By definition, all metallic materials that do not have iron (Fe) as their major ingredient are called non-ferrous metals.

The arbitrary classification of non-ferrous metals:

1. **Light metals**: Aluminum, Magnesium, Titanium, Beryllium, and so on.
2. **Heavy metals**: Copper, Zinc, Lead, Tin, and so on.
3. **Refractory metals**: Tungsten, Nickel, Molybdenum, Chromium, and so on.
4. **Precious metals**: Gold, Silver, Platinum, and so on.

Aluminum is the highest ranking material in use next to steel. Copper and its alloys (brass and bronze) rank second while Zinc ranks third in consumption.

Light weight of certain nonferrous materials are of special importance in aircraft and space industry. Zinc, tin and lead (with low melting points) are used in special applications. Tungsten, molybdenum and chromium are used in products that must resist high temp. Nickel and cobalt are also suitable as heat resistant alloys. Precious metals (with high cost) are not only used in jewelry, but also in many applications requiring high electrical conductivity and corrosion resistance.
The border of light and heavy metals is around 5000 kg/m$^3$. Metals with densities below 5000 kg/m$^3$ are called light metals.

The lightest metal is Lithium (with density of 530 kg/m$^3$) whereas the heaviest metal is Osmium (with density of 22500 kg/m$^3$). Steel has a density of 7800 kg/m$^3$.

**Aluminum (Al):**

- It is probably the most important non-ferrous metal. It has outstanding physical properties (e.g. light weight, high thermal and electrical conductivity, and corrosion resistance). It is suitable for all machining, casting and forming operations.

**Titanium (Ti):**

- It is used in corrosive environments or in applications of light weight, high strength and nonmagnetic properties. It has good high temperature strength as compared with other light metals.
- Titanium is available in many forms and alloys such as pure titanium (98.9-99.5%), Ti-Pd alloy (titanium-0.2% palladium), high strength Ti-Al-V-Cr (alpha-beta type) alloys. Ti-6Al-4V (6% Al, 4% V, remainder Ti) and Ti-3Al-13V-11Cr (3% Al, 13% V, 11% Cr, remainder Ti) are the most commonly used ones in specific industries.
**Beryllium (Be):**

- Beryllium is a recently emergent material having **several unique properties** of low density (one-third lighter than aluminum), high modulus-to-density ratio (six times greater than ultrahigh-strength steels), high melting point, dimensional stability, excellent thermal conductivity and transparency to X-rays.

- However, it has serious deficiencies of **high cost, poor ductility, and toxicity.** It is not especially receptive to alloying.

- All conventional machining operations including some nontraditional processes (e.g. EDM and ECM) are possible. However, it must be machined in specially equipped facilities due to its toxic effect. In addition, surface of beryllium is damaged after machining, and hence secondary finishing operations must be carefully conducted.

- It is typically used in military aircraft brake systems, missile guidance systems, satellite structures, and X-ray windows.
Magnesium (Mg):

- It is the lightest "engineering" material available. The combination of low density and good mechanical strength has made it one of the most specified materials in aircraft, space, portable power tools, luggage and similar applications as competing with the aluminum alloys.

- Alloys of magnesium are the easiest of all engineering metals to machine. They are amenable to die casting, and they are easily welded. Also, magnesium parts can be joined by riveting and adhesive bonding. Other notable characteristics are high electrical and thermal conductivity as well as very high damping capacity.

- On the down side, it is highly susceptible to galvanic corrosion since it is anodic. Under certain conditions, flammability can be a problem as it is an active metal.

- Magnesium alloys are best suited for applications where lightness is of primary importance. When lightness must be combined with strength, aluminum alloys are better material alternatives.
Copper (Cu):

- It is probably the first engineering metal to be used. Unlike other metals, it can occur in nature in the metallic form as well as an ore. It has very good heat and electrical conductivity and resists to corrosion when alloyed with other metals. However, due to lower density, aluminum has higher conductivity per unit weight.

- **Copper alloys** consist of the following general categories:
  1. Coppers (minimum 99.3\% Cu)
  2. High coppers (99.3-96\% Cu)
  3. Brasses (Cu-Zn alloys with 5-40\% Zn)
  4. Bronzes (mainly Cu-Sn alloy, and also alloys of Cu-P, Cu-Al, Cu-Si)
  5. Copper Nickels (Cu-Ni alloys, also known as cupro-nickels)
  6. Nickel Silvers (Cu-Ni-Zn alloys which actually do not contain silver)
**Zinc (Zn):**

- Zinc is an inexpensive material with moderate strength. It is chemically similar to magnesium. Mechanically, however, zinc is more ductile but not as strong.

- Although its metal and alloy forms are important, zinc is *most commonly used to extend the life of other materials* such as steel (galvanizing), rubber and plastic (as an aging inhibitor), and wood (in paint coatings).

- The zinc-base alloys have an important place as a die-casting metal as it has low melting point (419.5 °C) which does not affect steel dies adversely, and hence it can be made into alloys with good strength properties and dimensional stability.

**Tin (Sn):**

- As with many metals, *pure tin is too weak* to be used alone for most mechanical applications. It is *often alloyed with elements* such as copper, antimony, lead, aluminum and zinc to improve mechanical or physical properties.

- *It is commonly used as a coating for other metals such as tin cans, copper cooking utensils. Other applications include die-casting alloys, pewter chemicals, bronze, bearing alloys and solder.*
Lead (Pb):

- Lead is a versatile material due to special properties of high atomic weight and density, softness, ductility, low strength, low melting point, corrosion resistance and ability to lubricate. On the down side, toxicity is one of the chief disadvantages.

- There are two principal grades: chemical lead and common lead. Typical uses include chemical apparatus, batteries, and cable sheathing. For corrosion resistance and X-ray and Gamma-ray shielding, pure lead gives best performance.

- Lead is alloyed with tin and antimony to form a series of useful alloys employed for their low melting points. Solder is the alloy of lead and tin containing small amount of antimony and silver. The solders are mainly used in soldering electronic circuits due to their lower melting points.
Refractory Metals

- **Tungsten, molybdenum, tantalum** and **niobium** (with melting points above 1900 °C) are characterized by high-temperature strength and corrosion resistance.

- In addition, **chromium** and **nickel** also have major importance as high-temp. materials. Although nickel has a lower melting point (1455 °C), it is also categorized in this group due to its specific corrosion resistance and high-temp. strength.

**Niobium - formerly known as “Columbium” (Nb) & Tantalum (Ta):**

- These elements are distinguished by excellent ductility even at low temperatures. Both metals **occur together in ores** and they **must be separated for nuclear use** since tantalum has a higher neutron absorption than columbium.

- They **can be fabricated by most conventional processes**, usually worked at room temperature. They are usually considered together since **most of their working operations are identical**. *They are used as anode and grid elements in medium to high-power tubes as well as in capacitors and foil rectifiers.*
**Tungsten - also known as “Wolfram” (W) & Molybdenum (Mo):**

- **Tungsten** is the only refractory metal with good electrical & thermal conductivity, excellent erosion resistance, low coefficient of expansion and high strength at high temp. Although having low ductility and malleability, it can be fabricated into many forms with proper procedures. *Thomas Edison's trials with tungsten during invention of incandescent lamp was the most important application. Other uses are electrodes for inert-gas welding, electron tube filaments, anodes for X-ray and electron tubes.*

- **Molybdenum** is a special metal having some resistance to hydrofluoric acid. It is very similar to tungsten, but more ductile, easier to fabricate, and cheaper. *Its typical applications are electron tube anodes, grids for high-power electron tubes, dies withstanding “thermal cycling”, and supports for tungsten filaments in light bulbs.*

- **Both metals** have brittleness at room temp. and oxidation at relatively low temp.

- **Chromium (Cr):** Most refractory metals oxidize and lose their strength at high temp. whereas chromium (less subjected to oxidation) loses strength above 1090 ºC. *It is used in chrome-plating and steel alloys to improve hardness, strength at high temp. and corrosion resistance.* Its brittleness may limit its application areas.
Nickel (Ni):
- Nickel alloys have desirable properties like **ultra-high strength**, **high proportional limit** and **high modulus of elasticity**. Commercial pure nickel has **good electrical**, **magnetic** and **magnetostrictive properties**. Nickel alloys are **still strong, tough and ductile at cryogenic (very low) temperatures**.
- Most nickel alloys can be hot and cold worked, machined and welded successfully. They can be joined by shielded metal-arc, gas tungsten-arc, gas metal-arc, plasma-arc, electron beam, oxy-acetylene, resistance welding, brazing and soft soldering.

Hafnium (Hf): Melting point of 2130 ºC. Exist in all zirconium ores. **Not commercially available.** *Limited use in rectifiers and electronic applications in aerospace.*

Rhenium (Re): High strength, good ductility and high melting point (3165 ºC), but strong oxidation tendency. **Used in filaments in high-power vacuum tubes and high-temperature thermocouples.**

Vanadium (V): Melting point of 1900 ºC. **Added to steels in small amounts.**
Precious Metals

- They are divided into three subgroups: gold and gold alloys, silver and silver alloys, platinum group metals (consists of six metals extracted from nickel ores: platinum, palladium, rhodium, iridium, ruthenium, osmium).

- These metals are nearly completely corrosion resistant. Platinum metals withstand up to 1760 °C without any evidence of erosion and corrosion.

- **Gold (Au):** Extremely soft, ductile material that undergoes very little work hardening. It is often alloyed with other metals (such as copper) for greater strength. It has occasional uses as a reflecting surface, attachments to transistors and jewelry.

- **Silver (Ag):** The least costly metal of this group. Very corrosion resistant. Plated onto low-voltage electrical contacts to prevent oxidation of surfaces when arcing occurs. Used in photographic emulsions due to photosensitivity of silver salts.

- **Platinum (Pt):** A silver-white metal. Extremely malleable, ductile and corrosion resistant. When heated to redness, it softens and easily worked. Since it is inert, nearly non-oxidizable and stable even at high temp. Used for high-temp. handling of high purity of chemicals and laboratory materials. Also used in thermocouples, spinning and wire-drawing dies, components of high power vacuum tubes, glass-working environment and electrical contacts.
Precious Metals

- **Palladium (Pd):** A silver-white metal. Very ductile, slightly harder than platinum. *Principally used in telephone relay contacts and as a coating on printed circuits.*

- **Rhodium (Rh):** The hardest metal with the highest electrical & thermal conductivity in platinum group. Its high polish and reflectivity make it *ideal as a plated coating for special mirrors and reflectors.* *Rhodium and its alloys are used in furnace windings and in crucibles at certain temperatures that are too high for platinum.*

- **Iridium (Ir):** The most corrosion-resistant metallic element. Together with Cobalt-60, radioisotope Iridium-192 satisfies *most of the industrial radiography requirements.* It has high-temp. strength comparable to that of tungsten up to 1650 ºC. *It is used for spark plug electrodes in aircraft and other engines where high reliability is needed.*

- **Ruthenium (Ru):** Very hard and brittle metal. Its tetraoxide is quite volatile and poisonous. *It is added to platinum to increase resistivity and hardness.*

- **Osmium (Os):** The heaviest known metal, having a density of about three times that of steel. It *oxidizes readily when heated in air* to form a very volatile and poisonous tetraoxide. *It has been used predominantly as a catalyst.*
Other Nonferrous Metals

- **Bismuth (Bi):** The common constituent of all low melting alloys (95-150 °C) and ultra-low melting groups. Increases in volume on solidification, which makes its alloys **excellent for casting as they pick up every detail when expand into the mould.**

- **Antimony (Sb):** Also expands upon solidification. **Used as a hardener in bearing alloys and semiconductors, and as alloying element in thermoelectric materials.**

- **Cadmium (Cd):** Easy to deposit, excellent ductility and good resistance to salt water and alkalies. **Used for plating of steel hardware and fasteners, as an alloy in bearing materials and in special batteries. Not permitted in food industry due to toxicity.**

- **Indium (In):** Similar in color to platinum. **One of the softest metals. Can be deformed almost indefinitely by compression. Used in semiconductor devices, bearing metals and fusible alloys.**

- **Cobalt (Co):** Hard metal melting at 1493 °C. **Used in hot-working steels, heat-resistant castings, superalloys, sintered carbide cutting tools. Invar alloy (54% Co, 36% Ni) used in strain gauges. Co-Cr alloys in dental and surgical applications.**

- **Zirconium (Zr):** Outstanding corrosion resistance to most acids and chlorides. Increase in its mechanical strength when alloyed with hafnium. **Consumed in fuel rods for nuclear reactors.**
A plastic is a **synthetic material (not found in nature)** of high molecular weight, composed of organic chemical units. Plastics can be molded or formed into useful shapes by various processes usually involving heat and/or pressure.

Polymers are composed of **carbon atoms** in combination with other elements (hydrogen, nitrogen, oxygen, fluorine, silicon, sulfur, chlorine) to create thousands of different plastics.

Plastics are made from basic chemical raw materials: "**monomers**"

A polymer made from two different monomers is called "**copolymer**", and the one with three different monomers is called "**terpolymer**".

When a family of polymers includes copolymers, "**homopolymer**" is used to identify single monomer type.
Thermoplastics vs. Thermosets

- Plastics are classified into two main groups: **thermoplastics** and **thermosets**

**Thermoplastics (linear plastics):**
- They can be reshaped upon being **heated**, and hence can be **reground** or **remolded**. Since they can be reused, there is **little waste**.
- They can be obtained in **any shape and color with any desired degree of transparency** including crystal clear and opaque. This is an advantage to eliminate the finishing operations for achieving desired sales appearance.

**Thermosets (cross-linked plastics):**
- They complete their polymerization under heat and effect of other agents, and hence **remolding is not permitted**.
- They have **improved resistance to heat, chemical attack, stress cracking and creep** as compared to the same plastic in thermoplastic form. In addition, they have **better dimensional stability and electrical properties**. However, they are **more brittle**, thus **difficult to process**.
**Common Plastics**

**Thermoplastics**
- Acrylonitrile Butadiene Styrene
- Acrylic
- Phenylene Oxide
- Polyster *
- Acetal
- Polyphenylene Sulfide
- Polysulfone
- Polyethylene
- Polypropylene
- Polystyrene
- Polycarbonate
- Fluoroplastics
- Vinlys
- Polyimide *
- Cellulosics
- Nylon (Polyamides)
- Polyurethane *

**Thermosets**
- Alkyd
- Allylic
- Epoxy
- Aminos (Urea, Melamine)
- Polyster *
- Phenollic
- Polyimide *
- Silicone
- Polyurethane *

*These plastics are available in forms of thermoplastics and thermosets.*
Nearly all plastics contain additives to facilitate processing or reduce costs:

- **Colourants**: Improve sales appearance of plastics. Great variety of pigments. Available as metal-base (cadmium, lead and selenium) and liquid.

- **Fillers**: Being inert (inactive). Used to reduce cost and increase bulk. Common types are wood-flour, chopped fabrics, talc, asbestos, mica, and milled glass.

- **Catalysts**: Keep curing cycle in control by regulating the polymerization. Used to improve the shelf-life of plastics. Available as metallic or organic compounds.

- **Plasticizers**: Added in minimum amounts to improve flowability and flexibility. Phthalates of high boiling points and polysters of low molecular weight are used.

- **Stabilizers**: Added to prevent breakdown or deterioration when exposed to heat, sunlight, oxygen, or ozone. They are metal compounds, phenols, and amines.

- **Fire Retardents**: Limiting the spread of fire (not improving the heat resistance) of flammable polymers (notable exception is PVC).

- **Lubricants**: Added in minimum amounts to improve mouldability and facilitate removal of parts from moulds. Wax, stearates and some soaps are used.
Fiber-Reinforced Plastics

The fastest growing engineering material group. Though their cost is higher, they offer properties and performance benefits considerably beyond unreinforced resins.

They are composed of three major components: matrix, fiber, and bonding agent. Most plastic resins serve as the matrix having embedded fibers. Adherence of matrix and fibers is achieved by a bonding agent of binder (also called “coupling agent”). In addition to these three, various fillers are used to meet specific needs.

They are extremely versatile composites with relatively high strength-to-weight ratios and excellent corrosion resistance. In addition, they can be formed economically into any shape and size (from tiny electronic components to large cruising boat hulls).

1. Glass-Reinforced Thermoplastics: Practically all thermoplastics such asnylons, polypropylenes and polystyrenes (and their copolymers) are available in this form. Their mechanical properties (tensile modulus and strength, dimensional stability, impact strength, fatigue endurance, etc.) are improved by a factor of two or more.

2. Carbon-Reinforced Thermoplastics: Available in certain number of thermoplastics including nylon, polysulfone, polyester, polyphenylene sulfide and fluorocarbon. These materials cost about two or more times than glass-reinforced thermoplastics, but offer highly improved tensile strength and stiffness.
3. Reinforced Thermosets: Compared with metals, these plastics have improved mechanical properties, better dimensional stability and weight saving.

   a. Resins: Polyester and epoxy resins, phenolics, melamines, and silicones. Improved properties for use in various specific applications.

   b. Reinforcements: In addition to epoxies, phenolics, melamines and silicones; glass, asbestos, carbon graphite and boron are other reinforcements.

4. Laminated and Sandwich Plastics: They consist of plies of reinforced materials that are formed with bonded thermosets and cured under heat and pressure. They can be in the form of laminated, sandwich, honeycomb, corrugated, or waffle.

   a. Resins: Phenolics, melamines, epoxies, polyesters and silicones.

   b. Reinforcements: Papers, cotton, paper-type asbestos, woven and nylon fabrics.
Elastomers (Rubbers)

- They can be stretched at room temperature to at least twice of their original length and will return to original length upon release of the stress.

- **Thermoset elastomers** have the following classes:
  1. **R class**: with unsaturated carbon chain (*natural rubber, polyisoprene, styrene butadiene, isobutene isoprene, neoprene, nitrile butadiene*)
  2. **M class**: with saturated chain of polymethylene type (*polyacrylic, ethylene propylene, chlorosulfonated and chlorinated polyethylene, fluorocarbon*)
  3. **O class** including silicone rubbers (*fluorosilicone*)
  4. **U class** having carbon, oxygen and nitrogen in the polymer chain (*polyurethane*)

- **Termoplastic elastomers (Elastoplastics)** have similar properties with thermoset rubbers plus the advantages of thermoplastic materials (*polyurethanes, copolysters, styrene copolymers, olefins*).
They are made of **metal oxides**, **metal carbides** and **silicates**. Hard and brittle, and cannot endure high tensile loads or sudden impact. On the other hand, they have high compressive strengths and resistance to high temperature.

They are preferred to provide requirements (e.g. extreme rigidity, resistance to creep, corrosion resistance at high-tem, etc.).

**Typical applications** are turbine blades, grinding wheels and carbide bits of cutting tools. Also used in electrical appliances due to high electrical resistance.

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Refractory Hard Metals

- Such metals, also called **cemented carbides (cermets)**, are **composite of a metal and a ceramic**. They combine some of the high refractoriness of ceramics with toughness and thermal-shock resistance of metals.

- To produce parts from these metals, **powders are pressed into molds** at medium and high presses, and **then sintered** in controlled atmosphere furnaces at about 1650 °C.

- **Oxide-based cermets** have **chromium-alumina** or **chromium-molybdenum-alumina-titania**. **Carbide-based cermets** are mainly **tungsten/titanium carbides** and **tantalum carbides**.

Four different systems are used **for structural applications (not for metal cutting)**:

1. **Tungsten carbide** with 3% to 10% matrix of cobalt is often specified for combined wear and impact resistance.

2. **Combination of tungsten and tantalum carbides** in a matrix of nickel, cobalt or chromium provides a formulation especially suited for a combination of corrosion and wear resistance.

3. **Tungsten titanium carbides** (WTiC₂) in cobalt is used primarily for metal forming dies and similar applications.

4. **Titanium carbide** has a molybdenum or nickel matrix, formulated for **high-temp. use**.
Glass is a noncrystalline (amorphous) solid, which means that its atoms never arrange themselves in a crystalline order). However, atomic spacing in glass is tight.

Most glass is based on silicate system that is made from three major constituents: silica (SiO$_2$), lime (CaCO$_3$), sodium carbonate (NaCO$_3$). Additions of oxides of boric, aluminum, zinc and lead as well as other materials are used to tailor some properties of glass (such as strength and viscosity) to meet specific requirements. Silicate-system glasses are soda-lime glass, borosilicate glass, aluminosilicate glasses, lead glass, and fused-silica glass.

Non-silicate system glasses account for a minor percentage of all glass produced including phosphate glasses (resist hydrofluoric acid), rare-earth borate glasses (for high refractive index), heat absorbing glasses (made with FeO) and other systems based on oxides of aluminum, vanadium, germanium and other metals.
Carbon is a nonmetallic element, and it exists in three generic forms: **diamond**, **graphite** and **black (amorphous) carbon**, which are useful engineering materials:

- **Diamond**: the hardest naturally occurring material (although “synthetic boron nitride (borazon)” has similar mechanical properties, and it will scratch diamond). Pure diamonds are colourless, but diamonds containing mineral impurities may be red, blue, green, yellow or black. **Black diamonds** are “industrial diamonds” that are not valuable for jewels, and hence *they are used in cutting tools, grinding wheels and other high-hardness applications*.

- **Graphite**: soft, shiny material formed of layers of carbon atoms. Their compounds usually contain “black carbon” added to improve mechanical properties. It is readily machinable, resists heat and thermal shock, a good heat conductor, and chemically inert to almost all corrosives (except strong oxidizing agents).

- **Black carbon**: specified for low-friction applications. The coefficient of friction between carbon and another material depends on the grade of carbon and other specific factors.
Composites consist of a matrix material with some reinforcing elements to have the enhanced mechanical properties.

Matrix material gives composite its bulk form.

Structural constituents (fibres, flakes, fillers, particles, laminas,) define character of composite’s internal structure.