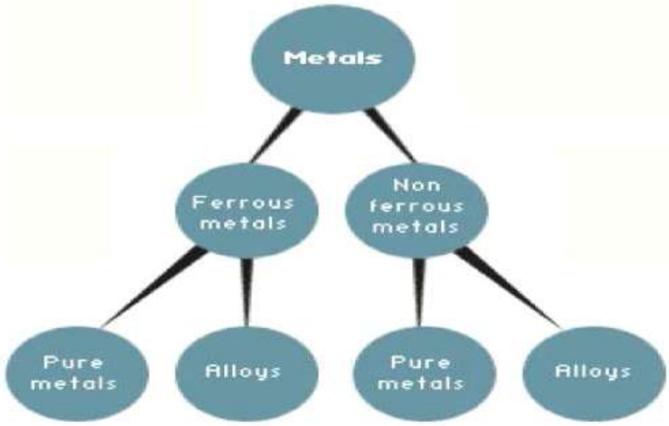
MODULE 4

MODULE-4
Engineering Materials and Introduction to Composites

A **metal** is a material that is typically hard, opaque, shiny, and features good electrical and thermal conductivity. Metals are generally malleable, fusible and ductile
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).



Classification of Metals

Ferrous metals
Ferrous metals contain iron. Examples are cast iron, mild steel, medium carbon steel, high carbon steel, stainless steel, and high speed steel.
Non-ferrous metals
Non-ferrous metals do not contain iron. Some common non-ferrous metals are aluminium, copper, zinc, tin, brass (copper + zinc), and bronze (copper + tin).

Engineering Materials Properties
Strength: It is a measure of its ability to resist the applied load without fracture
Stiffness: It is force per unit deformation of structure
Hardness: It is the resistance to abrasion/plastic deformation
Ductility: A material which can be drawn into wire is ductile material
Malleable: A material which can be drawn into thin sheet is malleable
Toughness: The amount of energy required to rupture a material under static load.
Resilience: It is the amount of energy absorbed in stressing a material upto the elastic limit
Elasticity: Elasticity is the property of a material by virtue of which deformations caused by stress disappear on removal of the stress
Plasticity: It is property that enables material to undergo permanent deformation without rupture
Thermal Conductivity: It is the property of a material to conduct heat
Electrical Conductivity: It is the property of a material to conduct electricity

Ferrous Metals & Alloys:-

- Ferrous metals and alloys contain principal element as iron, which includes carbon steel, stainless steel, cast iron and wrought iron
- These metals/alloys possess good tensile strength and durability

- They possess good magnetic properties, hence make them suitable for electrical appliances
- They can be recycled, while they are vulnerable to rust when exposed to atmosphere
- Principally iron is found in the iron ore such as hematite which in later stage reduced to pig-iron
- Pig-iron is used to produce the following iron products: (i) Wrought iron (ii) Cast iron & (iii) Steel

Types of Ferrous metal:

Wrought Iron:

- Pig iron is melted and combined with metal oxides that reduces carbon %, making the resulting wrought iron more usable and less brittle
- It can be easily welded, hot forged and can resist impact loading. Wrought iron is used to make bolts, nuts, chains, hooks, boiler tubes and plates

Steels

- Steels are iron-carbon alloys that may contain appreciable concentrations of other alloying elements
- The mechanical properties are susceptible to the heat treatment and alloying elements%, specifically carbon% which is normally less than 10% by weight
- Based on carbon % steels are classified as,
  - Low carbon steel
  - Medium carbon steel
  - High carbon steel
- Plain carbon steel contains residual concentration of impurities other than C and Mg
- For alloy steels, more alloying elements are intentionally added in specific concentration.

Low Carbon Steels

- Generally contains less than 0.25% C and are unresponsive to heat treatments, strengthening is accomplished by cold work
- These alloys are relatively soft and weak, but have outstanding ductility and toughness
- They are machinable, weldable and less expensive to produce
- Plain low carbon steels, typically have yield strength of 275 Mpa, tensile strength b/w 415 and 550 Mpa and ductility of 25% elongation
- High strength low alloy (HSLA) typically contains other alloying elements such as Cu, V, Ni and Mo in combined con. as high as 10% wt. and possess higher strengths,
- HSLA may be strengthened by HT, giving tensile strength in excess of 480 MPa, they are ductile, formable and machinable
- HSLA are resistant to corrosion than plain carbon steel

Applications:

- Automobile body components
- Structural shapes
- Sheets that are used in pipelines, buildings, bridges and tin cans
- Low temperature pressure vessels
- Nails and wires
- Structures used at low ambient temperatures
- Truck frames and railway cars
- Structures that are bolted or riveted

Medium Carbon Steels
- Generally contains less than 0.25-0.6% C
- They may be heat treated to improve their mechanical properties
- The plain medium carbon steels have low hardenabilities and can be successfully heat treated only in very thin sections and with very rapid quenching rates
- Addition of Cr, Ni, and Mo improve the capacity of these alloys to be heat treated, giving rise to a variety of strength-ductility combinations
- These heat-treated alloys are stronger than the low-carbon steels, but at a sacrifice of ductility and toughness
- These alloys possess good combination of high strength, wear resistance and toughness

Applications:
- Railway wheels and tracks
- Gears
- Crankshafts, bolts
- Chisels, hammers
- Knives, hacksaw blades
- Springs, hand tools
- Bushings, aircraft tubing
- Shafts, pistons, gears

High Carbon Steels
- Generally contains less than 0.6-1.4% C
- They are the hardest, strongest and yet least ductile of carbon steels
- They are especially wear resistant and capable of holding a sharp cutting edge
- The alloying elements such as Cr, V, W and Mo are added generally to form very hard and wear resistant carbide compounds
- These alloys possess low toughness and poor formability characteristics.

Applications:
- Drills, saws, lathe and planer tools
- Punches, embossing dies
- Cutlery, drawing dies
- Shear blades, cutting tools
- Pipe cutters, concrete drills
- Blacksmith tools, woodworking tool
- Knives, razors, hacksaw blades
- Springs and high strength wire

Stainless Steels (SS)
- The stainless steels are highly resistant to corrosion (rusting) in a variety of environments
- The predominant alloying element is Cr with at least 11% wt concentration.
- The corrosion resistance can be further enhanced by the addition of Ni and Mo
- On the basis of predominant phase constituent of microstructure, they are classified as
- Martensitic SS
- Ferritic SS
- Austenitic SS

Martensitic Stainless Steel
- They can be heat treated
- They contains 12-18% Cr
- They possess high strength, moderate toughness and poor weldability

- They are used in surgical tools and cutlery

Austenitic Stainless Steel

- They contains 16-25% Cr and 7-20% Ni
- They possess better corrosion resistance than other SS
- They are weldable and also exhibit excellent surface finish
- Typical Applications are shafts, pumps, fasteners, equipments for food processing chemicals, food and dairy products.

Ferritic Stainless Steel

- These alloys contains 12-30% Cr and carbon is kept low
- They possess poor ductility, poor weldability and cannot be hardened by heat treatment
- Ferritic SS are sued in heat transfer equipments in chemical and petrochemical industries and are less expensive

Applications:

- Automotive exhaust components,
- Tanks for agricultural sprays
- Valves (high temperature)
- Glass molds, Combustion chambers
- Chemical and food processing equipment
- Cryogenic vessels
- Welding construction
- Rifle barrels, Cutlery, Jet engine parts
- Bearings, Surgical tools, Knives
- Springs, Pressure vessels

Tool Steels

- Tool steels are basically high-carbon steels, modified by alloy additions and heat treatment to get the required strength and toughness. They are
- Water-hardening tool steels – High-carbon steels
- Manganese tool steels – 0.75 – 1% C and 1-2% Mg
- HSS – 0.7%C, 18W, 4% Cr and 1% V
- Hot-work tool steels – 0.5%C, 9-18%W, 3-4% Cr
- Shock-resisting tool steels – 0.4-0.56%C, alloying with Cr, V & Si.

Properties of tool steels:

- Resistance to wear/abrasion
- Strength at high temperature
- Thermal shock resistance
- High toughness
- Low frictional coefficient

Cast iron

- Cast irons are class of ferrous alloys with carbon content above 2.14%, in practice however most cast irons contain b/w 3-4.5%C, in addition other alloying elements
- Generally, they become liquid at temperature approx. b/w 1150-1300o C, hence they are easily melted and amenable to casting i.e., it has good castability.
- Further, some cast irons are very brittle, and casting is the most convenient fabrication technique
- It has low ductility and poor machinability with fair mechanical properties
- According to their micro-structure, they are classified as
  (i) Grey cast iron,
  (ii) White and Malleable cast iron

(iii) Ductile/Nodular cast iron,
(iv) Compacted graphite cast iron

Grey Cast Iron

- The C and Si contents of GCI vary b/w 2.5 – 4% and 1-3% respectively
- Carbon is present in the form of graphite flakes, hence the fracture surface appearance is gray hence its name
- They are relatively weak and brittle in tension
- The graphite flakes are sharp and pointed and may acts as points of stress concentration when an external tensile stress is applied
- Strength and ductility are much higher under compressive loads
- They are effective in damping vibrational energy, good compressive strength, excellent wear resistance, good thermal conductivity and machinability.

Applications:

- They are used in the manufacture of pulleys,
- Piston
- Piston rings
- Engine cylinders
- Machine frames
- Household appliances
- Small cylinder blocks
- Cylinder heads
- Transmission cases
- Clutch plates
- Diesel engine castings, liners
- Cylinder heads

Ductile/Nodular Cast Iron

- Addition of small amount of Mg, Ni and/or cerium to the GCI before casting produces ductile/nodular cast iron
- Graphite still forms but as nodules or sphere like particles instead of flakes
- They are relatively tough and stronger than GCI
- They possess excellent corrosion resistance and low temperature impact properties
- The ductile cast iron has mechanical characteristics approaching those of steel.

Applications:

- Valves
- Pump bodies
- Crankshafts
- Gears
- Furnace doors
- Construction machineries
- Heavy machinery frames
- Compressors

White and Malleable Cast Iron

- The fractured surface of low-silicon cast irons (containing less than 1.0 wt.% Si) with rapid cooling rates has a white appearance, and thus it is termed white cast iron
- White iron is extremely hard but also very brittle, to the point of being virtually unmachinable.
- Its use is limited to applications that necessitate a very hard and wear-resistant surface, without a high degree of ductility—for example, as rollers in rolling mills

- Generally, white iron is used as an intermediary in the production of yet another cast iron, malleable iron
- Grey and ductile cast irons are produced in approximately the same amounts; however, white and malleable cast irons are produced in smaller quantities.

Applications:

- General engineering service at normal and elevated temperatures
- Pump impellers
- Crushing and grinding equipments
- Brake shoes
- Automotive rear axles housing
- Low pressure valves
- Pipe fittings
- Wrenches
- Switch gears
- Wheel hubs
- Connecting rods

Compacted Graphite Cast Iron

- A relatively recent addition to the family of cast irons is compacted graphite iron (CGI)
- Silicon content ranges between 1.7 and 3.0 wt%, whereas carbon concentration is normally between 3.1 and 4.0 wt%
- Magnesium and/or cerium is also added, but concentrations are lower than for ductile iron.
- Tensile and yield strengths for compacted graphite irons are comparable to values for ductile and malleable irons, yet are greater than those observed for the higher strength grey irons
- In addition, ductilities for CGIs are intermediate between values for grey and ductile irons; also, moduli of elasticity range between 140 and 165 Gpa
- Compared to the other cast iron types CGI possess higher thermal conductivity, better resistance to thermal shock, lower oxidation at elevated temperatures.

Applications

- Diesel engine blocks
- Exhaust manifolds
- Gearbox housings
- Brake discs for high-speed trains
- Flywheels
- Base structures of machinery & heavy equipment that are subjected to vibrations

<u>Types of Non Ferrous metals and alloys:</u>

- Steel and other ferrous alloys are consumed in exceedingly large quantities because they have such a wide range of mechanical properties, may be fabricated with relative ease, and are economical to produce.
- However, they have some distinct limitations chiefly:

(i) a relatively high density
(ii) a comparatively low electrical conductivity and
(iii)An inherent susceptibility to corrosion in some common environments.

- Thus, for many applications it is advantageous or even necessary to utilize other alloys having more suitable property combinations.

- Alloy systems are classified either according to the base metal or according to some specific characteristic that a group of alloys share

Copper and its Alloys

- Pure copper is dense, reddish, malleable and ductile metal and non-magnetic
- The melting point of copper is 1084°C
- Copper exhibits high thermal conductivity, high electrical conductivity, good formability and low mechanical properties
- Furthermore, it is highly resistant to corrosion in diverse environments including the ambient atmosphere, seawater, and some industrial chemicals.
- Properties can be further improved by adding alloying elements such as Zinc, Tin and Aluminium.

Applications:

- Electrical cables and bus bars
- Radiator and heat exchanger
- Pipes and tubes to carry hot and cold fluids
- Cooking pots and pans
- Copper tubes are used in refrigerators and air conditioners.
- Copper tubes are used in electrical wires, cables.
- Used in roofing, sheathing and flushing drains.
- Used in brewing plants and chemical plants
- Used to make alloys such as brass and bronze
- Used to make sculptures, statues, door knobs.

Brass

- Brasses are alloys made from copper and zinc
- The variation in zinc content will results in desired color, strength, ductility, machinability, corrosion resistance and castability
- Brasses are known for their ease of fabrication and excellent plating characteristics
- Some of the common brasses are yellow, naval, and cartridge brass, muntz metal, and gilding metal

Applications:

- Plumbing fixtures and decorative hardware
- Radiator cores and heat exchanger tubing
- Low pressure valves and bearings
- Lamp fixtures and springs
- Filler metal in brazing
- Cooking pots and pans
- Electrical fittings, valves, tap.
- Radiator shells, head lamp reflectors.
- Marine fittings and ship components like anchors etc.
- Fire extinguisher and musical instruments.
- Marine fittings and ship components like anchors etc.
- Fire extinguisher and musical instruments.

Bronze

- Bronze is the alloy of copper and tin
- Based on the addition of alloying elements, bronzes are classified as tin bronze, aluminium bronze, phosphor bronze, beryllium bronze, etc.
- These alloys are somewhat stronger than the brasses
- These alloys can achieve high strength combined with good corrosion resistance.

Applications:

- Plumbing fixtures and decorative hardware
- Radiator cores and heat exchanger tubing
- Low pressure valves and bearings
- Lamp fixtures and springs
- Filler metal in brazing
- Cooking pots and pans

Phosphor bronze:

- It is an alloy of copper, tin and traces of phosphor
- Phosphor bronzes have high fatigue resistance, excellent formability and high corrosion resistance
- They are used in corrosion resistance bellows, diaphragms, spring washers, bearings, worm wheels and clutch drives

Aluminium bronze:

- It is an alloy of copper, nickel, iron and aluminium
- Aluminium bronzes provide high strength, excellent corrosion resistance and wear resistance
- Aluminium bronzes are used in marine hardware, pump and valve components for handling sea water, propeller shafts and heavy duty sleeve bearings.

Beryllium bronze:

- It is an alloy of copper and beryllium
- Beryllium bronzes provide good strength and hardness
- Beryllium bronzes are used in bourdon tube, welding equipments, bellows and springs

Gun Metal:

- Gun metal is an alloy of copper, tin and zinc
- These alloys are sued for valves, bearings, pumps, gears, boiler fittings and guns

Bell Metal:

- Bell metal is an alloy of copper and tin
- Bell metals are used for making bells, canons, utensils, etc.

Aluminium and its Alloys

- Aluminium and its alloys are characterized by a relatively low density (2.7 g/cm3), high electrical and thermal conductivities and resistance to corrosion in common environments, including ambient atmosphere
- Aluminium is a light, silvery white metal with a low melting point of 660°C
- Pure aluminium has good malleability, formability, high corrosion resistance, high electrical and thermal conductivity
- The strength-to-weight ratio of Al is high
- The mechanical strength of Al is high at low temperatures
- It is non-magnetic and non-sparking metal.

Applications

- Widely used in automotive and aircraft industries
- It is used in cryogenic and space applications
- It is used in household utensils, beverage cans and other packaging materials
- It is also used in electric cables and high voltage applications
- It is used as structural material
- Metallurgical Application
- Electrical Industry
- Aircraft Industry, Automotive Industry
- Packing Industry
- Domestic use & construction

Classification of Aluminium alloys:

- The common alloying elements used in commercial Al alloys are Cu, Mg, Si, Mn and Zn
- These elements help to improve the mechanical properties of Al
- The Al alloys can be divided into 2 major groups –
  (i) Wrought alloys and (ii) Cast alloys
- Within each group, the alloys can be subdivided into heat-treatable and non-heat-treatable alloys

Wrought Al alloys:

- Wrought Al alloys are those that are shaped as solids by plastic deformation
- They have low yield strength, good ductility, good fracture resistance and good strain hardening
- Extrusion, forging and deep drawing operations can be carried out quite easily with good dimensional tolerances

Wrought Al alloys:

- Casting Al alloys have low melting point, high fluidity and high strength
- Al casting alloy contains enough Si % to have high as-cast strength
- Cu and Zn can be used as other alloying elements

Lead and its Alloys

- Pure lead is soft, dense, malleable and bluish gray in color
- It exhibits high electrical conductivity, low thermal conductivity and high co-efficient of thermal expansion and low melting temperature of 327°C
- Also lead exhibits low Young's modulus, low tensile strength, and it is sensitive to creep
- The combination of its high density with low stiffness and good damping capacity makes lead an excellent material for absorbing sound and vibration.

Applications:

- Used in battery grids
- Font type metal in printing industry
- Cable sheathing materials for high voltage power cells
- Used as solders, bearings and gaskets
- Piping for handling corrosive chemicals
- Used as shield against X-rays
- Lead bricks are used in reactor radiation shielding.
- Used in lead-acid batteries
- Used to make water pipes due to its corrosion resistance.
- In building industry for Roofing ,weathering to prevent water penetration.

Lead-base alloys

- Antimony, tin and arsenic are the most common alloying elements
- Antimony is used to give greater hardness and strength
- Lead-tin alloys are most commonly used for their good melting, casting and wetting properties
- Lead-arsenical is used as sheathing around electrical power and communication cables for protection against moisture and corrosion
- Another widely used lead alloy is lead-antimony-tin, it is called lead-based Babbitt metals (white metal) extensively used for bearings

Alloys of lead

1. Solder

- It is an alloy of tin and lead used to join together the workpieces.

2. Babbitt Metal

- It is a lead alloy obtained by adding antimony, Tin and arsenic.
- It is used as a bearing material for crankshafts and axles.

3. Lead alloys made out of lead, arsenic, and antimony:

- Used to make shots for ammunitions for military and sports purposes.

4. Lead antimony alloys:

- Used in battery grids, pipes, sheets.

Nickel and its Alloys

- Pure nickel is hard, strong, very ductile, Ferro magnetic silvery grey in colour and high melting point of 1453°C
- Also nickel exhibits excellent resistance to corrosive environment, retain its strength at elevated temperature and high electrical conductivity.

Applications:

- Used as electrodes in batteries and fuel cells
- Electroplating on more corrosive substrates
- Food processing equipment and chemical processing equipment.
- Manufacture of electrical and electronic parts
- Aircraft gas turbines, nuclear power systems, steam turbine power plants

Nickel-base alloys

- Nickel is generally alloyed with Cu, Cr and Fe
- Ni-Cu alloys have high strength and toughness over a range of temperature, good weldability and excellent corrosion resistance
- Monel metal contains 67% Ni and 33%Cu
- It is used in valves, pumps, marine fixtures and chemical processing equipment.
- Ni-Cr alloy offer better oxidation resistant and possess high temperature strength, widely used in industrial furnaces, electronic components, heat exchanger tubing and food processing equipment.

Applications of Nickel

- **Used in food processing equipment.**
- **Used in medical equipment.**

Zinc

Composition: - Pure zinc (an element)

Properties and characteristics: - Weak metal, extremely resistant to corrosion

Application; - Usually used for coating steel to make galvanised items

Tin

Composition: - Pure tin (an element)

Properties and characteristics: - Soft, weak, malleable, ductile and resistant to corrosion

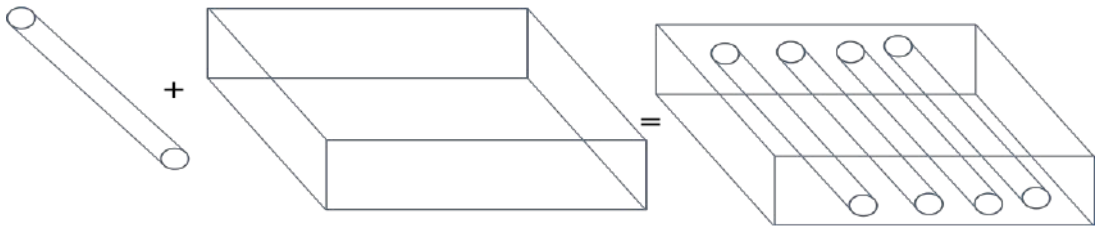
Application; - Usually used for coating steel to form tinplate

Composite Materials

Composite materials are defined as a macroscopic combination of two or more physically distinct identifiable materials which when combined together have improved properties over the individual materials.

Constituents of a composite

- The main constituent of composites are the **reinforcements** and the **matrix**
- One material forms a matrix to bond together the other material called the reinforcement material.



Reinforcement + Matrix = Composite

Matrix

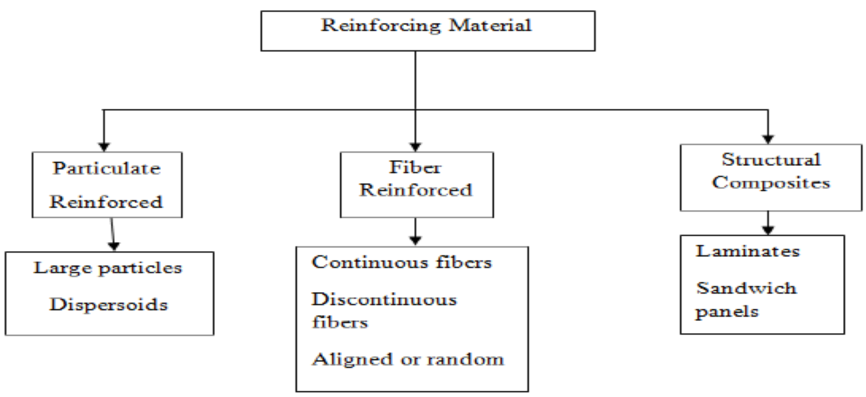
- The matrix is the monolithic material into which the reinforcement is embedded and is completely continuous
- The matrix serves two paramount purposes viz.,
- Binding the reinforcement phases in place
- Deforming to distribute the stresses among the constituent reinforcement
- The matrices may need to have properties for temperature variations, be conductors or resistors of electricity, have moisture sensitivity etc.
- This may offer weight advantages, ease of handling and other merits which may also become applicable depending on the purpose for which matrices are chosen.

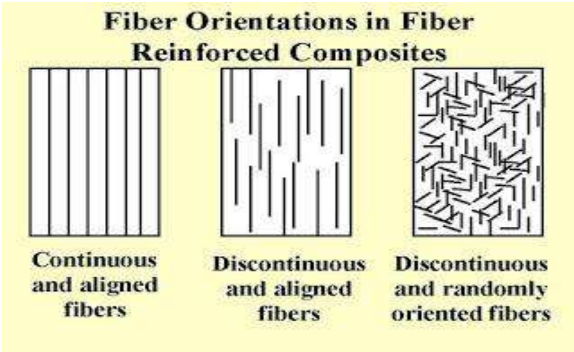
Reinforcement

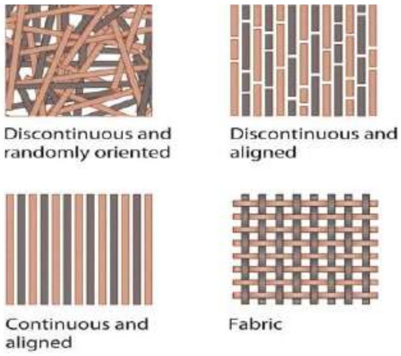
- Reinforcements for the composites can be fibers, fabrics particles or whiskers.
- Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular.
- Particles have no preferred orientation and so does their shape.
- Whiskers have a preferred shape but are small both in diameter and length as compared to fibers.
- Reinforcing constituents in composites, as the word indicates, provide the strength that makes the composite what it is.
- They also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity.
- Reinforcement can be made to perform all or one of these functions as per the requirements.

Classification of composite material

1. **Classification based on reinforcement material**







1. Fibre reinforced composite

- Fiber composite consists of either continuous or chopped fibers suspended in matrix material
- A continuous fiber is geometrically characterized as having high length-to-diameter ratio and are generally stronger and stiffer
- The discontinuous fibers or whiskers have either random or preferred orientation
- Fibers are generally polymers or ceramics. Ex: glass, aramid, carbon, boron, metal wires, alumina, etc.
- Fibre reinforced composite are those where the reinforcement is in the form of fibre.
- A natural example for fibre reinforce composite is wood in which strong cellulose fibre are aligned in a base matrix of lignin which bind the fibres.
- A Fibre is characterized by its length being much greater compared to its cross sectional dimensions.
- The dimensions of the reinforcement determine its capability of contributing its properties to the composite.
- Technologically the most important type of composites is fibre reinforced ones because of their wide range of application.
- Fibre reinforced composites with exceptionally high specific strength and modulus have been successfully produced using fibres of different material.

2. Laminated composites

- One of the unique characteristics of FRC is that their properties can be tailored to meet different types of loading conditions
- If layers of FRCs are stacked and bonded together in such a way that successive layers have their fibers aligned in different directions, the composite on the whole will have high strength and uniform properties in all directions
- In fibre –reinforced composites, if the fibres are of uniform alignment, the composites show anisotropic properties i.e., different properties along different direction.
- But if layers of such composites are stacked and bonded together in such a way that successive layers have their fibres aligned in different direction, the composite on the whole will have high strength and uniform properties in all direction.
- The best example for laminated composites is plywood where successive layers of wood having different orientation of grains are cemented together and composite on the whole has better strength in all direction.

3. Particulate composites

- A particulate composite consists of particle suspended in a matrix
- Particles can have virtually any shape, size or configuration
- Typical particulate materials are SiC, Al2O3, B4C, WC, etc

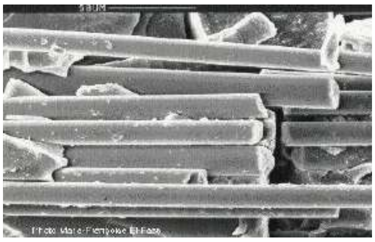
- For effective reinforcement and better properties, the particles should be small and of uniform size
- They should also be evenly distributed throughout the matrix
- The volume fraction of the two phases influences the behavior of composite with mechanical properties being enhanced with increased particulate content.
- In particulate composites the reinforcement is of particle nature. It may be spherical, cubic, tetragonal, a platelet, or of other regular or irregular shape.
- In this type of composites, particles of varying shape and size of one material is dispersed in a matrix of second material.

4. Flake Composites

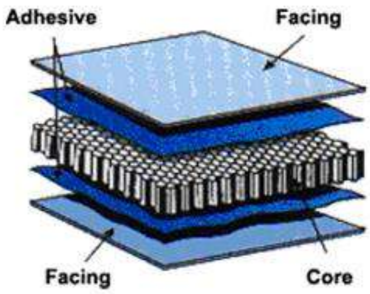
- A flake composite is generally composed of flakes with large ratios of area to thickness, suspended in a matrix material
- Typical flake materials are glass, mica, aluminium and silver

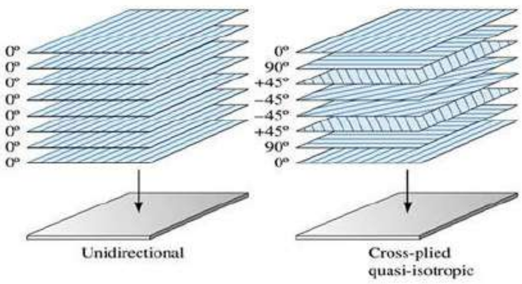
Microscopic Image

Particle Reinforced

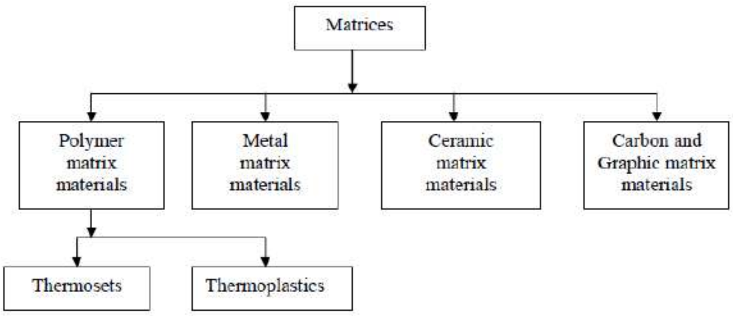


Fibre Reinforced





2. Classification based on matrix material



1. Polymer Matrix composites (PMC)

- Polymer matrices are most common and least expensive.
- They are ease to process, offer good mechanical properties
- Polymers may be of thermoplastics or thermoset
- Commonly used are epoxy, polyester, urethane, etc.
- Comprise of variety of short or continuous fibers that are bound together in an organic polymer matrix. They contain matrix from thermoset (unsaturated polyester (UP),

epoxy EP) or thermoplastic (polycarbonate (PC), Polyvinylchloride, Nylon, polysterene) and embedded fibres are of glass, carbon, steel.

- **Thermoplastic** are soften when heated and hardened when cooled. Processes are totally reversible. **Thermosetting plastics** become permanently hard when heated and do not soften upon subsequent heating.

Properties

- Superior corrosion resistance
- high strength and stiffness along the direction of reinforcement
- Very light weight.

Applications

- Sports industry applications: bike frames, canoes, fishing rods, racquets, archery bows, golf clubs, ski poles, skies, surf boards
- Marine applications: due to anti-rust properties, PMCs are used in boat parts such as propeller shafts, boat hulls etc
- Automotive applications: car exterior body panel, battery trays, bumper, instrument panels and fuel lines, dashboard etc
- Thermoplastic polymer and thermosetting polymers are used extensively as matrix material.

2. Ceramic Matrix Composites (CMC)

- Ceramic has high melting point, good corrosion resistance, stability at elevated temperature and high compressive strength
- Ceramic matrix is usually brittle
- Commonly used ceramics are alumina, Si, Calcium-alumino-silicate
- CMCs consists of ceramic fibers embedded in a matrix made from ceramic materials such as carbon (C), Silicon Carbide (SiC), Alumina ($Al_2 O_3$) or Zirconia (ZrO_3)

Properties

- good corrosion resistance
- low crack resistance
- High Mechanical strength at high temperature

Applications

- Automotive brakes
- Space applications to withstand high temperatures
- Gas turbine blades
- Domestic consumer applications: used in sanitary ware, bath unit, shower enclosures and sinks.

3. Metal- matrix composite (MMC)

- Most metals and alloys make good matrices
- Commonly used metals are Al, Cu, Mg, Ni, Fe, W, Ti, etc.
- The metal matrix have high elastic properties, high service temperature and high electric and thermal conductivities
- Composites that contain at least two component parts, one of which is metal and the other material may be a metal or ceramic or an organic compound.

Properties

- Higher strength and stiffness
- Higher operating temperature
- Low coefficient of thermal expansion
- Greater wear resistance.

Applications

- Piston of Diesel Engine
- High speed machinery and rotating parts of ships
- Aircraft and missile structures

Application of composite material in automobile system:

1. Suspension system for damping and stiffness.
2. Rocker arm for lower weight, high stiffness and wear resistance.
3. Valves for high temperature, creep, wear, fatigue.
4. Housing for lubricating pump for wear resistance and lower weight
5. Calipers for brake for low wear and weight.
6. Drive shafts for specific stiffness and fatigue resistance.
7. Connecting rods for fatigue wear resistance.
8. Car body
9. Instrument panel
10. Bumpers
11. Radiator grill

Application of composite material in aircraft

1. Main landing gear door
2. Nose landing gear door
3. Flap linkage fairing forward and mid aircraft
4. Fixed forward and trailing edge
5. Beech star ship to wing assemble
6. Helicopter rotor blades
7. Propellers of aircrafts
8. Aircraft seats
9. Instrument enclosures
10. Fiberglass and also graphite honeycomb structure for flaps

Advantages of composites

When compared to metals,

- Non – corrosive and resistant to chemical agents like acid rain, salt spray.
- Lower weight than their metal counterparts.
- Outstanding strength to weight and stiffness to weight ratios can be achieved.
- Good resilience, ability to deform and spring back to its original shape without resulting in major damage.
- Good thermal properties.
- Fiber reinforced composites are low in electrical conductivity and are very good insulators.
- Innovative designs can achieved with no loss in performance or strength.
- High strength or stiffness to weight ratio
- High resistance to fatigue
- High corrosion resistance
- High impact resistance
- Improved friction and wear properties
- Low coefficient of thermal expansion
- Design flexibility
- Dimensional stability
- Due to greater reliability, there are fewer inspections and structural repairs.

Disadvantages

- Cost of manufacturing/ fabrication is high (10 to 15 times the material cost).
- Repair of composites is not a simple process unlike that in metals

- Cost of raw materials for composites is high.
- Composite materials are not isotropic.
- Composite material is subject to environmental degradation.
- More brittle
- Low toughness
- High manufacturing cost
- Anisotropic property
- Low recyclability
- Difficult to repair composites
- High cost of raw materials
- Transverse properties may be weak.
- Reuse and disposal may be difficult.

Applications

- **Aerospace** – much of the structural weight of todays airplanes and helicopters consist of advanced FRP's (Fiber reinforced Polymer)
- **Automotive** – somebody panels for cars and truck cabs
- Satellite and space structures
- Sports and recreation: boat hulls, fishing rods, tennis rackets, golf club shafts, helmets, skis, bows and arrows
- Jet engine fan blades
- Superconductors in power reactors
- Storage battery plates
- High temperature structures and engine components
- Storage tanks, scrubbers, piping, pumps and blowers in chemical industries

Aircraft Applications

- Composite materials are important to the aviation industry because they provide good structural strength with light weight
- It leads to improved fuel efficiency and reduced direct operating cost of air crafts
- Most of the aircraft structures are made of CFRP, GFRP, carbon sandwich composites
- Components such as wings and tail of an aircraft as well as propellers and rotors are often made from composites
- One of the high temperature resistant and light weight composite material is CMC
- CMCs are used throughout combustor, turbine and exhaust nozzle
- CMC allow high operating temperature, which favors greater combustion efficiency leading to reduced fuel consumption.

Automobile Applications

- The main advantage of composite material is that their physical, mechanical and thermal properties are tailor able.
- Most of the automobile parts are made of MMC since MMCs can be extruded, forged, rolled, machined and heat treated
- The various parts made of MMCs are engine components like piston rings, cylinder liner, disc brake, clutch plates and drive shaft components
- The automobile bodies are made of glass fiber reinforced polymer composites due to its light weight and low cost

Biomedical Industry

- Widely used in orthopaedic applications such as bone fixation plates, hip join replacement, bone cement and bone grafts.
- Also used in dental applications such as in preparation of crowns, repair of cavities or entire tooth replacement.

MODULE-4

JOINING PROCESSES – WELDING, BRAZING & SOLDERING

Fabrication Process: - Joining two or more elements to make a single part is termed as fabrication process.
Fairly large numbers of industrial components are made by fabrication process.
Examples: Aircraft, Shipbuilding, Bridges, Sheet metal parts etc.
Mechanical joining by means of bolts, screws and rivets, Welding, Brazing and Soldering.

Soldering:

Soldering is a method of uniting two thin metal pieces using a dissimilar metal or alloy by the application of heat. The alloy of lead and tin called soft solder, is used in varying proportions for sheet metal work, plumbing work and electrical junctions. The melting temp of the soft solder will be between **150° to 350°** C. To clean the joint surfaces and to prevent oxidation a suitable flux is used while soldering. Zinc chloride is the flux that is commonly used in soft soldering. A soldering iron is used to apply the heat produced from the electrical source. An alloy of copper, tin, and silver known as hard solder is used for stronger joint. The soldering temp of hard solder ranges from **600° to 900° C**

Method of soldering

(i) Cleaning of joining surfaces
(ii) Application of flux
(iii) Tinning of surface to be soldered
(iv) Heating
(v) Final clean-up

(i) Cleaning of joining surfaces: Firstly, the joining surfaces are cleaned mechanically to remove dust, oil, scale etc and ensure that the molten filler metal wets the surfaces.

(ii) Application of flux: The joining surfaces are coated with a flux usually rosin or borax. This cleans the surfaces chemically and helps the solder in making a strong bond.

(iii) Tinning of surface to be soldered: Before carrying out the soldering operation, the soldering iron must be tinned. This is to remove a thin film of oxide that forms on the copper bit, which in turn does not allow the job to be heated and thus it becomes difficult to solder.

(iv) Heating: The soldering iron is then heated and flowing molten filler metals fills the joints interface. Allow the soldered area to cool and then solidify thus making the joint.

(v) Final clean-up: After soldering clean the joint with steel wool or solvent to remove left over flux. After this clean the soldering iron using a damp sponge.

Advantages of soldering

1. Low cost and easy to use
2. Soldered joints are easy to repair or do rework
3. The soldered joint can last for many year
4. Low energy is required to solder
5. An experienced person can exercise a high degree of control over the soldering process

Disadvantages of soldering

1. Not suitable for heavy sections
2. Temperature is limited

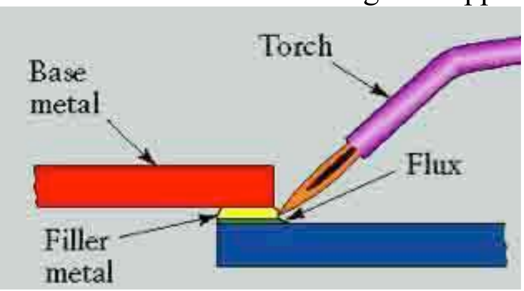
3. Strength is limited.

Application

Assembling electronic components to printed circuits boards(PCB's)
Join sheet metal objects
Joining of cooking vessel
Different types of flux are:
Rosin-alcohol, zinc chloride

Brazing:

Brazing is the method of joining two similar or dissimilar metals using a special fusible alloy. Joints formed by brazing are stronger than that of soldering. During the brazing, the base metal of the two pieces to be joined is not melted. The filler metal must have ability to wet the surfaces of the base metal to which it is applied. Some diffusion or alloying of the filler metal with base metal takes place even though the base metal does not reach its melting temp. The materials used in brazing are copper base and silver base alloy.



Method of brazing:

1. Cleaning the surface of the parts.
2. Application of flux at the place of joint.
3. Common borax and mixture of borax and boric acid is used as flux.
4. The joint and the filler material are heated by gas welding torch above the melting temperature of the filler material.
5. It flows into the joint space and a solid joint is formed after cooling.

Advantages of Brazing

1. It is easy to learn.
2. It is possible to join virtually any dissimilar metals.
3. The bond line is very neat aesthetically.
4. Joint strength is strong enough for most non-heavy-duty type of application.

Disadvantages of Brazing

1. Brazed joints can be damaged under high temp.
2. Brazed joint require a high degree of cleanliness.
3. The joint colour is often different from that of the base metal.

Welding:

Welding may be defined as the metallurgical joining of two metal pieces together to produce essentially a single piece of metal.

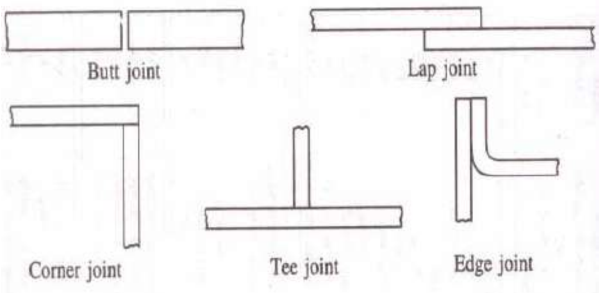
Principle of welding

A welding is a metallurgical process in which the junction of the two parts to be joined are heated and then fused together with or without the application of pressure or filler metal to produce a homogenous material of the same composition and characteristics of the part which are being joined.

Types of welding
Welding are classified in to two type
• Pressure welding or Plastic Welding
• Fusion welding or Non Pressure welding

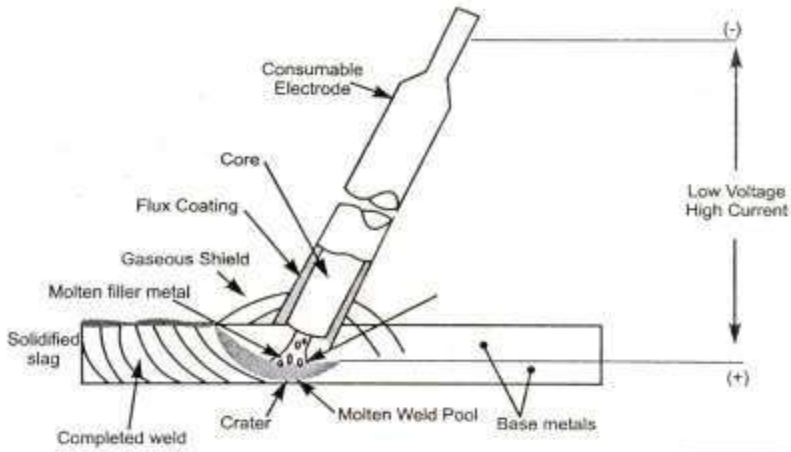
In **Pressure welding** the parts to be joined are heated only up to the plastic state and then fused together by applying the external pressure.
Ex: forge welding, resistance welding

In **Fusion welding** which also known as non-pressure welding, the joints of the two parts are heated to the molten state and allowed to solidify.
Ex: arc welding, gas welding.
Different types of Welding
Gas welding (Oxy acetylene, air –acetylene, oxy -hydrogen)
Resistance welding (Butt, Projection, percussion, spot, seam)
Thermit welding
Solid state welding (Friction, diffusion, ultrasonic, explosive)
Advance welding (Electro beam, laser beam)
Types of Joints
The welding joints are classified as
Butt
Lap
Tee
Corner joints
Edge joints.
The choice of the type of joint is governed by the kind of metal to be welded, its thickness and technique of welding.



Arc welding:
- The arc welding operates under the principle that when two conductors of an electric circuit are touched together momentarily and then instantaneously separated slightly, an electric arc is formed.
- Both AC and DC are used for arc welding. For AC arc welding a step down transformer is used. It receives AC supply between 200 to 440V and transforms it to required low voltage of 80 to 100V. A high current of 100 to 400A is suitable for arc welding.
- Due to this high temperature and current concentrated heat is produced throughout the length of the arc at a temperature of about 5000 to 6000°C.
- In arc welding, usually the parts to be welded are wired as one pole of the circuit, and the electrode held by the operator forms the other pole.
- When the arc is produced, the intense heat quickly melts the work piece metal which is directly under the arc.

- The molten metal in the pool is agitated by the action of the arc, thoroughly mixing the base and the filler metal.
- A solid joint will be formed when the molten metal cools and solidifies. The flux coating over the electrode produces an inert gaseous shield surrounding the arc and protects the molten metal from oxidizing by coming in contact with atmosphere.



Advantages of ARC Welding
The strength of the joint obtained is much stronger than the workpiece
Metals with different chemical compositions can be welded easily
Welding equipments are portable
Parts can be fabricated at reasonable costs
Welding process can be automated

Disadvantages of ARC Welding
The process gives out harmful radiations, fumes. Hence care should be taken during welding
Skilled operator is required to produce a good joint
The high heat involved in the process causes changes in the structure of metal (strength, ductility)

Electrodes used in arc welding
Consumable electrode
Non-consumable electrode
Consumable electrodes are those which get consumed during the welding process. These electrode help to establish the arc and also act as filler metal to deposit additional material to fill the gap between the workpieces.
Coated, plain (bare), tubular type
Coated Electrodes
The metallic wire called core is coated with a flux. Coating is done by dipping the heated end of the metal rod in the constituents of flux. Various constituents like: titanium oxide, cellulose, manganese oxide, calcium carbonates, mica, iron oxide etc
Functions of Coated Electrodes
Stabilizes the arc
Prevents oxidation of molten metal
Helps in removal of oxides and other undesirable substances on the surface of the workpiece
Chemically reacts with the oxides and form slag
Eliminate weld metal porosity.

Plain /bare Electrodes
The metallic wire is left plain or uncoated with flux. These electrodes do not prevent oxidation of the weld and hence the joint obtained is weak

Tubular electrode:
Tubular electrodes are hollow materials containing flux constituents inside and are used in flux-coated arc welding process.

Non consumable electrode: are made of carbon, graphite or tungsten and do not consume during welding

Gas welding:
It is a fusion welding, in which a strong gas flame is used to raise the temperature of the work piece to melt them. As in the arc welding, a filler metal is used to fill the joint. The gases that can be used for heating are

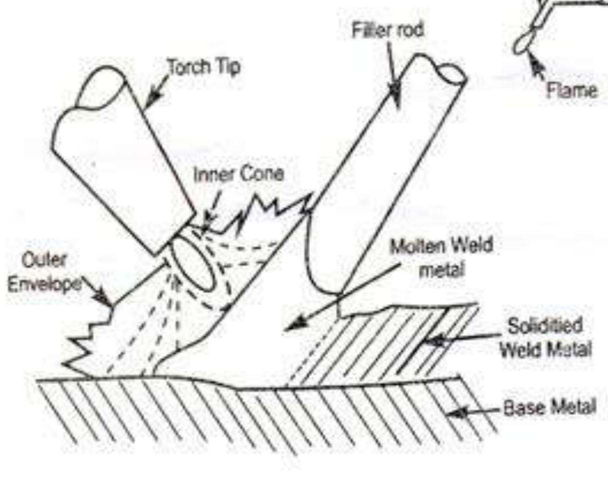
(i) Oxygen and acetylene
(ii) Oxygen and hydrogen.

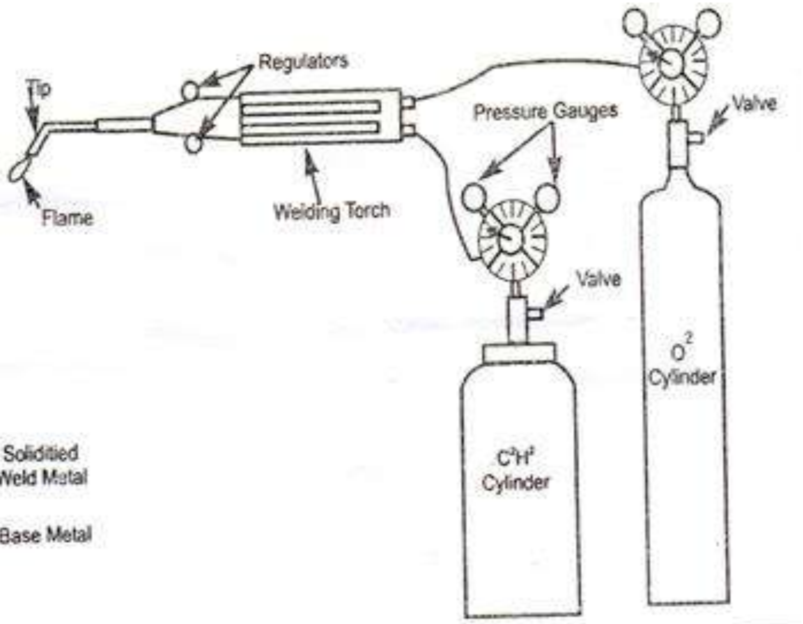
Oxy-acetylene gas mixture is most commonly used in gas welding

Oxy-acetylene welding:
When Right proportions of oxygen and acetylene are mixed in the welding torch and then ignited, the flame produced is called as the *oxy-acetylene flame.* The temperature attained n this welding is around 3200^0 C hence has an ability to melt all commercial metals.

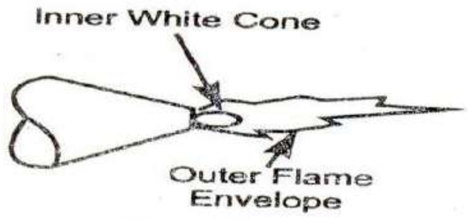
Types of oxy-acetylene flames
The types of flames depends on the gas ratio i.e ratio of the parts of oxygen to the parts of the acetylene Depending on the gas ratio following flames are obtained.

(i) Neutral flame
(ii) Oxidizing flame
(iii) Reducing flame (carburising flame)





(i) Neutral flame

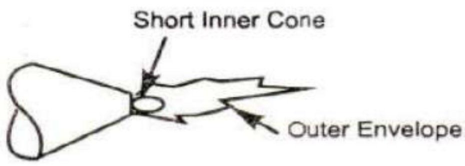


a) Neutral Flame

A neutral flame is obtained by supplying equal volume of oxygen and acetylene. It consists of a small whitish inner cone surrounded by sharply defined blue flame. Most of the gas welding is done using the neutral flame.

(ii) Oxidizing flame

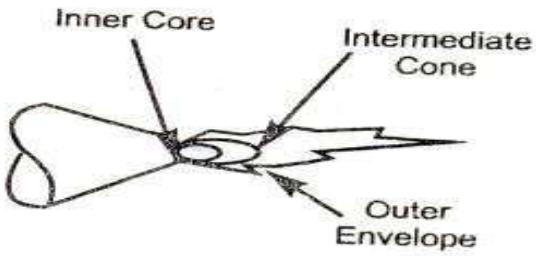
This is obtained when there is excess of oxygen, gas ratio. It appears to be similar to that of neutral flame but the inner white cone flame is shorter than that of neutral flame**.** This flame is generally used in metal cutting rather than welding since weld metal gets oxidized



c) Oxidising Flame

(iii) Reducing flame

This is obtained by supplying excess of acetylene in the gas ratio. It has 3 cones, an inner white cone, surrounded by an intermediate whitish cone known as "intermediate flame feather" and a bluish envelope flame. This flame is used for welding alloy steels, cast iron, and aluminium.



b) Carburising Flame

Advantages of oxy-acetylene welding

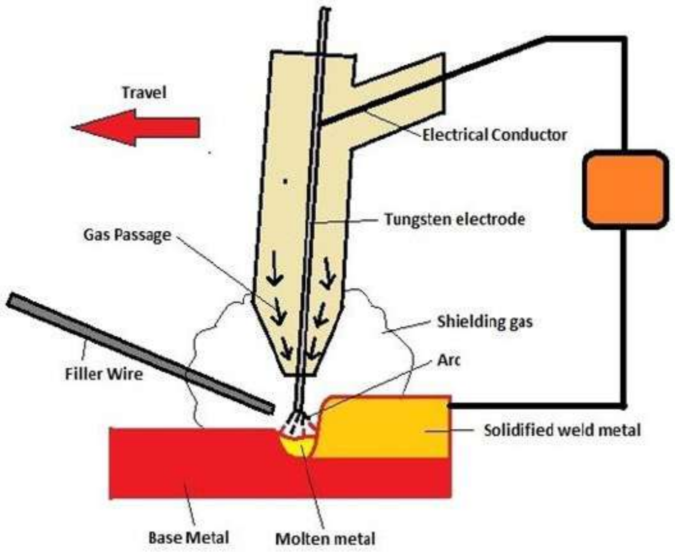
1. Most versatile process of welding with wide use in various manufacturing process
2. Low cost of the equipment and low cost of maintenance of the equipment
3. Because of separate heat source and filler metal the control can be exercised on the rate at which the filler metal deposits.
4. The equipment is portable and multi-functional because, apart from gas welding, it can also be used in torch brazing, braze welding, preheating and post heating.

Disadvantages

1. Difficult to attain low cost target while joining heavy section.
2. Handling and storage of gases not an easy job.

3. It takes long time for the flame to heat up the metal piece than compared to the arc welding.
4. Possible hazards due to explosion of gases.

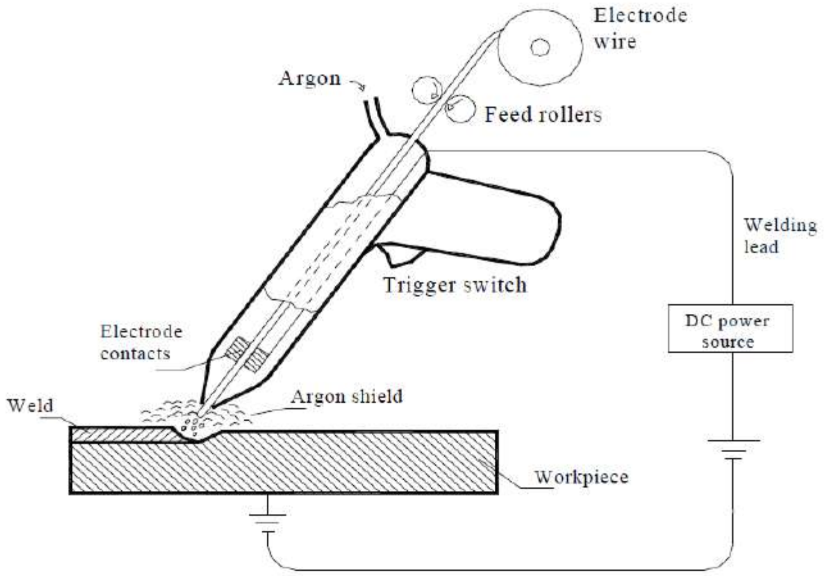
TIG (Tungsten Inert Gas) Welding:



- Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld.
- The weld area and electrode is protected from oxidation or other atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used.
- A constant-current welding power supply produces electrical energy, which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma.
- TIG is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys.
- The process grants the operator greater control over the weld than other processes, allowing for stronger, higher quality welds.
- However, TIG is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques.

MIG (Metal Inert Gas) Welding:

- Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt and join.
- Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air.
- GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation.



Applications of Welding

Used in Aircraft Industries to join various constituent parts.
Used in manufacture of furnaces and tanks.
Used in manufacture of steel furniture.
Used in building bus, truck, railway equipment, car bodies and parts.
Used in building structures like bridges, buildings and ships

Difference between Welding, Soldering and Brazing

Si.No	Welding	Soldering	Brazing
1	These are the strongest joints used to bear the load. Strength of a welded joint may be more than the strength of base metal.	These are weakest joint out of three. Not meant to bear the Load. Use to make electrical contacts generally.	These are stronger than soldering but weaker than welding. These can be used to bear the load up to some extent.
2	Temperature required is up to 3800°C of welding zone	Temperature requirement is up to 450°C.	It may go to 600°C in brazing.
3	Work piece to be joined need to be heated till their melting point.	No need to heat the work pieces.	Work pieces are heated but below their melting point.
4	Mechanical properties of base metal may change at the joint due to heating and cooling.	No change in mechanical properties after joining.	May change in mechanical properties of joint but it is almost negligible.
5	Heat cost is involved and high skill level is required	Cost involved and skill requirements are very low.	Cost involved and skill required are in between others two.
6	No preheating of work piece is required before welding as ¡t is carried out at high temperature.	Preheating of work pieces before soldering ¡s good for making good quality joint.	Preheating is desirable to make strong joint as brazing is carried out at relatively low temperature.

MODULE-4
TRANSMISSION OF POWER

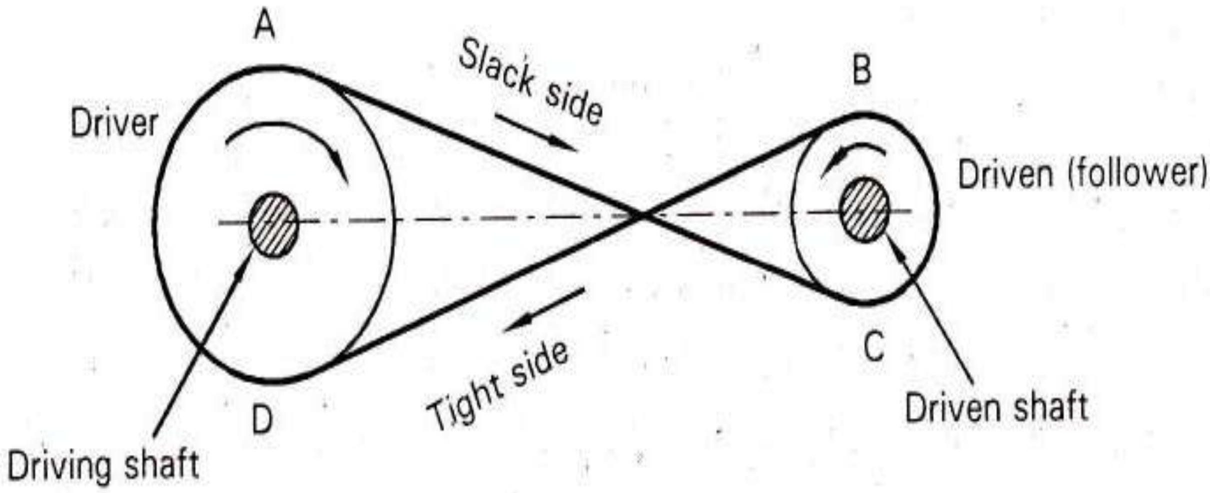
The rotational motion can be transmitted from one mechanical element to the other with the help of certain systems known as transmission system (Drive).

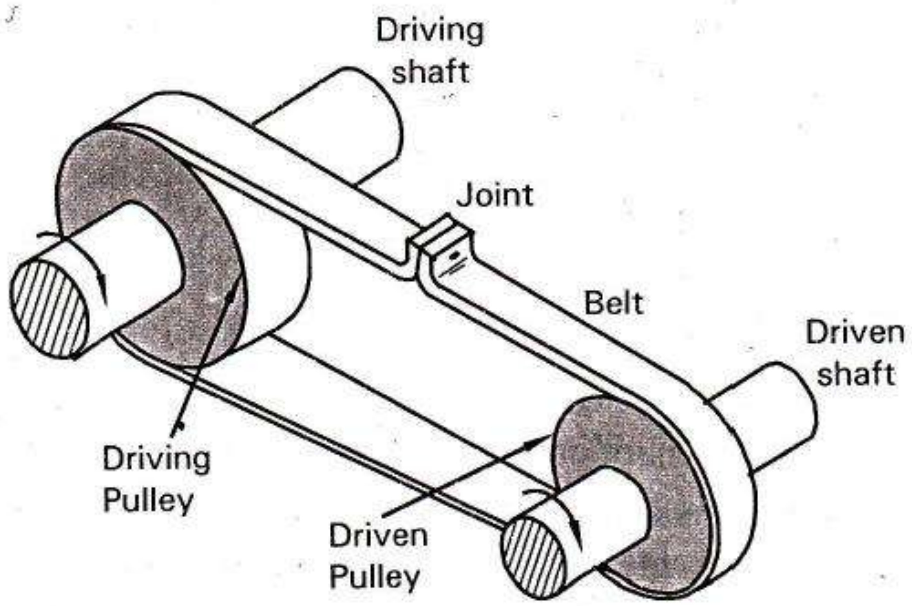
Methods of power transmission (Types of drives)

(i) Belt drive
(ii) Chain drive
(iii) Gear drive
(iv) Rope drive

Types of Belt drives

I. Open belt drive
II. Crossed belt drive





BELT DRIVES

MATERIALS USED FOR BELTS

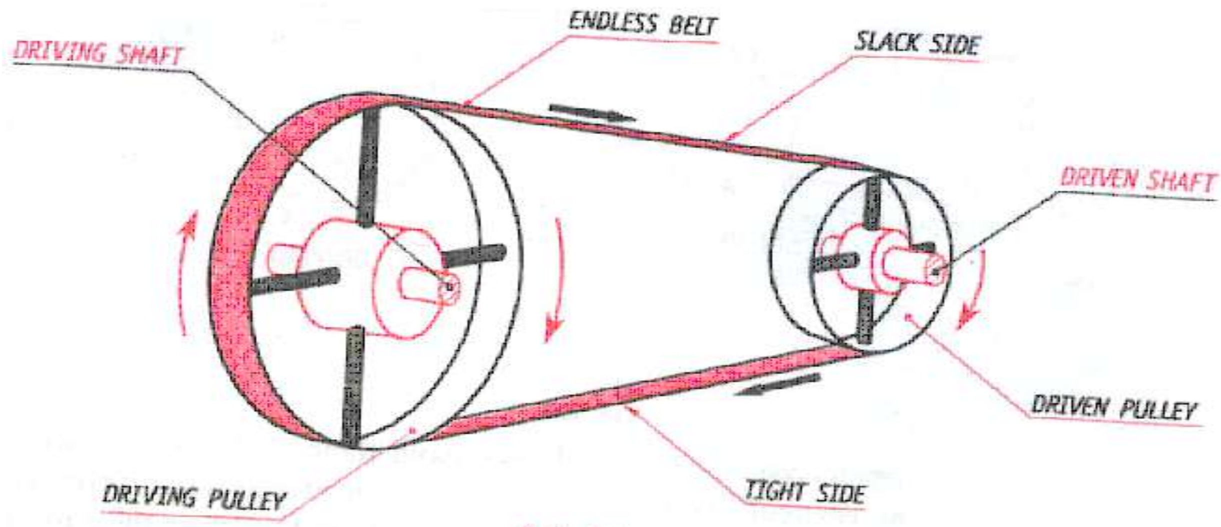
The materials used for manufacturing belts must be strong, flexible and durable. It must have a high coefficient of friction. The different materials used in manufacturing of belt includes
Leather belts - cut from the back bone of steer hides.
Cotton/fabric belts - made by folding canvass to three or more layers & stitching together.
Rubber belt - layers of fabric impregnated with rubber.
Balata belt - similar to rubber belts except that balata gum is used in place of rubber.

OPEN BELT DRIVE

It is employed when the two parallel shafts have to rotate in the same direction.

When the shafts are placed far apart, the lower side of the belt should be the tight side and the upper side must be the slack side.

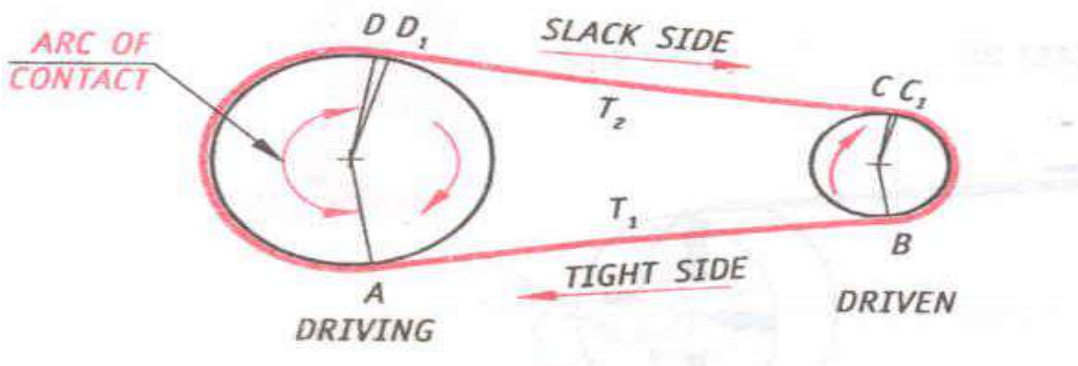
When the upper side becomes the slack side, it will sag due to its own weight and thus increases the arc of contact.



Belt Drive

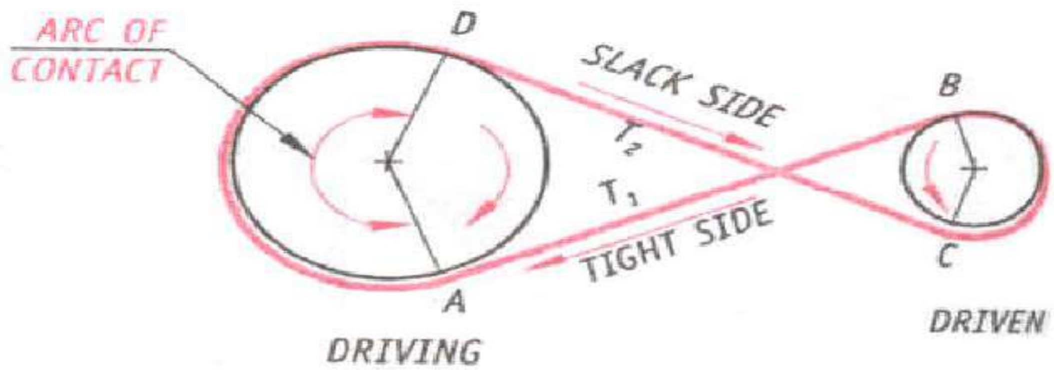
Arc of Contact or Angle of Contact or Angle of Lap:

The angle subtended by the arc of belt in contact with the pulley at the centre.

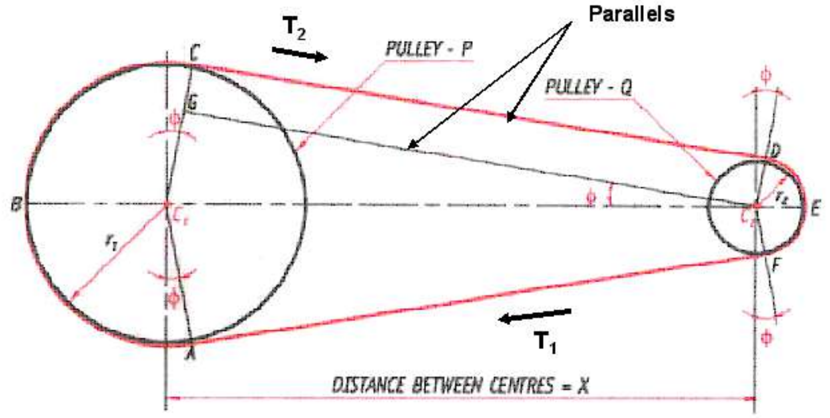


CROSS BELT DRIVE

Employed when two parallel shafts have to rotate in opposite direction. At the junction where the belt crosses, it rubs against itself and wears off. To avoid excessive wear, the shafts must be placed at a maximum distance from each other and operated at very low speeds.



Length of Belt in Open belt drive



Let P and Q are the two pulleys that are connected by an open belt

Let x = Distance between the centers of 2 pulleys = C_1C_2

r_1, r_2 = Radii of driver (P) and driven (Q) pulleys respectively

Length of belt,

$$L = 2 * (\text{Arc length BC} + CD + \text{Arc length DE})$$

$$= 2 * [(\Phi + \frac{\pi}{2})\, r_1 + CD + (\frac{\pi}{2} - \Phi)\, r_2]$$

$$= 2 * [\frac{\pi}{2} * (r_1 + r_2) + CD + \Phi * (r_1 - r_2)] \quad \ldots\ldots\text{(i)}$$

But from figure Triangle GC_1C_2, $CD = GC_2$

$\cos\Phi = GC_2 / C_1C_2$

or $CD = GC_2 = C_1C_2 \cos\Phi = x \cos\Phi$ ……..(ii)

Also, from figure Triangle GC_1C_2,

$$\sin\Phi = GC_1 / C_1C_2 = \frac{(r1 - r2)}{x}$$

We know that, $Cos^2\Phi + Sin^2\Phi = 1$

i.e., $\text{Cos}\,\Phi = \sqrt{(1 - Sin^2\Phi} = (1 - \text{Sin}^2\Phi)^{1/2}$

$GC_1 = CC_1 - GC = (r_1 - r_2)$

$\text{Sin}\,\Phi = \frac{(r1 - r2)}{x}$

→ For small values of Φ,

$$\Phi = \frac{(r1 - r2)}{x} \qquad \text{.............(iii)}$$

$$(1 - \text{Sin}^2\Phi)^{1/2} = \{1 - [(r_1 - r_2) / x]^2\}^{1/2}$$

$$= \{1 - ½\, [(r_1 - r_2) / x]^2\} \text{ ....(iv)}$$

→ Applying Binomial theorem & neglecting higher order terms. Substituting (ii), (iii) and (iv) in equation (i), we get,

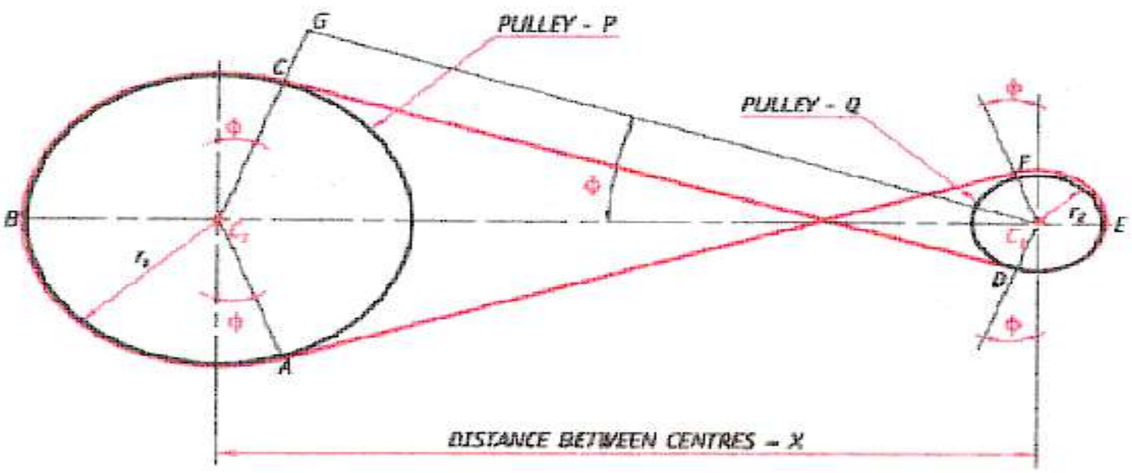
$$L = 2 * \{ (r_1 + r_2)\, \pi /2 + x\, [1 - ½\, [(r_1 - r_2) / x]^2] + [(r_1 - r_2) / x](r_1 - r_2)\}$$

$$= \{\pi (r_1 + r_2) + 2x\, [1 - ½\, [(r_1 - r_2) / x]^2] + 2[(r_1 - r_2) / x](r_1 - r_2)\}$$

Length of belt,

$$\mathbf{L = \pi (r_1 + r_2) + 2x + [\frac{(r_1 - r_2)}{x}]}$$

Length of Belt in Crossed belt drive:



Let P and Q are the two pulleys that are connected by crossed belt.

Let x = Distance between the centers of 2 pulleys = C_1C_2

r_1, r_2 = Radii of driver (P) and driven (Q) pulleys respectively.

Length of belt,

$$L = 2 * (\text{Arc length BC} + CD + \text{Arc length DE})$$
$$= 2 * [\, (\Phi + \frac{\pi}{2})\, r_1 + CD + (\frac{\pi}{2} + \Phi)\, r_2 \,]$$
$$= 2 * [\frac{\pi}{2} * (r_1 + r_2) + CD + \Phi * (r_1 + r_2)\,] \;.....(i)$$

But from figure Triangle GC_1C_2, $CD = GC_2$

$$\text{Cos}\ \Phi = GC_1 / C_1C_2$$

or $CD = GC_2 = C_1C_2 \text{ Cos } \Phi = x \text{ Cos } \Phi$ ……..(ii)

Also, from figure $\Delta\ GC_1C_2$,

$$\text{Sin}\ \Phi = GC_1 / C_1C_2 = \frac{(r1 + r2)}{x}$$

We know that, $\text{Cos}^2\Phi + \text{Sin}^2\Phi = 1$

i.e., $\text{Cos}\ \Phi = \sqrt{(1 - \text{Sin}^2 \Phi)} = (1 - \text{Sin}^2 \Phi)^{1/2}$

$$GC_1 = CC_1 + GC = (r_1 + r_2)$$

$$\text{Sin}\ \Phi = [(r_1 + r_2) / x]$$

→ For small values of Φ,

$$\Phi = [\frac{(r1 + r2)}{x}] \qquad ....(iii)$$

$$(1 - \text{Sin}^2 \Phi)^{1/2} = \{1 - [(r_1 + r_2) / x]^2\}^{1/2}$$

$$= \{\, 1 - \tfrac{1}{2}\, [(r_1 + r_2) / x]^2 \,\} \;..................(iv)$$

→ Applying Binomial theorem & neglecting higher order terms.

Substituting (ii), (iii) and (iv) in equation (i), we get,

$$L = 2 * \{\, (\, r_1 + r_2\,)\, \pi /2 + x\, [1 - \tfrac{1}{2}\, [(r_1 + r_2) / x]^2\,] + [(r_1 + r_2) / x](r_1 + r_2\,)\}$$

$$= \{\pi\, (r_1 + r_2\,) + 2x\, [1 - \tfrac{1}{2}\, [(r_1 + r_2) / x]^2\,] + 2[(r_1 + r_2) / x](r_1 + r_2\,)\}$$

Length of belt,

$$\mathbf{L = \pi\, (\, r_1 + r_2\,) + 2x + [(r_1 + r_2)^2\ / x]}$$

Velocity Ratio of Belt Drive (Speed Ratio)

The velocity ratio of a belt drive is defined as the ratio of the speed of the driven pulley to the speed of the driving pulley.

Expression for velocity ratio of belt drive:

Let
$d1$ = Diameter of the driving pulley, mm
$d2$= Diameter of the driven pulley, mm
$N1$= Speed of the driving pulley, RPM
$N2$= Speed of the driven pulley, RPM

If there is no relative slip between the pulleys and the portions of the belt which are in contact with them, the speed at every point on the belt will be same.

The circumferential speeds of the driving and driven pulleys and the linear speed of the belt are equal.

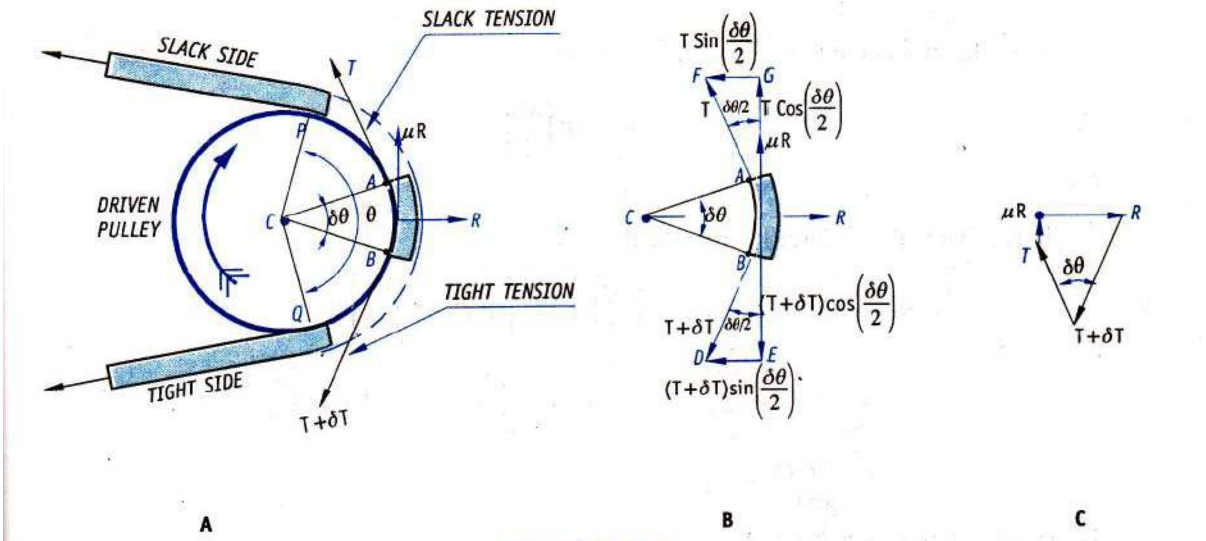
Linear speed of the belt	=	Circumferential speed of the driving pulley	=	Circumferential speed of the driven pulley

$= \pi d_1 N_1$ $\quad\quad$ $= \pi d_2 N_2$

$= d_1 N_1$ $\quad\quad$ $= d_2 N_2$

Velocity Ratio $= \dfrac{N_2}{N_1} = \dfrac{d_1}{d_2}$

Ratio of tensions in a flat belt drive



Ratio of Tensions

The element AB is in equilibrium under the action of the following forces as shown in figure B.

(i) the slack side tension T acting at A
(ii) the tight side tension T + δT acting at B
(iii) the normal reaction R
(iv) the force of friction μR acting perpendicular to R.

The polygon of forces acting on the element is represented by the closed quadrilateral as shown in figure.

Resolving all the forces in direction of R.

$R = [\ T \text{ Sin}(\frac{\delta\theta}{2})] + [(T + \delta T) \text{ Sin } (\frac{\delta\theta}{2})]$

$= [2\ T \text{ Sin}(\frac{\delta\theta}{2})]\ + [\delta T \text{ Sin } (\frac{\delta\theta}{2})]$

For small angles the following two assumptions can be made,

(i) $\text{Sin}(\frac{\delta\theta}{2}) = (\frac{\delta\theta}{2})$

(ii) The product, $\delta T \text{ X } (\frac{\delta\theta}{2})$ can be neglected

$R \quad = \quad 2T\ (\frac{\delta\theta}{2})$

$R \quad = \quad T\ \delta\theta$ ---------------------------(1)

Again resolving all the forces perpendicular to R

$$\mu R = \left[(T + \delta T)\cos\left(\frac{\delta\theta}{2}\right) \right] - \left[T\cos\left(\frac{\delta\theta}{2}\right) \right]$$

$$= \left[T\cos\left(\frac{\delta\theta}{2}\right) \right] + \left[\delta T\cos\left(\frac{\delta\theta}{2}\right) \right] - \left[T\cos\left(\frac{\delta\theta}{2}\right) \right]$$

$$= \delta T\cos\left(\frac{\delta\theta}{2}\right)$$

For small angles, $\cos\left(\frac{\delta\theta}{2}\right) = 1$

$$\boxed{\mu R = \delta T} \qquad \text{..........(2)}$$

Substituting equation 1 in 2:

$$\mu T\delta\theta = \delta T$$

$$or \qquad \frac{\delta T}{T} = \mu\delta\theta$$

Integrating $\delta\theta$ between 0 and θ and tension δT between T_2 to T_1

$$\int_{T_2}^{T_1} \frac{\delta T}{T} = \int_0^{\theta} \mu\delta\theta$$

$$or \qquad \log_e\left(\frac{T_1}{T_2}\right) = \mu\theta$$

$$Or \qquad \boxed{\frac{T_1}{T_2} = e^{\mu\theta}} \qquad \text{.................3}$$

Where,

θ = angle of contact

μ = Coefficient of friction

Taking logarithms of equation 3

$$\log\left(\frac{T_1}{T_2}\right) = \mu\theta\log e \qquad \text{......4}$$

Where, e = Base of Napierian logarithms = 2.718

$$\log\left(\frac{T_1}{T_2}\right) = \mu\theta \log 2.718$$

$$= 0.4343\mu\theta$$

$$\boxed{\log\left(\frac{T_1}{T_2}\right) = 0.4343\mu\theta}$$

Effect of thickness of Belt on the Velocity Ratio

The velocity ratio derived holds good when the thickness of the belt is negligible.

But when the thickness of the belt is considerable, the circumferential speed should be the mean speed reckoned at the centre of the belt thickness.

If t= thickness of the belt,

$$\begin{bmatrix} Linear speed \\ of\ the\ belt \end{bmatrix} = \begin{bmatrix} Mean\ circumferential\ speed \\ of\ the\ driving\ pulley \end{bmatrix} = \begin{bmatrix} Mean\ circumferential\ speed \\ of\ driven\ pulley \end{bmatrix}$$

$$= \left[\pi\left(\frac{t}{2} + d_1 + \frac{t}{2}\right)N_1\right] = \left[\pi\left(\frac{t}{2} + d_2 + \frac{t}{2}\right)N_2\right]$$

$$= \left[\pi\left(d_1 + t\right)N_1\right] = \left[\pi\left(d_2 + t\right)N_2\right]$$

$$\Rightarrow \left(d_1 + t\right)N_1 = \left(d_2 + t\right)N_2$$

$$\boxed{Velocity\ ratio = \frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}}$$

Slip in Belt Drives

Slip mainly occurs when the differences between tensions in the tight and slack sides is very large, or when the coefficient of friction between the belt and pulley decreases owing to the stretch of the belt, or when the smoothness of the pulley surface is more.

Effect of slip on the Velocity Ratio

The slip is expressed as the percentage of speed.

Let,

S1 = percentage of slip between the driving pulley and the belt.

S2 = percentage of slip between the driven pulley and the belt.

$$\therefore \text{ Total percentage slip } S = S_1 + S_2$$

Circumferential speed of the driving pulley $= \pi d_1 N_1$

Considering the percentage slip S1 between the driving pulley and the belt passing over it

Reduced linear speed of the belt because of slip

$$S_1 = \pi d_1 N_1 \times \left[\frac{100 - S_1}{100}\right]$$

The circumferential speed of the belt on the driven pulley when slip S2 occurs between the belt and its rim is given by

$$\pi d_1 N_1 = \left[\begin{array}{l}\text{Speed of the belt}\\ \text{on the driven pulley}\end{array}\right] \times \left[\frac{100 - S_2}{100}\right]$$

$$= \left[\pi d_1 N_1 \times \left\{\frac{100 - S_1}{100}\right\}\right] \times \left[\frac{100 - S_2}{100}\right]$$

$$= \pi d_1 N_1 \times \frac{(100 - S_1)(100 - S_2)}{100 \times 100}$$

$$= \pi d_1 N_1 \times \frac{100(100 - S_1 - S_2) + S_1 S_2}{100 \times 100}$$

$$= \pi d_1 N_1 \times \frac{100[100 - S_1 + S_2]}{100 \times 100} \qquad \left(\begin{array}{l}\textit{Since } S_1 \textit{ and } S_2 \textit{ are very}\\ \textit{small}, S_1 S_2 \textit{ is negligible}\end{array}\right)$$

$$= \pi d_1 N_1 \times \frac{[100 - S_1 + S_2]}{100} \qquad i.e. \quad \pi d_2 N_2 = \pi d_1 N_1 \times \frac{[100 - S]}{100}$$

$$\boxed{\therefore \quad \frac{N_2}{N_1} = \frac{d_1}{d_2} \times \left[\frac{100 - S}{100}\right]}$$

When thickness of the belt is considered

$$\boxed{\therefore \quad \frac{N_2}{N_1} = \frac{(d_1 + t)}{(d_2 + t)} \times \left[\frac{100 - S}{100}\right]}$$

Power transmitted by a Belt drive

The driven pulley rotates because of the difference in tensions in the tight and slack sides of the belt.

Therefore, the force causing the rotation is the difference between the two tensions.

If v is the velocity of the belt m/min and T1 and T2 are the tensions on the tight and slack sides of the belts expressed in Newton, then

$$\text{Work transmitted per second} = \frac{(T_1 - T_2)\times v}{60} \quad W$$

$$\boxed{\text{Power transmitted} = \frac{(T_1 - T_2)\times v}{60\times 1000} \quad kW}$$

Initial tension in belt drive

Definition:

It is a uniform tension that exists initially when the drive is not in motion.

It is designated as To.

Formula:

$$To = \frac{T_1 + T_2}{2}$$

Creep in Flat belt drive

The phenomenon of alternate stretching and contraction of the belt results in a relative motion between the belt and the pulley surface. This relative motion is called creep.

Creep Results in:

Loss of power (Due to creep, the actual power transmitted is lesser than the calculated amount).

Decrease in the velocity ratio.

Timing or toothed belt drive

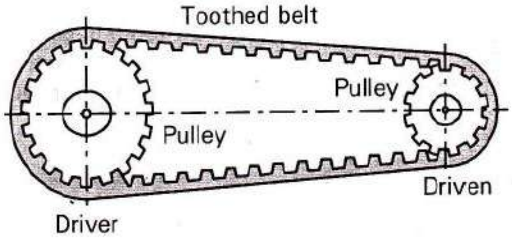


Figure 11.8 Timing or Toothed belt drive

Advantages of toothed belt drives

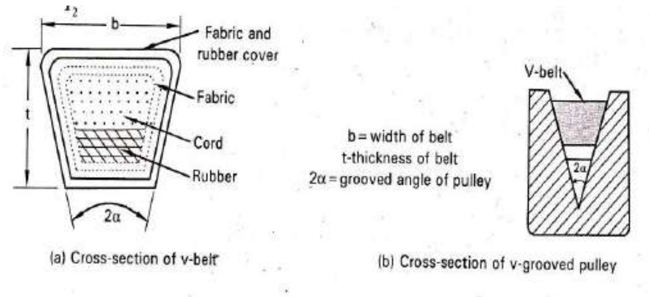
1) Provides a compact, resilient synchronous transmission.
2) No slipping between the belt and the pulleys. Hence high power transmission efficiency.
3) High torque carrying capacity due to better gripping power between the belt and pulleys
4) Power transmission at constant speed .
5) No creep effect in belt
6) Low noise and vibration
7) Weight savings in belt and pulley
8) No lubrication required

Disadvantages

1) Complex design of belt and pulley

2) Requires accurate alignment of the belt with the pulleys for efficient and reliable operation
3) High cost

V-Belt



(a) Cross-section of v-belt (b) Cross-section of v-grooved pulley

Advantages and Disadvantages of V-Belt over Flat Belt

Advantages

1. V-belt transmits more power.
2. Slip between the belt and the pulley is negligible.
3. Can be used to transmit power for short center distances.
4. High velocity ratio can be obtained.
5. Operation is smooth and quiet
6. Shaft axis may be horizontal, vertical or inclined.
7. Since V-belts are made endless, there is no joint trouble.

Disadvantages

1. Not suitable for large center distance.
2. V-belts are endless and also the pulley has to be provided with grooves. Hence, construction of belt and pulley are complicated.

GEAR DRIVES

The transmission of power or motion from one shaft to another by means of gears is called gear drive.

The gear mounted on the shaft to which power source is connected is called driver gear.

The gear which is driven by the driver gear called driven gear.

Functions:

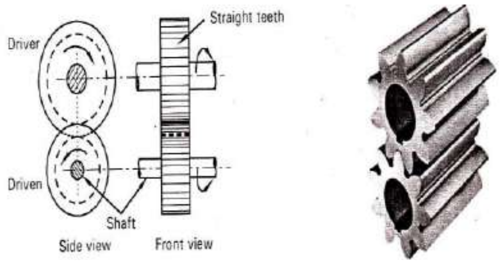
To increase or decrease speed of motion

To move rotational motion to a different axis

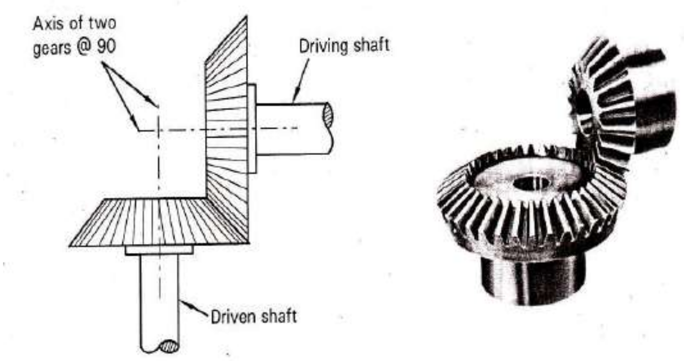
To reverse the direction of rotation

To keep the rotation of two axis synchronized

Spur Gear



Bevel Gear



Spiral bevel Gear

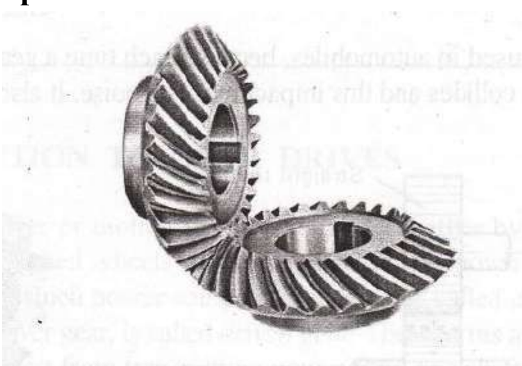


Figure 12.4 Spiral Bevel gear

Helical Gear

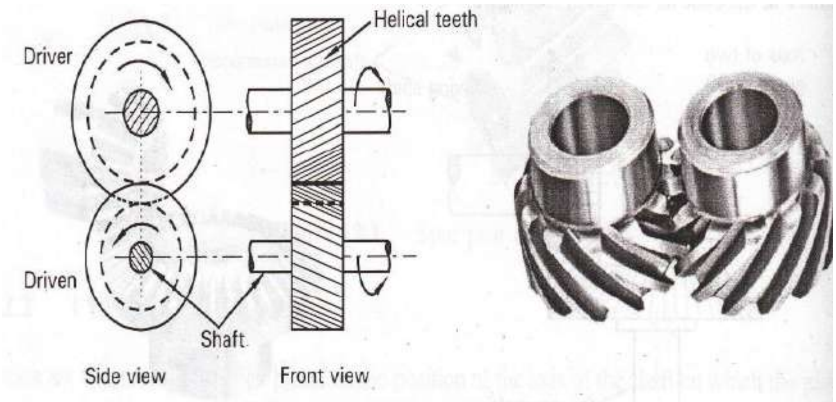


Figure 12.5 Helical gear

Worm Gear

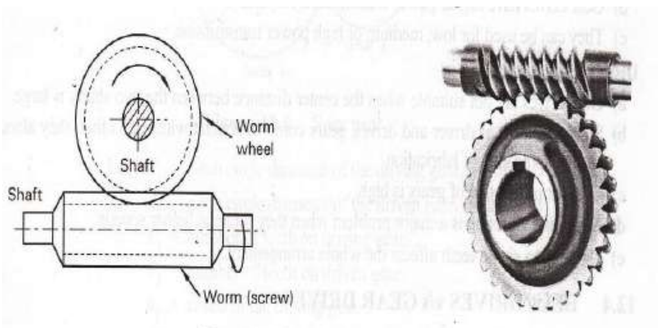


Figure 12.6 Worm gear

Rack and Pinion

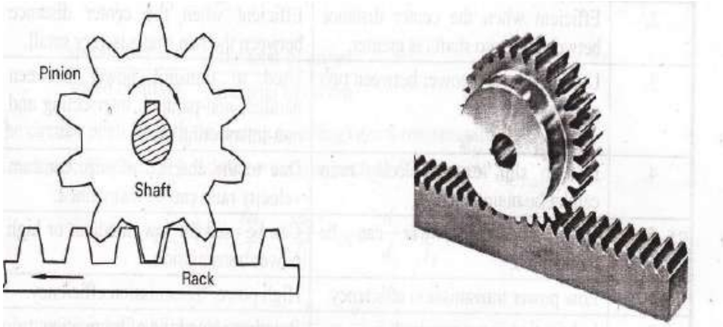


Figure 12.7 Rack and Pinion

ADVANTAGES OF GEAR DRIVES

Gear drives can be used to transmit power or motion between parallel, non-parallel, intersecting and non-intersecting shafts

Gear drives preferred when centre distance between the two shafts is very small

Power can be transmitted with a constant speed ratio

Higher power transmission efficiency

Can be used for low, medium, high power transmission.

DIS-ADVANTAGES OF GEAR DRIVES

Not suitable when centre distance is large

Lubrication is required

Cost of production of gears is high

Noise and vibration is a major problem when they rotate at higher speeds

Damage to single to single teeth effects the whole arrangement.

COMPARISION BETWEEN BELT AND GEAR DRIVES

Si.No	Belt Drives	Gear Drives
1	They are non-positive drives, as there is a reduction in power transmission due to slip	They are positive drives
2	Efficient when the center distance between the two shafts is greater.	Efficient when the center distance between the two shafts is very small.
3	Used to transmit power between two parallel shafts	Used to transmit power between parallel, non-parallel, intersecting and non-intersecting shafts.
4	Due to slip, exact velocity ratio cannot be maintained.	Due to the absence of slip, constant velocity ratio can be maintained.
5	Only moderate power can be transmitted.	Can be used for low, medium or high power transmission.
6	Low power transmission efficiency.	High power transmission efficiency.
7	Lubrication is not required	Requires some kind of lubrication

VELOCITY RATIO OF GEAR DRIVE

VELOCITY ratio of gear drive is defined as the ratio between the speed of the driven gear and speed of the driving gear.

d = Diameter of the wheel
N = Speed of the wheel
ω = Angular speed

Velocity ratio (n) = $\frac{\omega_2}{\omega_1} = \frac{N_2}{N_1} = \frac{d_1}{d_2}$