ENGINEERING MATERIALS

UNIT-I METALLIC MATERIALS:

Introduction to different types of metals - Carbon steels, Cast Iron, Stainless steels, Dual Phase steels, HSLA steels, TRIP steels, Maraging steel - Types, properties and applications. Aluminium, copper, Titanium and Nickel - Types, properties and applications.

Introduction to Metals:

Generally materials comes under metal group which composed of one or more metallic elements such as Iron, Aluminium, copper, Titanium and Nickel.

They are also composed of non metallic elements such as carbon, nitrogen and Oxygen in relatively small compositions.

Atoms in metals and their alloys are arranged in a very orderly manner, and in comparision to the ceramics and Polymers, are relatively dense.

Metals have large number of non localized electrons. These electrons are not bound to particular atoms.

When it comes to mechanical characteristics, these materials are relatively stiff and strong, yet are ductile and are resistant to fracture, which accounts for their wide spread use in structural application.

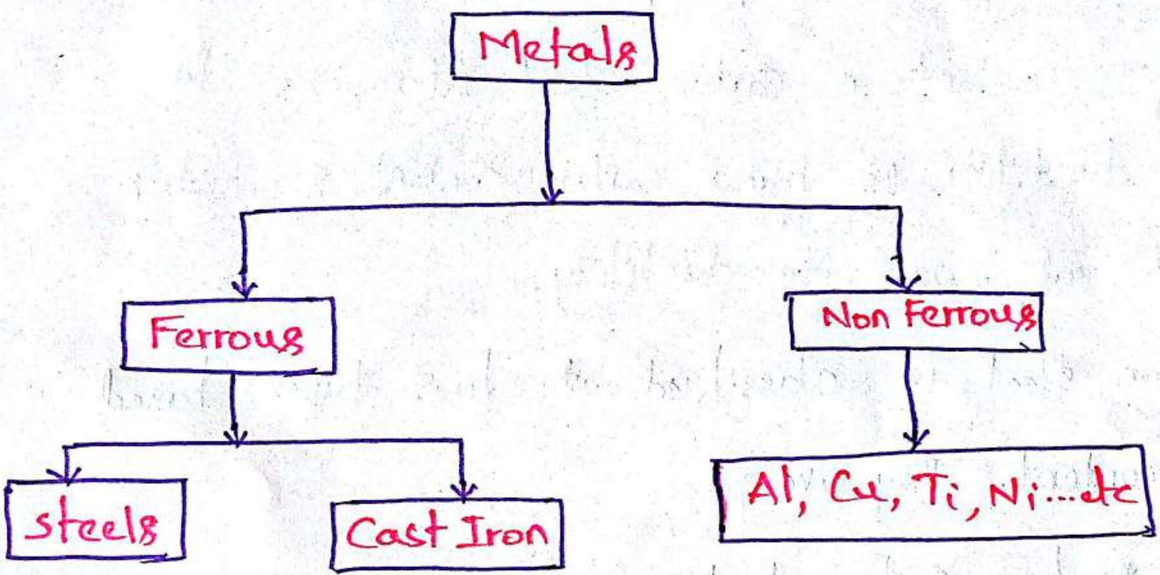
Metals are extremely good ~~character~~ conductors of electricity and heat, which are not transparent to visible light. Metals like Fe, Ni and Co have desirable magnetic properties.

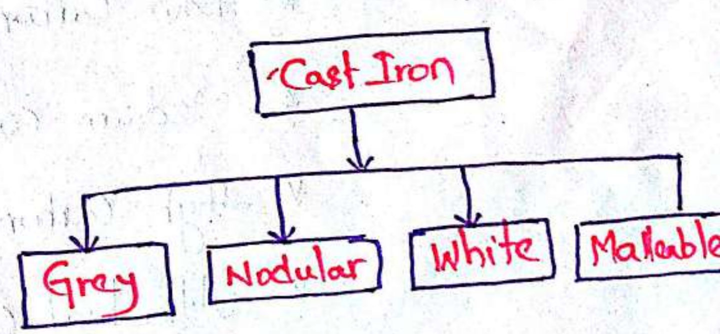
In general, metals are chemical elements that are known generally for their metallic lustre, strength, hardness and ability to conduct heat and electricity.

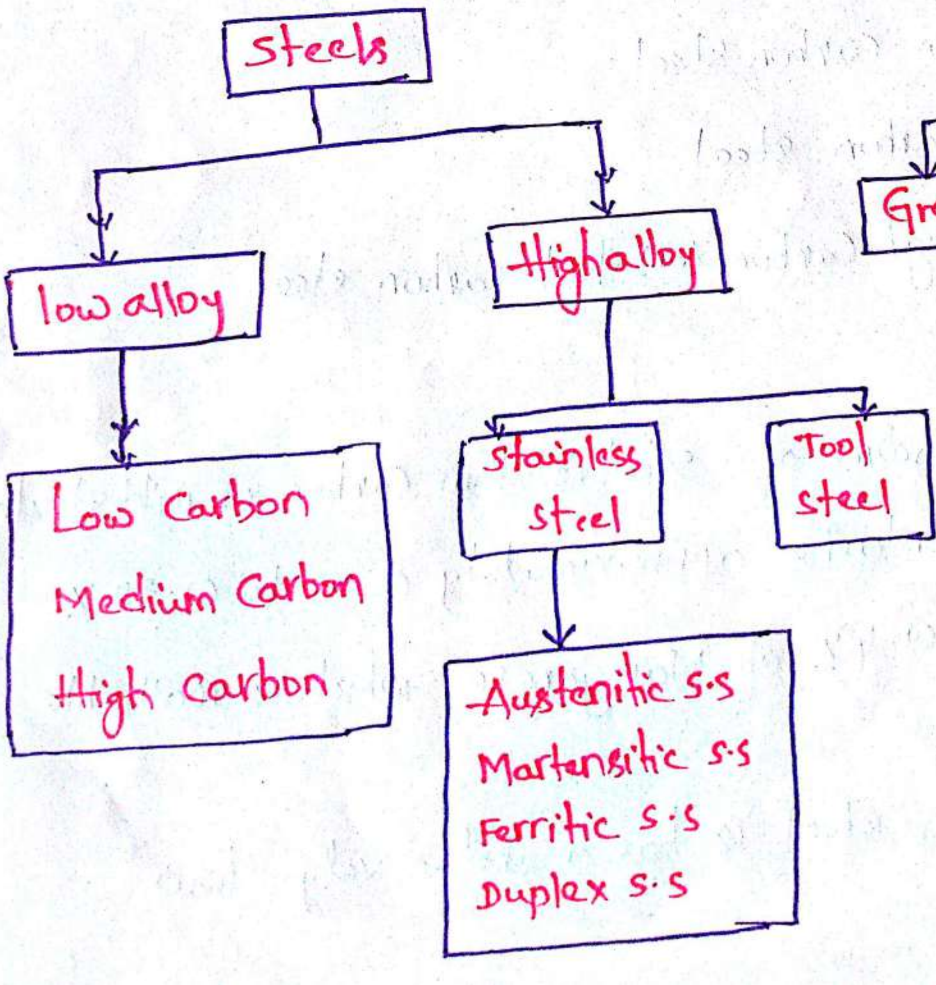
Metals are generally not used in pure state but as a mixture of metals (or) metal and non-metal constituents reffered as Alloys. Alloying allows metals to be created with a vast range of properties allowing them to be used in a great variety of appliation.

Metals are divided into two main categories, ferrous and non-ferrous.

Ferrous metals contain iron whereas non ferrous metals do not. Ferrous and non ferrous metals possess different properties of particular importance is the rate at which they corrode in the natural environment.







LOW ALLOY STEELS: (or) Carbon Steels:

i) Low Carbon Steel:

Carbon steels are iron-Carbon alloys Containing upto 2.06% of carbon, upto 1.65% of manganese, upto 0.5% of silicon and sulphur and phosphorus as impurities.

Carbon Content in carbon steel determines its strength and ductility. The higher carbon content, the higher steel strength and lowers its ductility.

Carbon steel is classified into four types, based on Carbon content. They are

* Low Carbon steel (or) Mild Carbon steel.
* Medium Carbon Steel
* High Carbon steel
* Ultra high Carbon (or) tool Carbon steel

* Low Carbon Steel:

→ The most Common form of Steel is low Carbon or mild steel.

→ Low Carbon steel Contains approximately 0.05 to 0.32% carbon and upto 0.4% of Manganese, which is malleable and ductile.

Properties: 1. Low Carbon steel has a relatively low tensile strength.

2. Good formability and weldability.

3. The surface hardness is increased through 'carburizing'.

Examples: Structural steel (AS3679 grade 250 or 300).

Applications: Low carbon steel is suitable for many applications such as carbody panels, Nuts & bolts, foodcans, metal chains, wire ropes, engine parts, bicycle rims, nails & screws.

* Medium carbon steel:

Medium carbon steel contains approximately 0.30 to 0.59% of carbon with 0.60% - 1.65% manganese.

It balances ductility and strength and has good wear resistance.

Properties: Good toughness

Relatively good strength

may be hardened by quenching.

Example: AISI 1045 (American Iron and Steel Institute).

Applications: Railway wheels, tracks, gears, axles, screws, cylinders, crankshafts and heat treated machine parts.

* High carbon steel:

High carbon steel contains approximately 0.60 to 1.70% of carbon with 0.30% to 0.90% manganese.

The high carbon steel usually containing chromium, Vanadium, tungsten and molybdenum. These alloying elements combine with carbon to form very hard and wear resistant compounds (Eg: Cr_2C_6, V_4C_3, and WC).

Properties: High strength, hardness and wear resistance
moderate ductility.

Applications: rolling mills, rope wire, Screw drivers, hammers, wrenches, springs and high strength wires.

Ultrahigh Carbon (or) Tool Carbon Steel:

Ultrahigh Carbon steel has approximately 1.0 to 2% of carbon. Its high carbon content makes it an extremely strong material.

Properties: Very high strength, hardness, wear ~~&~~ resistance
poor weldability
low ductility.

Applications: It is used in manufacturing knives, axles or punches, shear blades, springs, milling cutters.

More steels with more than 1.2% carbon content are made using powder metallurgy.

CAST IRON :

Cast Iron is Iron or ferrous alloy which has been heated until it liquefies, and is then poured into a mould to solidify (1150°c to 1300°c). It is usually made from pig Iron.

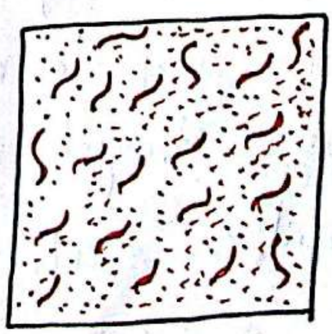
Steel with Carbon Content above 2.14%. is Cast Iron. Cast Iron properties are changed by adding various alloying elements.

There are four types of Cast Iron

1. Grey Cast Iron.
2. Ductile (or) Nodular Cast Iron.
3. White Cast Iron.
4. Malleable Cast Iron.

1) Grey Cast Iron :

* Grey cast Iron contains graphite in the form of flakes.



* When the material get fractured it has a grey appearance.
* It has Excellent wear resistance.
* It is the most Common cast Iron and the most widely used cast material based on weight. It has high thermal Conductivity.

Composition: Carbon - 2.4 to 3.8%

Silicon - 1.2 - 3.5%

Manganese - 0.5 - 1.0%

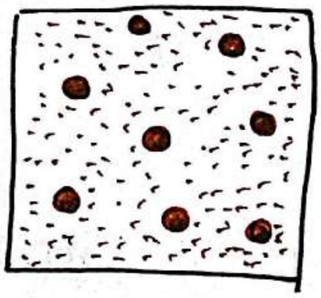
Sulphur - 0.06 - 0.12%

phosphourus - 0.1 to 0.9%

Appliations: disc brakes in Car, Hydraulic Components, Values, Truck suspension Componeents, Wind turbine housings, Machinery bases and Internal combustion engine Cylinder blocks.

2. Ductile (or) Nodular Cast Iron:

* Tiny amounts of Magnesium or Cerium added to the Gray Cast Iron, it Converts the graphite flakes to nodules.
* Castings are stronger and much more ductile than grey Cast Iron.



* It has more tensile strength, high elastiity and toughness than any of other Cast Iron types.
* The mechanical properties are inflenced by the arrangement of the graphite nodules. (Mechanical properties like toughness, tensile strength, elastiuty, ductility, hardness & fatigue strength).

Composition: Carbon - 3.3 to 3.4% Magnesium - 0.03 to 0.05%

Silicon - 2.2 to 2.8% phosphorus - 0.005% to 0.04%.

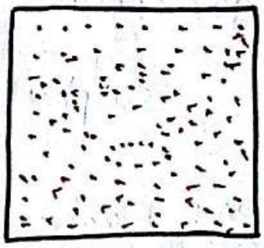
Manganese - 0.1 to 0.5% Sulphur - 0.005% to 0.02%.

Applications: Crank shafts, pump bodies, Values and gears.

White Cast Iron:

This type of Cast Iron displays white fractural surface due to the presence of Cementite. (Fe_3C)

It is very hard and brittle.



It is used as intermediate to produce malleable Cast Iron.

Composition: Carbon - 2.5%   Mo - 0.5%

Mn - 0.4%   Ni+Cu - 0.15%

Cr - 17%

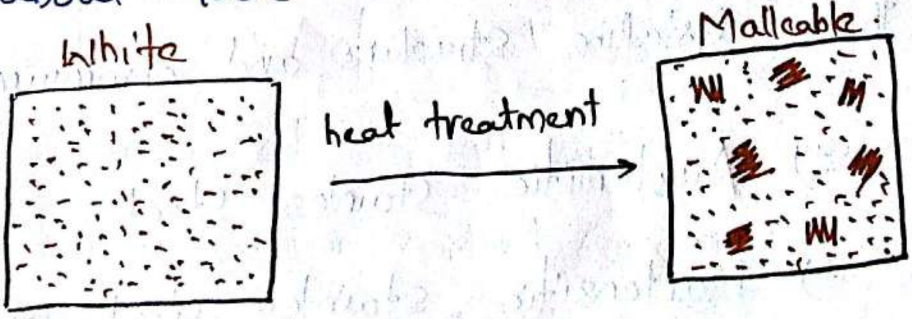
Si - 1.3%

S - 0.15%

Applications: Decorated furnitures, rollers in rolling mills

Malleable Cast Iron:

Malleable Cast Iron forms by heating white cast Iron at about 900°C



It has reasonable strength and improved ductility.

Graphite in nodular form. Graphite nodules are irregular clusters.

Composition: Carbon - 2.00 to 2.65%.

Silicon - 0.90-1.40%.

Manganese - 0.25 to 0.55%.

phosphorus - less than 0.18

Sulphur - 0.05.

Application: Electrical fittings, hand tools, pipe fittings, washers, fence fittings, Power line hardware, mining hard ware.

STAINLESS STEEL:

Stainless steels generally contain chromium (10 to 26 as the main alloying element.

They exhibits extraordinary Corrosion resistance like 200 times than low Carbon steel due to the presence of chromium.

These steels are further divided into 4 groups based on their Crystalline structure and chromium Content. They are

1) Austenitic Stainless Steel
2) Martensitic stainless steel
3) Ferritic Stainless steel
4) Duplex Stainless steel.

1) Austenitic Stainless steel:

* These are non heat treatable and generally contains 18% of chromium, 8% of Nickel and less than 0.8% of Carbon.

* Austenitic steels form the largest portion of the global stainless steel market.

Properties:
- Good to excellent Corrosion resistance
- Good weldability and formability
- Good Creep resistance
- Non-magnetic

Applications: These steels are used in food processing equipment, kitchen utensils and piping.

2) Martensitic Stainless steel:

* The martensitic grades are the smallest group of stainless steels.

* These are heat treatable contains 11 to 17% of chromium, less than 0.4% of nickel and 1.2% of Carbon.

* For improved strength and hardenability they have a higher carbon content compared to other grades.

Properties:
- High strength
- High wear resistance
- Limited Corrosion resistance
- Magnetic

Applications: These steels are used in knives, cutting tools, as well as dental and surgical equipment.

3. Ferritic stainless steel:

Ferritic steels contain trace amounts of nickel, 12-17% chromium, less than 0.1% carbon, along with other alloying elements, such as molybdenum, aluminium & titanium.

Molybdenum is improve the corrosion resistance and titanium improves the weldability.

The ferritic grades are magnetic due to their ferritic microstructure.

properties:
- Low carbon and nickel content
- Good corrosion resistance
- Good weldability and toughness
- Magnetic.

Applications: Ferritic stainless steels are used in automotive applications, kitchenware and industrial equipment.

4. Duplex stainless steel:

Duplex stainless steels contain high chromium (20.1 to 25.4%) content and low nickel content (1.4-7%).

Molybdenum (0.3-4%) and Nickel are added to improve corrossion resistance, while Nickel also increases strength.

Properties : • High strength and toughness
• Very good corrosion resistance
• Good weldability
• Light weight
• Magnetic

Applications : Chemical processing, transport and storage
Oil and gas refining
Pollution control equipment

HIGH STRENGTH LOW ALLOY STEELS : [HSLA STEELS]

High strength low alloy steels are designed to provide better mechanical properties and greater resistance to atmospheric corrosion than conventional carbon steels.

They are not considered to be alloy steels in the normal sense because they are designed to meet specific mechanical properties rather than a chemical composition.

HSLA steels are relatively strong low carbon steels with less than about 10wt% total of alloying elements. They contain other alloying elements such as 2% of Manganese and small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium and Zirconium

Low carbon steels (0.05 to 0.25% of C) + 10% wt of several alloying elements → HSLA steel

High strength low alloy steel possess

- High strength to weight ratio
- Improved low temperature toughness
- Fatigue resistance
- High temperature creep resistance
- Atmospheric corrosion resistance
- Weldability and formability.

Applications:

- Oil and gas pipelines
- Aerospace application
- Construction bridges, towers
- Industrial equipment and storage tanks
- Passenger car components
- Building beams and panels.

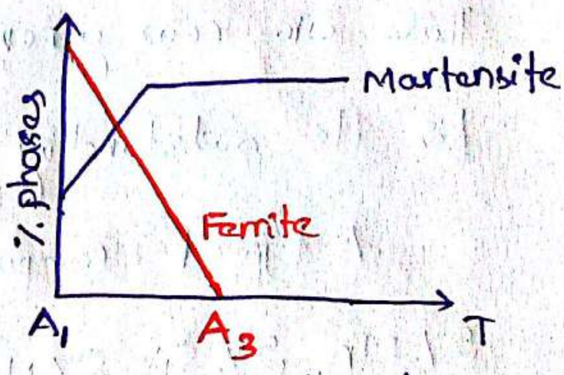
DUAL PHASE STEEL: (DPS):

Dual phase steel was designed in order to reduce the weight of used steel without loosing its benefits.

DPS is a high strength steel that has a ferrite and martensite microstructure.

It is a high strength material than a microalloyed steel.

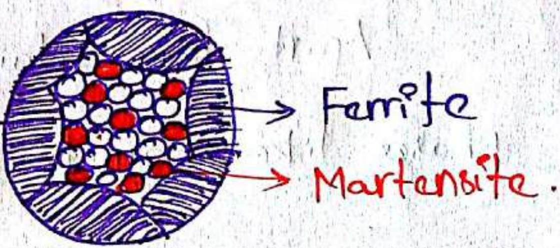
DPS starts as a low (or) medium carbon steel and quenched from a temperature above A_1 but below A_3 on a continuous cooling transformation diagram.



Continuos Cooling transformation diagram.

This result in a microstructure consisting of a soft ferrite matrix containing islands of martensite as the secondary phase.

Microstructure:



- 75 - 85% ferrite
- Remainder mixture of martensite (retained austenite)
- Usually consist of two or more phases.

Advantages:

- Low yield strength
- High initial strain hardening rates
- Good uniform elongation
- A high strain rate sensitivity (the faster it is crushed the more energy it absorbs)
- Good fatigue resistance.

Applications: DPS steel is used for automotive body panels, wheels and bumpers.

TRIP [Transformation Induced Plasticity] steels :

TRIP stands for "Transformation induced plasticity".

These are new generation of low alloy steel and known for its outstanding combination of 'strength and ductility'.

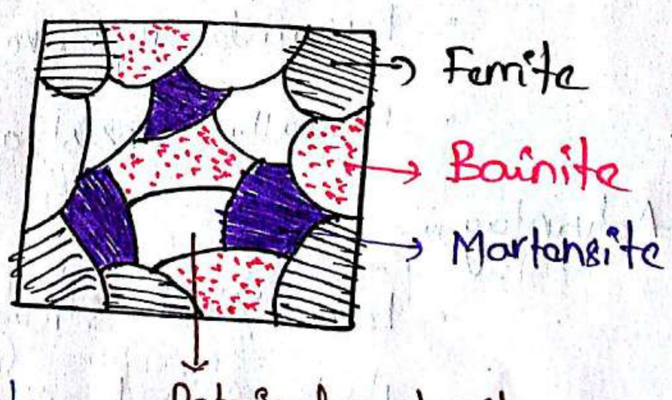
A typical composition of TRIP steel is 0.25% C, 2% Mn, 2% Si, 8% Ni, 9% Cr and 4% Mo.

Trip steel has a microstructure consisting of retained austenite in ferrite matrix.

Apart from retained austenite it also contains hard phases like Bainite and Martensite.

Properties:

- Enhanced combination of strength & ductility.
- Greater elongation.
- High strain hardening capacity
- Good formability



Applications :

- The use of TRIP steel could reduce the mass of the steel on a vehicle by 20% and the total vehicle mass by 11 percent.
- Use of TRIP steel could lead to a reduction in total fuel consumption of 0.64 percent.

- TRIP Steels are particularly well suited for automotive structural and safety parts such as cross members, longitudinal beams, pillar reinforcements and bumper reinforcements.

MARAGING STEEL:

These steels are a special class of low carbon ultrahigh strength steels.

The strength of maraging steel derive not from Carbon, but from precipitation of intermetallic compounds.

The principal alloying element is 15 to 25 wt% of Ni. Secondary alloying elements are added to produce intermetallic precipitates, which include cobalt, molybdenum and titanium.

The amount of carbon in this steel is negligible.

Properties:

- Due to the low Carbon content maraging steels have good machinability.
- These steels offer good weldability.
- These steels have a high hardenability.
- These are moderately corrosion resistant. Corrosion resistance can be increased by cadmium plating or phospating.

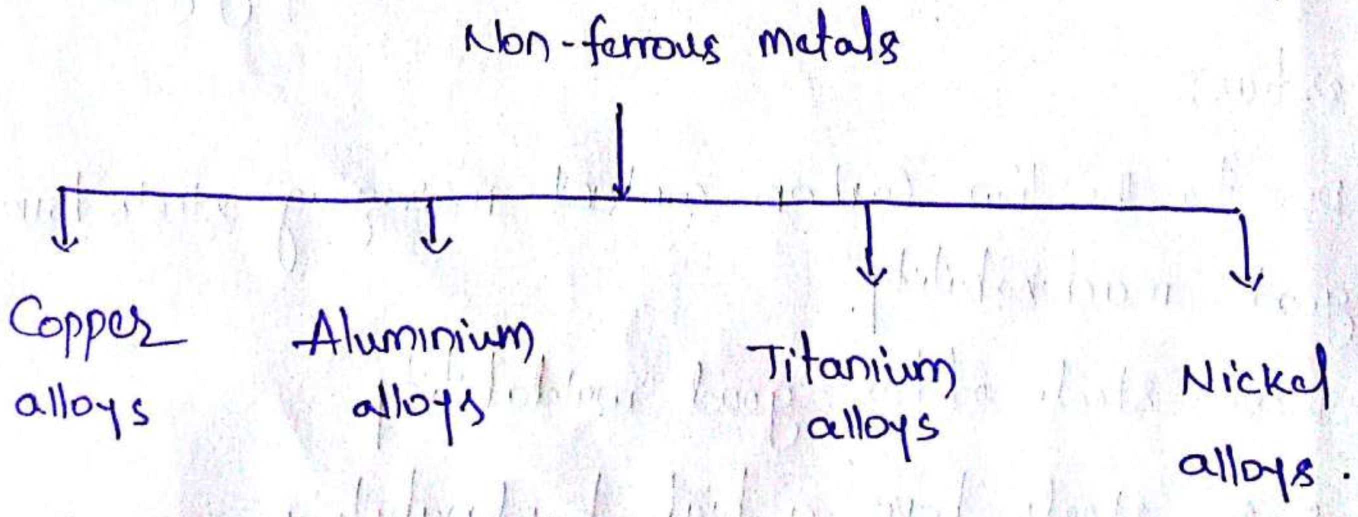
Applications:

- The maraging steels are suitable for engine components such as crankshafts and gears.
- They are used in bicycle frames and golf club heads.
- It is also used in surgical components and hypodermic syringes, but is not suitable for blades.

Non-Ferrous Metals:

Non-ferrous metals have specific advantages over ferrous metals. They can be fabricated with ease, high relatively low density and high electrical and thermal conductivities.

However, different materials have distinct characteristics, and are used for specific purposes.



Copper alloys:

- It is one of the earliest metals discovered by man
- The boilers on early steamboats were made from Copper
- copper is a ductile metal
- Pure Copper is soft, malleable and difficult to machine.
- It has very high electrical conductivity.
- It has an excellent thermal conductivity.
- Copper cookware is helpful in fast and uniform heating.
- Copper is widely used in electrical and Construction industries.
- The second largest use of Cu is in coins.

a) Copper alloy - 'Brass':

- Brass is the most common alloy of Copper. It is an alloy with Zinc [Cu + Zn → Brass]
- Brass has higher ductility than Copper (or) Zinc.
- It is easy to Cast and it has low melting point and high fluidity.
- Its properties can be tailored by Varying Zn content.
- Brasses have a range of attractive colours red, yellow, gold and brown.
- Brass is frequently used to make musical instruments, plumbing, decoration, low friction applications (values, locks).

b) Copper alloy - 'Bronze':

- Copper alloys usually with tin, but sometimes other elements including lead, aluminium, Silicon, nickel, manganese and phosphorus are classified as 'Bronzes'.
- (Cu - Sn) Bronze is one of the earliest alloy discovered as stronger than Brass.
- Bronze has good Corrosion and tensile properties.
- Usually bronze is in reddish brown and not as bright as brass.
- Melting point is higher than brass.
- It has wide range of applications such as in ancient chinese cast-artifacts, bronze sculpture, bearings, surgical and dental instruments.

c) Copper alloy - 'Beryllium': (or) Beryllium Copper:

- Copper - Beryllium alloys are heat treatable. Maximum solubility of Beryllium in Copper is 2.7% at 866°c
- It solubility decreases at lower temperature.
- It is ductile, weldable and machinable.
- It is resistant to non- oxidizing acids (HCl or H_2CO_3).
- Its thermal conductivity lies between steels and aluminium.
- Copper - Beryllium alloys are used in Contacts for batteries and electrical Conductors. They used in springs, load cells etc.

Aluminium:

- Aluminium is a light metal and easily machinable.
- It has a wide variety of surface finishes, good electrical and thermal Conductivities.
- It is highly reflective to heat and light.
- Al is non toxic. It has high formability.
- Al has good Corrosion resistance due to its natural oxide layer.
- It is a versatile metal. It can be cast, rolled, stamped, hammered, forged into many shapes.

Aluminium alloys:

- Aluminium alloys have high strength to weight ratio
- Al is easily alloyed and many of its alloys are stronger than pure Al.
- Al alloys are non-magnetic
- Principal alloying elements of Al are Cu, Mn, Mg, Si, Zn and Fe

a) Al+Cu alloy:
- Increases strength and Hardness.
- If > 12% makes the alloy brittle.
- Decreases Corrosion resistance.

b) Al + Mn alloy:
- Increases yield & tensile strength
- Improves ductility
- Good resistance to Corrosion.
- Decrease resistivity.

c) Al + Si alloy : • Increases tensile strength and hardness upto 13% wt.
- Decrease the hot Cracking

d) Al + Mg alloy : • Good Corrosion resistance
- Increases weldability and machinability.

e) Al + Zn alloy : • Gives heat treatable alloys when combined with Mg.
- Increased toughness but susceptible to stress corrosion Cracking.

Applications : • Pure Al has Electrical and chemical applications.
- Aircraft and transport applications (Al-Cu alloys)
- Heat transfer, packaging, roofing - siding applications. (Al-Mn alloys)
- Pistons, Complex - Shaped forgings (Al-Si alloys).
- Building & Construction, automotive, cryogenic and marine applications (Al-Mg alloys).
- Aerospace and automotive application (Al-Zn alloys).

* There are two principal classifications of Al alloys namely
(i) Casting alloys (ii) wrought alloys.

Both of which are further subdivided into the categories · heat treatable and non heat treatable.

· About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions.

Cast Al alloys yield cost effective products due to the low melting point, although they generally have lower tensile strength than wrought alloys.

Titanium :

* Pure titanium melts at 1670°c and has a low density of 4·55 g/cc
* It is 40% lighter than steel and 60% heavier than Al.
* It has high affinity towards Oxygen. It can catch fire and cause severe damage.
* It has an excellent Corrosion resistance due to the presence of protective thin oxide surface film.
* It has been used as a biomaterial.
* The only limitation of pure Ti is its lower strength, and hence alloying is done to improve strength.
* Oxygen, Nitrogen, and hydrogen can cause titanium to become brittle.

Titanium alloys: Titanium exhibits two phases

* Hexagonal α-phase at room temperature.

* BCC β-phase above 882°C.

* Alloying elements are either 'α' or 'β' stabilizer.

* Elements with electron/atoms ratio <4 are α stabilizer. (Al, O, Ga) and > 4 are β stabilizer (V, Mo, Ta, W).

* α-alloys have → low density
  → moderate strength
  → reasonable ductility and
  → good creep resistance.

* β-alloys are → heavier
  → stronger
  → less ductile
  → creep resistance reduces with increasing β-content.

* (α+β) two phase alloys can be obtained with right proportions of alloying elements.

* (α+β) alloys show a good strength - ductility combination.

Applications: Because of Ti high strength to weight ratio and excellent corrosion resistance, Ti is used in a variety of applications such as

* Aircraft body structure
* Engine parts
* sporting equipment
* chemical processing
* Turbine engine parts
* Valve and pump parts
* Medical implants
* Marine hardware etc.

Nickel :

* Nickel is a high density, high strength metal with good ductility, excellent corrosion resistance and high temperature properties.
* Ni has many unique properties including its excellent catylytic property.
* two-third of all nickel produced goes into stainless steel production.
* It's very difficult alloying with cheap elements.
* Relatively high cost.

Nickel alloys :

* High purity nickel contains 99.99% Ni
* Ni-Cu alloy contains 67% Ni and 33% Cu, called Monels.
* Ni-Cr alloys are called Inconel and Nichrome.

Ni-Cr → Inconel 600 (79.5% Ni + 15.5% Cr + 8% Fe)

Ni-Cr → Nicrome (80% Ni + 20% Cr).

* High temperature heat resistance alloys, which can retain high strengths at elevated temperatures is called Ni based super alloys.
* Some other Ni alloys are German Silver (60% Cu + 20% Ni + 20% Zn) and Haste alloy (45% Ni + 16% Cr + 15% Mo).

Applications:

* Pure Ni → Food processing equipment
  → Electrical and electronic parts
  → Caustic handling equipment.

* Ni-Cu alloys (Monels) → steam turbine blades
  → High temperature valves
  → Pump shafts, springs & valve stems

* Ni-Cr alloys
  → Gas turbine combustors
  → chemical equipment
  → furnace muffle
  → rocket skins
  } Inconel

  → resistance heating coils
  → rocket igniters
  → Ceramic manufacturing industry
  } Nichrome.

* Ni based superalloys → Aircrafts, space vehicles, rocket engines
  → Nuclear reactors, submarines
  → steam power plants and petrochemical equipment

* German silver → Silver plated jewellery
  → musical instruments, ornamental works of cars

* Haste alloy → Bearings
  → Pressure vessel linings, chemical reactor pipes.