|
| **Low-carbon steel** | < 0.25 | Low hardness and cost. High ductility, toughness, machinability and weldability |
| **Medium-carbon steel** | 0.25 – 0.60 | Low hardenability, medium strength, ductility and toughness |
| **High-carbon steel** | 0.60 – 1.25 | High hardness, strength, low ductility |

**Non- ferrous metals:**

• Non-ferrous metals are those which do not contain iron as main constituent or base metal.

• Non-ferrous metals have industrial applications because of their case of fabrication (like rolling, forging, casting, welding, and machining), electrical and thermal conductivity, resistance to corrosion, light-weight, etc. • However, at high temperatures, their strength is lowered, and shrinkage is more than ferrous metals. The principal non-ferrous metals used in engineering applications are Copper, Aluminium, Zinc, Tin, Lead, Cobalt, Nickel, Chromium, Magnesium, and their alloys.

• Following are the special advantages of non-ferrous metals over ferrous metals in some selected areas. In Civil Engineering Construction, Aluminium and some of its alloys offer a very suitable alternative material to steel in some special engineering construction. Thus, wrought aluminium alloys are:

➢ Economical,

➢ Resistant to Corrosion,

➢ Light in weight,

• Compared to steels, they have been used in, i.e., construction of bridges and roofs in situations where not much strength is required. In these situations, they have been found to save 50% of extra weight.

• In Engineering Industries, Copper, zinc, nickel, and chromium in their pure and alloyed forms have been used as materials in situations where:

➢ High tensile strength is required at elevated temperatures.

➢ High ductility and malleability are required.

➢ High resistance to heat is required.

➢ High electrical conductivity is required

## 1. Aluminium:

• Aluminium is mainly obtained from bauxite ore. The most common ore of aluminium is Bauxite ($Al2O3$ . n $H2O$). As a metal, aluminium was first discovered in 1825.

• It is highly resistant to corrosion. When exposed to moist air, aluminium forms a thin film of oxide at the top, which is impervious to air/moisture, and thus saves the metal from further corrosion.

## Properties of Aluminium.

Following are some important properties of this metal.

1. It is silvery-white metal and shows brilliant luster when fresh.

2. It is an excellent conductor of heat and electricity.

3. It is light in weight with a specific gravity of about 2.7.

4. It is a good reflector of light.

5. It is non-magnetic and has high resistance to corrosion.

## Uses of Aluminium:

1. It is used in the manufacturing of equipment for chemical and food industries, cooking utensils, cookers, steam-jacketed kettles, etc.

2. Due to its lightweight and high tensile strength, it is used in structural work of airplanes, ships, trains, buses, trucks, etc. And also used for roofing, sheathing, window frames, foils, posts, etc.

3. It is used for manufacturing of electric cables. Used for manufacturing of reflectors and mirrors.

4. Aluminium powder is used for preparing paints.

5. It is used in iron and steel making as a de-oxidizer.

## 2. Copper:

• Copper is extracted from copper ores such as copper pyrites, etc. Metallic copper and its various alloys have been used in engineering industries and for many other activities from 100 of years. This is due to some of the useful properties of copper.

## Properties of Copper:

Some of the most important properties of copper are as under:

1. It is soft, strong, tough, malleable, and ductile.

2. It is very malleable and ductile so that it can be converted into any desired shape.

3. It has excellent joining properties, i.e., it can be joined by almost all the common methods: welding, soldering, brazing, and riveting.

4. It becomes brittle just before melting.

5. It can be forged, soldered, rolled and drawn into wires.

6. It has good resistance to corrosion.

7. It is a good conductor of both heat and electricity next to silver.

8. It forms excellent alloys.

9. It is reddish-brown in color.

10. Its specific gravity is 8.93.

11. It has a melting point of 1083°C.

## Uses of Copper:

1. It is used for making cables and wires for electric applications.

2. It is used for electroplating.

3. Used for manufacturing of utensils and making of copper alloys.

4. It is used for making of munitions and tubes in engineering applications.

### Copper Alloys:

Following are the alloys of copper:

•Brasses.

•Bronzes

## 2. Lead:

• Lead has been used for centuries in buildings and other engineering industries. Lead is extracted from three chief ore minerals.

➢ Galena

➢ Cerrussite,

➢ Anglesite

## Properties of Lead:

The metallic lead has the following properties.

1. It has bluish Grey colour.

2. It has typically brilliant lustre.

3. It has a high density – 11.35 g/cm3 .

4. It has a low melting point of 327 centigrade.

5. It has a high boiling point of 1744 centigrade.

6. It is very good at resisting corrosion.

## Lead Alloys:

• In general, lead doesn't form many alloys. Its alloying capacity is limited because of its low melting point. Following are the important alloys of lead.

➢ Solder

➢ Bearing metal

## 3. Zinc:

Zinc is another non-ferrous metal. It is obtained from zinc ores like zinc blends and calamine. The chief ore mineral of zinc is sulphide called sphalerite. Smithsonite, Zincite (ZnO) and Calamine (ZnCO3 ) are other common zinc minerals.

## Zinc Properties:

Following are some important properties of Zinc.

1. It is bluish-white in colour and has bright lustre.

2. It resists corrosion.

3. It is brittle at normal temperature.

4. It becomes malleable and ductile when heated to a temperature of 100 to 150°C. Hence, at this temperature, it can be rolled into sheets and drawn into wires.

5. It has a melting point of 419 centigrade and boiling point of 907 centigrade.

6. It has a tensile strength of 700-1400 kg/cm2 .

7. Commercial zinc (spelter) is easily attacked by acids.

8. Zinc surface is covered by a dull basic zinc carbonate in moist air.

## 5. Nickel:

Nickel was first discovered in 1750. It is manufactured from its sulphide ore named pentlandite [NiFe(S)]. The ore is first concentrated by froth floatation process, and then roasted and smelted like other non-ferrous metals.

## Nickel Properties:

Following are some important properties of nickel.

1. It is the strongest metal in all the non-ferrous metals, having tensile strength ranges from 4200-8400 kg/cm2.

2. It is highly resistant to many types of corrosion. Thus, it can withstand in water, moisture, atmospheric gases, etc.

3. Its modulus of elasticity, thermal and electrical conductivity is the same as steel.

4. It is highly malleable and ductile.

5. Its density is 8.9 g/cm3 .

6. It has a melting point of 1455 centigrade.

## 6. Magnesium:

Magnesium forms the lightest materials used in structural engineering. It has a set of properties that make it suitable as an engineering material.

## Magnesium Properties and uses:

Magnesium is a very useful metal both as a pure metal and in alloys its main properties are as follows:

1. It is very light with a specific gravity of 1.74.

2. It has a melting point of 650 centigrade, which is similar to that of aluminium.

3. It has poor corrosion resistance.

4. It has quite a high thermal conductivity and a high coefficient of thermal expansion.

5. It forms very useful alloys with some metals like aluminium, thorium, zinc, zirconium, and tin, etc

## Ceramics:

A ceramic is an inorganic non-metallic solid made up of either metal or non-metal compounds that have been shaped and then hardened by heating to high temperatures. In general, they are hard, corrosion-resistant and brittle.

'Ceramic' comes from the Greek word meaning ‘pottery’. The clay-based domestic wares, art objects and building products are familiar to us all, but pottery is just one part of the ceramic world.

Nowadays the term ‘ceramic’ has a more expansive meaning and includes materials like glass, advanced ceramics and some cement systems as well.

The properties of ceramics, like those of any material, depend on the types of atoms involved, the bonds between them, and their arrangement. This atomic structure determines the material’s characteristics. Ceramic materials tend to be:

1. Harder and more brittle than metals
2. Wear-resistant
3. Refractory
4. Good thermal and electrical insulators
5. Nonmagnetic
6. Oxidation-resistant
7. Chemically stable
8. High compressive strength
9. Hardness and strength in compression, with a high softening temperature
10. Poor thermal shock resistance
11. Brittle nature

## Advantages of ceramics

- Most of them have high hardness hence they are used as abrasive powder and cutting tools.
- They have high melting point which makes them excellent refractory material.
- They are good thermal insulators this is another reason to use them as refractory material.
- They are high electric resistivity which makes them suitable to be used an insulator.
- They have low mass density which results in lightweight components.
- They are generally chemically inert which makes them durable.

## Disadvantages of ceramics

- They are brittle in nature.
- They have almost zero ductility
- They have poor tensile strength.
- The show a wide range in the variation of strength, even for the identical specimens
- They are difficult to shape and machine.

## Applications of ceramics

- They are used in space industry because of their low weight.
- They are used as cutting tools.
- They are used as refractory materials.
- They are used as thermal insulator.
- They are used as electrical insulator.

## Composite Materials.

composite materials are composed of a minimum of two materials. It combines to serve properties superior to the properties of the individual constituents.

Two or more materials make up a composite material with significantly different chemical or physical properties when they combine. As a result, it produces material different characteristics from the individual components.

The individual components remain separate and distinct with the final structure, differentiating the composites from the mixtures and the solid solutions as well.

This kind of materials consist of:

- Matrix: sets up the part geometrically, gives cohesion to the material, it is usually flexible and not very resistant and transmits efforts from one fibre to another.
- Reinforcement: provides rigidity and resistance.

## Types of matrices and reinforcements in composites

Depending on the type of matrix there are:

- Metal matrix composite materials
- Ceramic matrix composite materials
- Polymer matrix composite materials

## Advantages of Composite Materials

1. **Lighter than most materials** – Composite materials are less heavy compared to most other materials, making them ideal for applications where weight is a concern, like in aircraft.
2. **Strong and durable** – They are known for their strength and durability, which allows them to withstand high pressures and resist wear and tear.
3. **Resistant to corrosion** – These materials are also resistant to corrosion, meaning they don't easily rust or degrade, making them useful in harsh environments.
4. **Easily molded into shapes** – They can be easily shaped into various forms, providing flexibility in design and usage.
5. **Good thermal and electrical insulation** – They offer good insulation against heat and electricity, making them safe for use in electrical appliances and high-temperature environments.

## Disadvantages of Composite Materials

1. **Expensive to produce** – Composite materials can be costly to manufacture due to the high price of raw materials and the complex production process.
2. **Difficult to repair** – Repairing these materials can be challenging because damage is often hidden and not easily detected.
3. **Not resistant to UV light** – Exposure to UV light can degrade composite materials over time, which affects their durability and lifespan.
4. **Can't withstand high temperatures** – These materials may not perform well under high temperatures, which can lead to deformation or even failure.
5. **Limited material recycling options** – The recycling options for composite materials are limited, making them less environmentally friendly compared to other materials.

## **Applications of Composite** Materials

1. Space: antenna, radar, satellite structures, solar reflectors, etc.
2. Aircraft: aerofoil surfaces, compressor blades, engine bay doors, fan blades, rotor shafts in helicopters, turbine blades, turbine shafts, wing box structures, etc.
3. Automobiles: automobile body, bumper, mudguards, door panels, dashboard, driveshaft, fuel tank, CNG cylinder, chassis, fender, etc.
4. Wind turbine blades: rotor blades, nose cone, nacelle cover, accessories for wind electric generators.

5. Sports: Skis, surfboards, windsurfing, table tennis boards, slats, and gliding wing spar, Tennis, badminton, fishing rods, golf clubs, baseball bats, hockey sticks, pole shaft, Sword, etc.

## Smart Materials:

Smart materials are **materials that are manipulated to respond in a controllable and reversible way, modifying some of their properties as a result of external stimuli** such as certain mechanical stress or a certain temperature, among others. Because of their responsiveness, smart materials are also known as responsive materials. These are usually translated as "active" materials although it would be more accurate to say "reactive" materials.

For example, we can talk about **sportswear with ventilation valves that react to temperature and humidity by opening when the wearer breaks out in a sweat** and closing when the body cools down, about buildings that adapt to atmospheric conditions such as wind, heat or rain, or about drugs that are released into the bloodstream as soon as a viral infection is detected.

## TYPES OF SMART MATERIALS

Nowadays, there are different types of smart materials and new ones arise every day, Among them, the following should be highlighted:

### Piezoelectric materials

They can convert mechanical energy into electrical energy and vice versa. For example, they change their shape in response to an electrical impulse or produce an electrical charge in response to an applied mechanical stress.

### Shape memory materials

They have the ability to change the shape, even returning to their original shape, when exposed to a heat source, among other stimuli.

### Chromoactive materials

They change colour when subjected to a certain variation in temperature, light, pressure, etc. Nowadays, they are used in sectors such as optics, among others.

## Magnetorheological materials

They change their properties when exposed to a magnetic field. For example, they are currently used in shock absorbers to prevent seismic vibrations in bridges or skyscrapers.

## Photoactive materials

There are several types: electroluminescent emit light when they are fed with electrical impulses, fluorescents reflect light with greater intensity and phosphorescence are able to emit light after the initial source has ceased.

## EXAMPLES AND APPLICATIONS

Materials science is a constant supply of news about new **discoveries that could revolutionise our future.** We review some of the most amazing materials from recent years below:

- **Synthetic spider web.** This material is not only five times stronger than steel, but also has great elasticity. Its potential uses include bulletproof clothing, artificial skin for burns or waterproof adhesives.

- **Shrilk.** Its main component is chitin, a carbohydrate found in krill shells. It was created by researchers from Harvard University and is considered the ideal substitute for plastic,since its decomposition time is only two weeks and it also works as a stimulant for plant growth .