MODULE-4

Engineering Materials and Joining Process

Introduction

Material - consists of matter or occupies space. We need different materials for design and manufacturing of aircrafts, engines, ship building, construction etc. Materials which have many applications, in making an article of utility is called engineering material.

Definition:- A Solid material which is typically hard, shiny, malleable, fusible, and ductile, with good electrical and thermal conductivity

Metals are generally malleable: they can be hammered or pressed permanently out of shape without breaking or cracking well as fusible and ductile Metals can be either ferrous or non-ferrous.

Ferrous metals contain iron while non-ferrous metals do not. Both ferrous and non-ferrous metals are divided into pure metals and alloys.

Properties of Engineering Materials

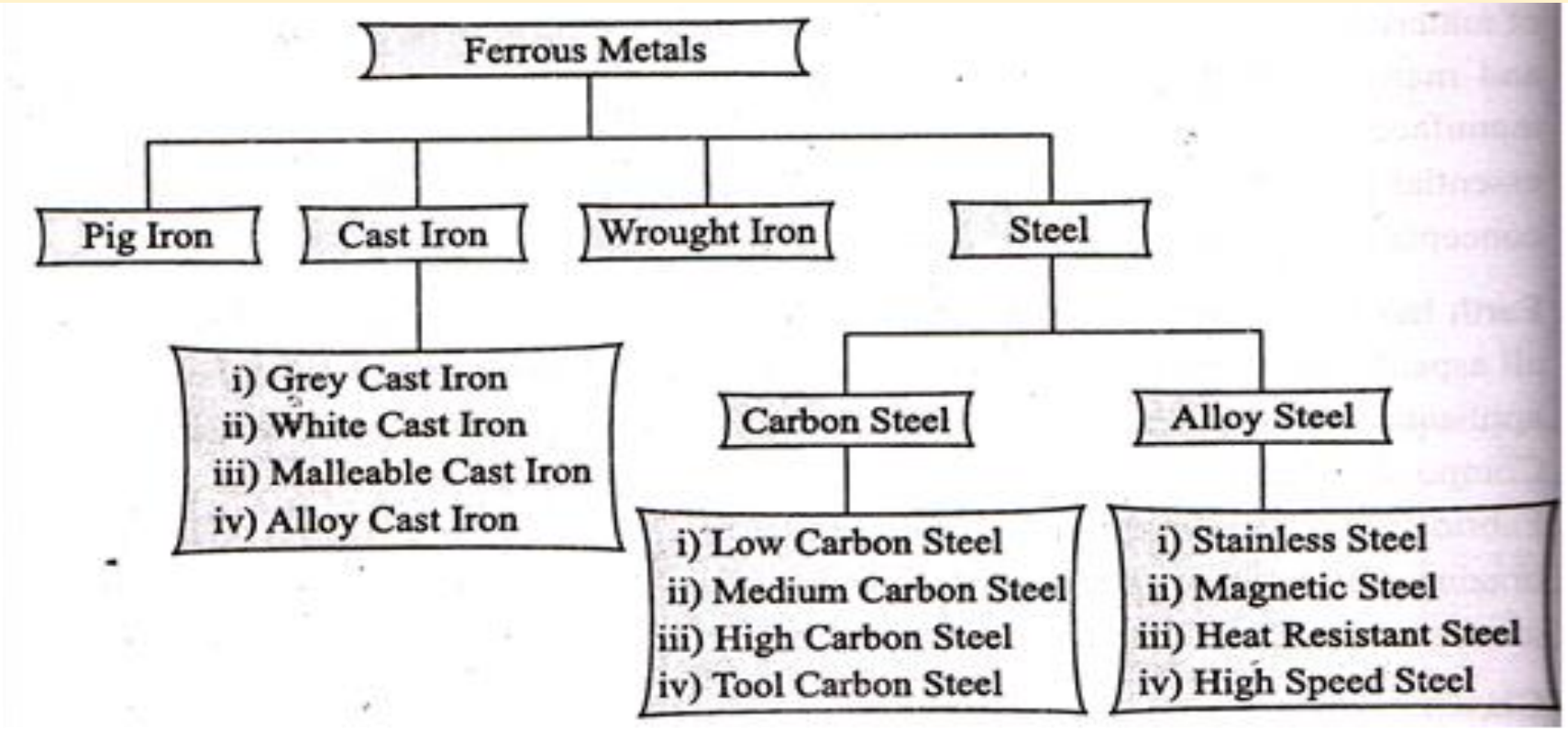
- **Hardness:** Resistance to abrasion and indentation.
- **Toughness**: measure of the amount of energy a material can absorb before fracturing.
- **Ductility:** Measure of the ability to deform plastically without fracture in tensile force.
- **Malleability:** Measure of the ability to deform plastically without fracture in compression force.
- **Stiffness:** A material's ability to resist significant elastic deformation while loading.
- **Machinability:** The ease of which a metal part can be cut without sacrificing the quality of the finish.

FERROUS METALS

Ferrous metals contain iron.

Examples: Cast iron, mild steel, medium carbon steel, high carbon steel, stainless steel, and high speed steel.

The properties of ferrous metals, such as hardness and malleability, are directly related to their carbon content. For example:- The more carbon that is found in steel, the harder and less malleable the steel becomes.



(a) Pig iron: These contain high percentage of carbon and other impurities. It is very hard and brittle hence can be further refined to get other forms of iron and steel.

(b) Cast iron: It is derived from pig iron and contains 2-4% of carbon. It is moderately hard compared to pig iron. It is further classified into grey cast iron, white cast iron, malleable cast iron and alloy cast iron.

(c) Wrought iron: It is a refined form of iron with very little amount of impurities. It is tough, malleable and ductile. It can be used in crane hooks, railway track etc.

(d) Steel: It is a widely used alloy of iron produced by combining carbon, sulphur, silicon. manganese etc. It consists of about 0.1-2.0% of carbon. It is further classified into carbon steels and alloy steels.

Carbon Steel: Carbon steel is a kind of steel in which the main alloying constituent is carbon in the range of 0.12-2%. This tiny amount of carbon produces a material that exhibits great strength, hardness and other valuable mechanical properties. Carbon steels are categorized as below.

Name	Percentage of Carbon
Low carbon/mild steel	0.05-0.3
Medium carbon steel	0.3-0.6
High carbon steel	0.6-1.5
Tool steel	0.9-2.0

Alloy Steels: Alloy steels are steels to which other elements are added to improve the basic properties.

- The common alloying elements are nickel, manganese, silicon, vanadium, chromium, tungsten, cobalt, zirconium etc.

- These elements provide specific quality to steel and are added as a combination or separately to produce the desired characteristics in the steel.

- Other than these alloys steels there are some special alloy steels which have specific applications like stainless steel, magnet steel, heat resistant steel, shock resistant steel, high speed steel etc.

Stainless Steel

Stainless steels are steels containing at least 10.5% chromium, less than 1.2% carbon and other alloying elements.

Characteristics:

- They are high alloy steels and have excellent corrosion and oxidation resistance.
- They have high strength and toughness.
- Used for surgical & dental equipment, turbine blades, food processing equipment etc.

Tool Steel

- Tool steel is a type of carbon alloy steel that used for machining operations. Its hardness, resistance to abrasion and ability to retain shape at elevated temperature.
- Generally, Tool steel alloys are high carbon chrome steels containing differing amounts of **molybdenum, cobalt and/or vanadium** or other elements.

High Speed Steel

High-speed steels are used primarily for the manufacture of cutting tools. It is used as cutting tool to perform machining operations on drilling, milling and lathe machine tools. Typically, they consist of steel alloyed with tungsten or molybdenum, together with percentages of chromium, vanadium and cobalt.

Tungsten increases the **wear resistance** of the cutting tool at high temperature.

Chromium increases **hardness and toughness** of the steel at very high cutting temperature.

Vanadium increases **shock resistance** of the cutting tool.

High-speed Steel = 18% Tungsten + 4% Chromium + 1% Vanadium

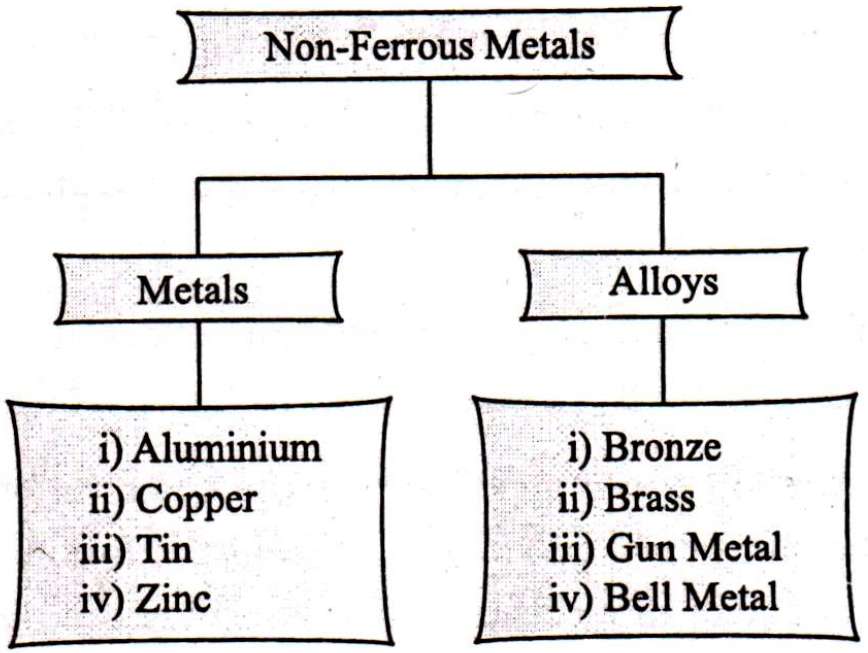
Non Ferrous Metals and Alloys

As the name indicates these are metals without iron content in it. They have low strength, lower melting point and higher shrinkage property than ferrous metal.

1. Good Corrosion Resistance
2. Ease of Casting
3. Ease of cold working
4. Good electrical properties

Ex: Aluminium, copper, lead,bronze etc.

Classification



Metals: It is substance in pure form, which is extracted from natural ore. They are usually soft in nature with limited applications

- **Aluminium:** Aluminium is a chemical element with symbol Al and atomic number 13. It is a silvery white, soft, nonmagnetic, ductile metal. Aluminium is the third most abundant element in the Earth's crust.
- ***Properties and characteristics:*** Good strength-to-weight ratio, light, soft, ductile, good conductor of heat and electricity
- ***Application*:** Kitchen equipment, window frames, general cast components

- **Copper:** is a chemical element with symbol **Cu** and atomic number 29. It is a ductile metal with very high thermal and electrical conductivity. Pure copper is soft and malleable; a freshly exposed surface has a reddish-orange colour. It is good conductor of heat and electricity.
- ***Properties and characteristics:*** Malleable and ductile, good conductor of heat and electricity, resistant to corrosion
- ***Application:*** Water pipes, electrical wire, decorative goods

- **Tin:** is a chemical element with the symbol Sn and atomic number 50.
- **Properties and characteristics:** Soft, weak, malleable, ductile and resistant to corrosion
- **Application:** Usually used for coating steel to form tinplate

- **Zinc:** Zinc is a chemical element with symbol Zn and atomic number 30. Zinc is the 24th most abundant element in Earth's crust.
- **Properties and characteristics:** Weak metal, extremely resistant to corrosion.
- **Application:** Usually used for coating steel to make galvanised items.

Alloys: When two or more metals are mixed together in different proportions to get a homogenous mixture is called as an alloy. They have better properties than metals and have wide applications.

- Bronze: Bronze is an alloy consisting primarily of copper and the addition of other metals like tin,phosphorus, aluminium, manganese, and silicon. These additions produces an alloy much harder than copper alone.

➢ **Composition:** Alloy of copper and tin,

➢ **Properties and characteristics:** Fairly strong, malleable and ductile when soft

➢ **Application:** Decorative goods, architectural fittings

- Brass: Brass is an alloy made of copper and zinc; the proportions of zinc and copper can be varied to create a range of brasses with varying properties.

- **Composition:** Alloy of copper and zinc,
- **Properties and characteristics:** Resistant to corrosion, fairly hard, good conductor of heat and electricity
- **Application:** Cast items such as water taps, ornaments

- Gun Metal: It is a special alloy which contains 10% tin, 88% Cu and 2% Zinc. It is very hard and resistant to corrosion by water and atmosphere. It is used in boiler fittings, bushes, bearing glands etc.

- Bell Metal: This contains 20% tin and rest copper. It is very hard and resistant to surface wear. It is used to make bell, utencils etc.

POLYMERS

- These are the organic materials with carbons as a common element in their formation. Polymers are composed of a large number of small molecules called monomers. The process of linking the monomers together is called polymerization

- **Examples:** Polyethylene, Poly Vinyl Chloride (PVC). Polystyrene, Nylon, Polypropylene.

Properties:

✓have low density

✓exhibit good corrosion resistance

✓have low coefficient of friction

✓possess good mouldability

✓give excellent surface finish

✓temperature resistance is poor

✓have poor / low mechanical properties

Thermoplastics

- These are the polymers which become soft on the application of heat with or without pressure. After cooling they regain their original shape. These plastics can be cooled and heated several times without any change in their chemical composition or mechanical properties. Examples: Polythene, Poly Vinyl Chloride (PVC), Polystyrene

- Composition: Plastics are mostly carbon-based atoms. In plastics, the carbon atoms also link to hydrogen, oxygen, nitrogen, chlorine, or sulphur. When the linking of these atoms results in long chains, like pearls on a string of pearls, plastic is termed as Thermoplastic.

Properties

- have low melting temperature
- are highly plastic and can be easily shaped
- can be heated & cooled any number of times below their decomposition temperature
- are fairly hard
- have good wear resistance
- have good resistance to chemicals
- are soluble in certain solvents
- are highly plastic and are easy for moulding/shaping

Thermosetting plastic

- These are the polymers which require heat and pressure to mould them to a required shape. Thermosetting polymers are those polymers that solidify into a permanent shape. These are stronger than the thermoplastics. These cannot be reformed or recycled

Examples: Polyester resin, Polyurethanes, Vulcanized rubber, Bakelite, Duroplast, Epoxy resin, Silicone and Vinyl ester

Properties:

- are generally stronger than the thermoplastics.
- are well suited for high-temperature applications.
- have high strength and hardness.
- cannot be re-softened once they have set and hardened.
- have high molecular weight.

Thermoplastics vs. Thermosetting plastics

Thermoplastics	Thermosetting polymers
1. Soften on heating	1. Do not soften on heating
2. Long chain linear	2. 3-D structure
3. By addition polymerisation	3. By condensation polymerisation
4. Can be reshaped and reused	4. Can not be reshaped
5. Soft weak and less brittle	5. Hard and strong
6. Soluble in org. solvents	6. Insoluble in org. solvents.
7. Reclaimed for wastes	7. Can not be reclaimed

CERAMICS

- These are defined as those containing phases that are compounds of metallic and non metallic compounds. Ceramics are good for high temperature applications mainly because of their unique chemical, structural and functional properties.

- Examples: Clay, Bricks, Tiles. Glass and Cement.

- Composition: These are non-metallic inorganic compounds formed from metallic (Al, Mg, Na, Ti) or semi-metallic (Si, B) and non-metallic (O, N, C) elements.

Glass

Any substance or mixture of substances that has solidified from the liquid state without Crystallization is called glass. It is an amorphous substance having a homogeneous texture.

Composition: Glasses are mostly consists of inorganic oxides such as oxides of SiO_2 and B_2O_3, known as glass formers. Silica, sodium/potassium carbonate, lime, magnesium dioxide, coloring substance are the constituents of glass. Many other oxides such as Al_2O_3, Cao, Na_2O etc., are added to glass forming oxides to obtain desired combination of properties such as refractive index, electrical conductivity.

Properties: Following are the properties of glass,

- do not have a definite crystalline structure.
- are extremely brittle
- are available in attractive colours
- do not possess a sharp melting point
- are excellent electrical insulators at elevated temperatures
- are not easily attacked by ordinary chemical reagent.

Industrial Applications: Following are the industrial applications

- They are used in the laboratory equipment and chemical glassware
- These are used in the manufacture of domestic utensils
- They are used in the manufacture of X-ray tubes
- They are used in the manufacture of computer and TV parts
- They are used in the indoor, windows and furniture
- They are used in the body parts of a guided missile

Silica

Silica is another name for the chemical compound silicon dioxide, represented as SiO_2. Each unit of silica includes one atom of silicon and two atoms of oxygen.

Properties

- It is colorless, fairly hard
- High boiling and melting points
- has high dielectric strength, so that it is used as an insulator and semiconductor.

Applications

- Used in the construction industry to produce concrete.
- Used in the production of glass.
- Used as an anti-caking agent in powdered foods like spices.
- Used pharmaceuticals for making tablets.
- Used in toothpaste to remove tooth plaque

Diamond

Diamond is a rare, naturally occurring mineral composed entirely of carbon. Each carbon atom in a diamond is surrounded by four other carbon atoms and connected to each of them by strong covalent bonds - the strongest type of chemical bond. This simple, uniform, tightly-bonded arrangement yields one of the most durable and versatile substances known. Diamond is the hardest known natural substance. It is also chemically resistant and has the highest thermal conductivity of any natural material. These properties make it suitable for use as a cutting tool and for other uses where durability is required.

Properties

- High Strength and Hardness
- Low coefficient of friction and thermal expansion coefficient
- High thermal conductivity and electrical resistivity

Applications

- Wear components
- Cutting tools
- Thermal management (in e.g. substrates, heat spreaders and heat sinks)
- Semiconductor devices
- Optical components

Graphite

Graphite is a naturally occurring form of crystalline carbon. It is a greyish black, opaque substance. It is a native element mineral found in metamorphic and igneous rocks. Graphite is a mineral of extremes. It is extremely soft, cleaves with very light pressure, and has a very low specific gravity. In contrast, it is extremely resistant to heat and nearly inert in contact with almost any other material. These extreme properties give it a wide range of uses in metallurgy and manufacturing.

Properties:

- Good conductor of heat and electricity
- Soft and Non-flammable.

Applications

- Writing Materials
- Lubricants
- Refractory
- Nuclear Reactors
- Batteries
- Graphene Sheets

SMART MATERIALS

- These are the materials that can significantly change their mechanical, thermal, optical or electromagnetic properties, in a predictable manner in response to their environment.

Examples: Shape memory alloys, piezoelectric materials, magneto-structure material Industrial

Applications:

- They are used in the manufacture of sensors and actuators,
- They are used for of artificial musicals
- They are used in the manufacture of Smart phone frames
- They are used in the manufacture of Robots.

Shape Memory Alloys

It is an alloy that remembers its original shape and that when deformed returns to its deformed shape when heated.

Properties: Following are the properties of shape memory alloys,

- have higher yield strength than the plastic or aluminum.
- high level of recoverable plastic strain

Composition: Copper-aluminium-nickel and nickel-titanium alloys. These can be created by alloying zinc, copper, gold and iron

Industrial Applications:

- manufacture of car seats
- manufacture of eye glass frames
- manufacture of stents
- manufacture of orthopedic surgery instruments
- manufacture of dental braces.

Shape Memory Alloys

Shape memory alloys (SMA) are metallic alloys that are able to undergo large reversible deformations under loading/thermal cycles and are able to generate high thermal–mechanical driving forces. **The behavior of SMA is due to their native capability to undergo reversible changes of the crystallographic structure, depending on temperature and state of stress.**

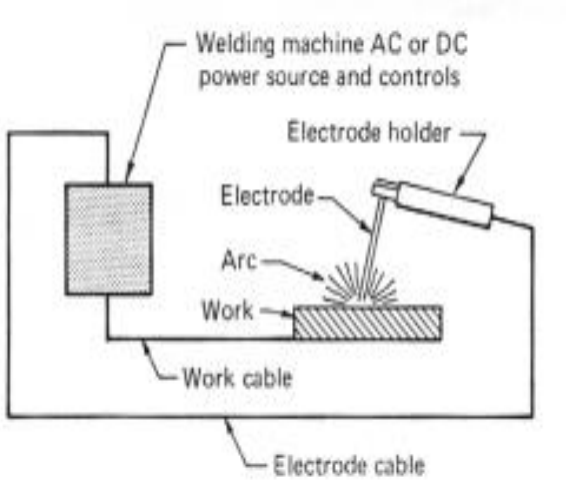
JOINING PROCESS-WELDING, BRAZING AND SOLDERING

Welding Process

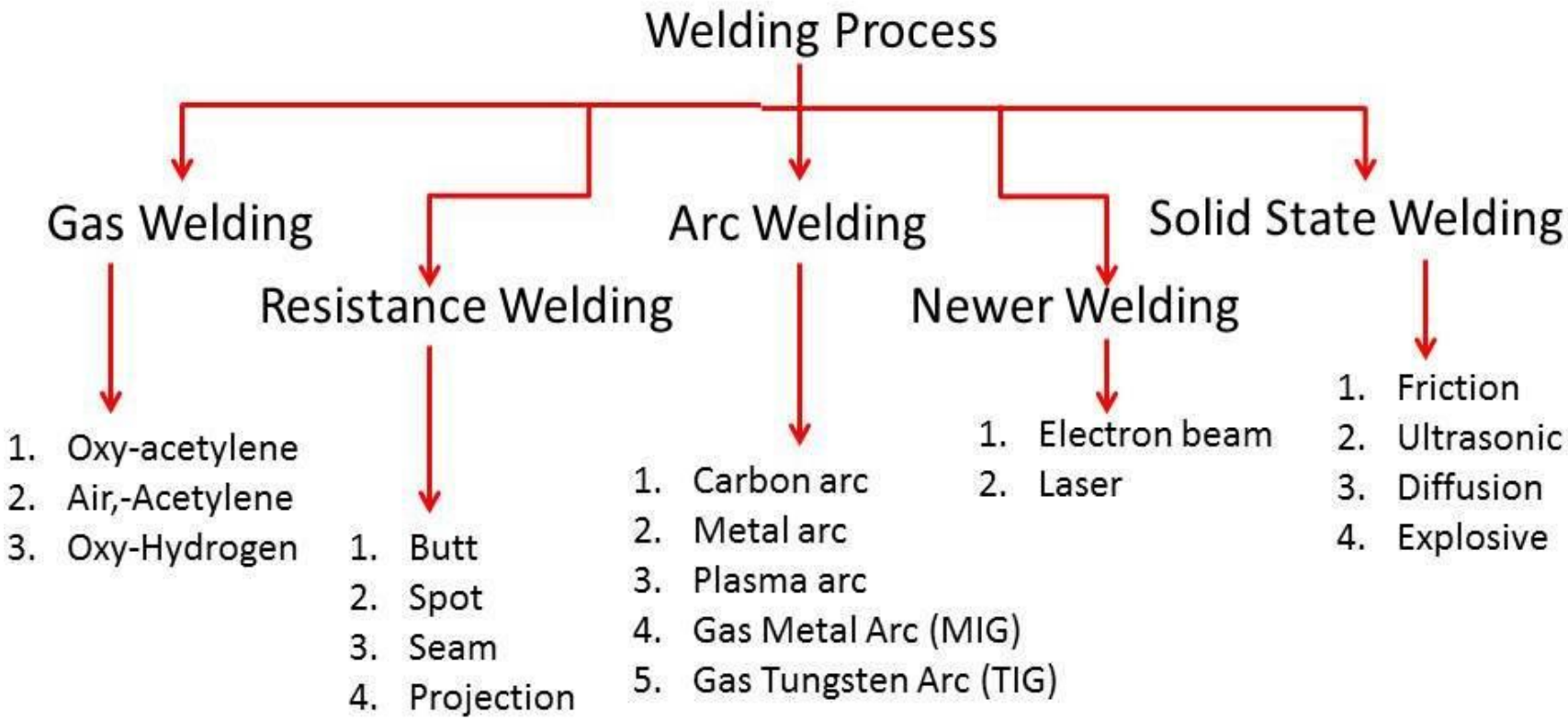
Definition: Welding is a permanent metal joining process where similar or dissimilar materials are joined by applying heat with or without using applying pressure with or without using filler material.

Principle of Welding:

- Welding is a fabrication in which two or more work pieces, usually metals are permanently joined to form a single component.
- Welding is carried out by heating the edges of the work pieces to a suitable temperature and then fused together with or without application of pressure.
- Filler material is filled between the edges or gap between the workpiece.



Classification of Welding



ADVANTAGE AND LIMITATIONS OF WELDING

ADVANTAGES

- Any metal or alloy can be welded
- Complex shapes can be easily welded
- Strength of the joint is better than the parent metal
- Better corrosion resistance compared to bolts and rivets
- They produce fluid tight joints
- Welding equipments are portable hence parts can be fabricated at relevant location
- Parts can be fabricated at reasonable cost.

LIMITATIONS

- Radiation is a major problem during the process
- Residual Stresses produced will distort and induces internal stress
- Operation involves skilled labor
- Edge preparation is must before welding
- Heat involved is very important during welding process which may alter the structure of the metal by lowering its properties.
- Jigs and fixtures are also needed to carryout complex shapes which will consume time and money.

Applications of Welding process

Fabrication of wide variety of components in fields like aircraft, ship building, space, buildings, boilers, pipes, bridges, automobile, power plants, pressure vessels, machine tools, storage tanks etc.

Arc Welding

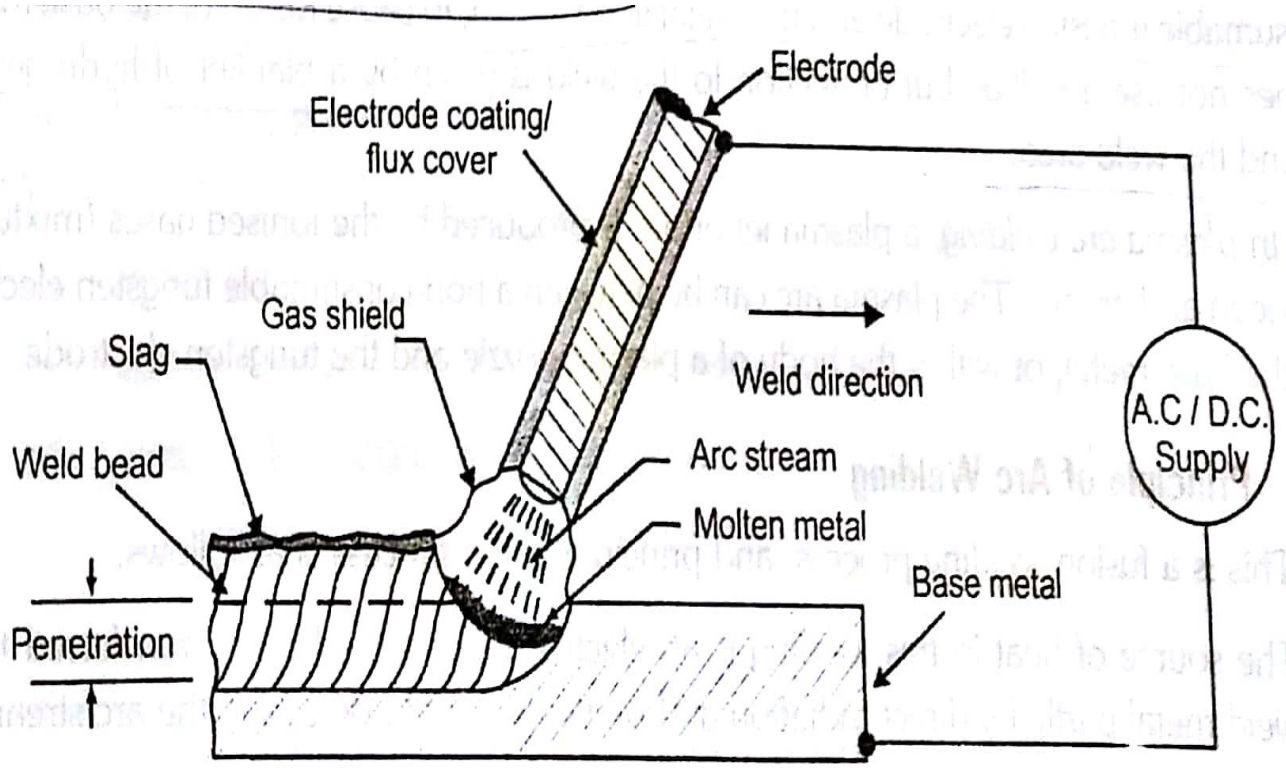


Fig. 5-8. Flux shielded metal arc welding (FSMAW)

Principle of Arc Welding:

- Electric arc is generated between the work piece and the electrode.
- Both work piece and electrode are connected to two different poles of the circuit.
- Arc will be generated between the gap of the work piece when the electrode tip brought in contact
- Electrical energy is converted into the heat energy.
- Temperature at the tip of the arc will be 6000 ^{0}C
- Both AC and DC can be used where arc supplies the required heat
- Coalescence takes place where both work pieces get fused
- Electrode may be consumable or non consumable
- Non consumable electrodes are tungsten, graphite etc are also used.
- Consumable electrodes are same material as that of the work piece
- The flux covered electrode melts and forms slag which covers the molten metal at the joint and gives stability to the arc
- A gaseous shield formed by the flux gives protection to the weld

Advantages and Limitations of Arc Welding

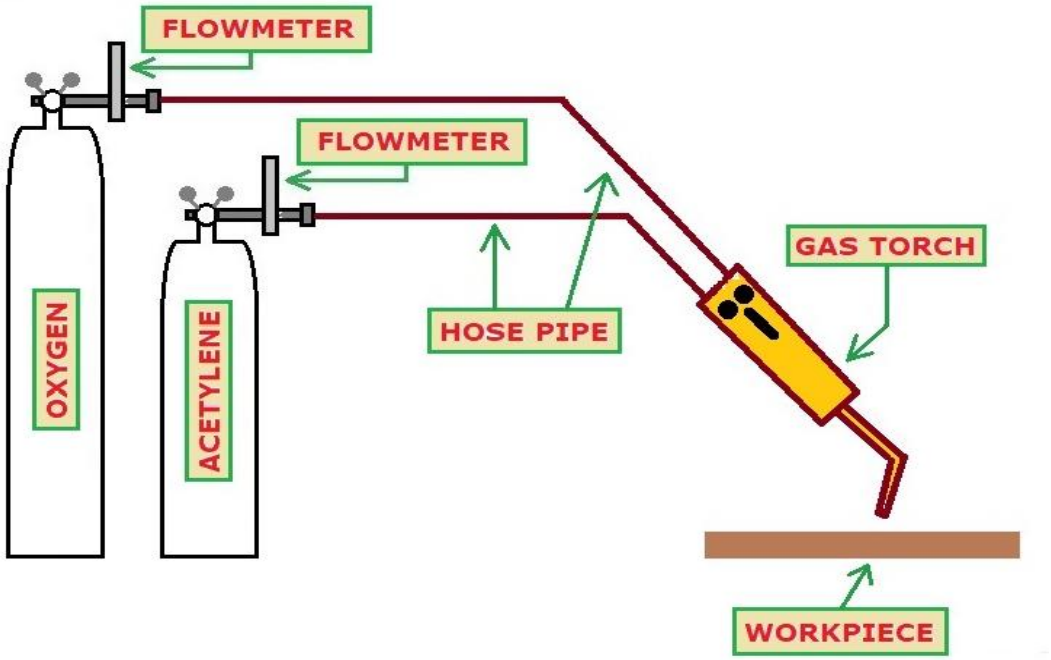
Advantages

- Most efficient joining process for a wide range of metals and alloys
- Welding is possible in any position of the electrode.
- Lowest-cost joining method
- Affords lighter weight through better utilization of materials
- Provides design flexibility and productivity

Limitations

- Difficult to mechanize and hence manually applied, therefore high labor cost.
- Process is slower because of breakage in welding while restarting with fresh electrode.
- Not convenient for disassembly.
- Defects are hard to detect at joints.
- More amount of Heat Affected Zones due to High welding temperature

Gas Welding (Oxy-Acetylene Welding)



- Heat is generated by the burning of fuel (Acetylene) in presence of oxygen. The burning of fuel and oxygen releases high temperature.

- This temperature is utilized to melt the metal. The temperature ranges from 3100 ^{0}C to 3500 ^{0}C.

- Combustion of oxygen and acetylene (C_2H_2) in a welding torch produces a temp.

$$C_2H_2 + O_2 \longrightarrow CO_2 + H_2O + \text{Heat}$$

- This reaction occurs near the tip of the torch.

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:

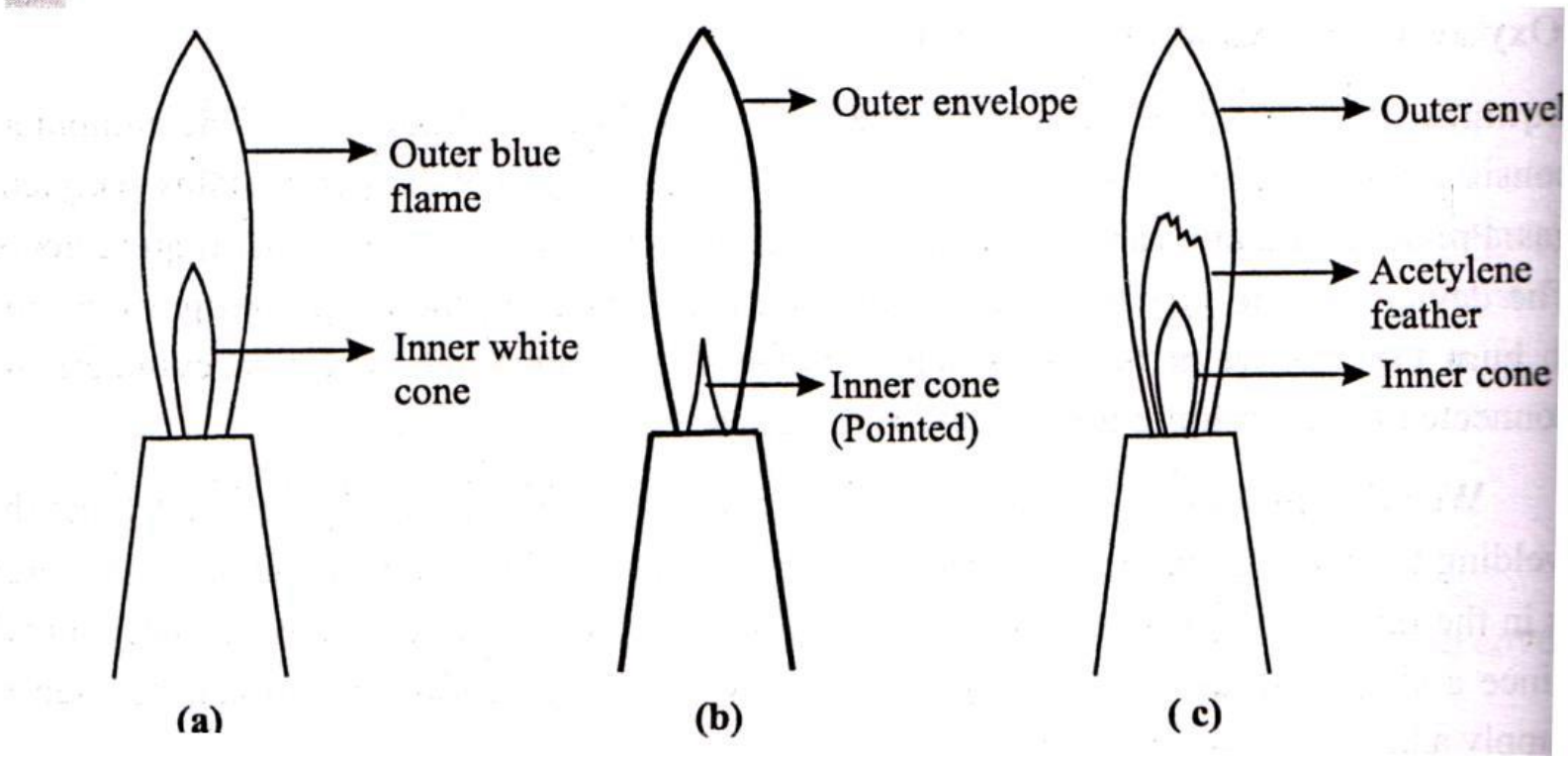
- A neutral flame is obtained by supplying equal volume of oxygen and acetylene
- It consists of a small whitish inner cone surrounded by sharply defined blue flame
- Most of the gas welding is done using the neutral flame

(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

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 and a bluish envelope flame
- This flame is used for welding alloy steels, cast iron, aluminium


Outer blue flame
Inner white cone
(a)
Outer envelope
Inner cone (Pointed)
(b)
Outer envel
Acetylene feather
Inner cone
(c)

Brazing

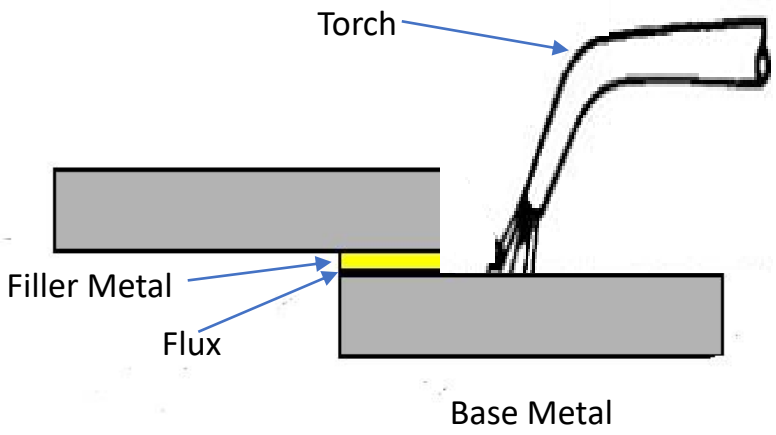


Fig: Brazing Operation

In case of brazing, joining of metal pieces is done with the help of filler metal. Filler metal is melted and distributed by capillary action between the surfaces of the metallic parts being joined. In this case only filler metal melts. There is no melting of workpiece metal. The filler metal (brazing metal) should have the melting point **more than 450^0C**. Its melting point should be lesser than the melting point of workpiece metal.

The metallurgical bonding between work and filler the **joint stronger than the filler metal**

Flux is applied to the part surfaces and a torch is used to focus flame against the work at the joint. A reducing flame is used to prevent the oxidation. Filler metal wire or rod is added to the joint. Torch uses mixture of two gases, oxygen and acetylene, as a fuel like gas welding.

Filler Material: Main property of brazing filler metal is its fluidity, its capability of penetration into the interface of surfaces. Melting point of filler metal must be compatible with workpiece metal. Molten filler metal should also be chemically insensitive to the workpiece metal.

Flux Material: Purpose of brazing flux is same it is in case of welding. It prevents formation of oxides and other unwanted by products making the joint weaker.

Common fluxes are borax, borates, chlorides and fluorides.

Advantages:

- It is simple and economic process
- Strong joint is obtained from the joint than soldering
- Since it is done at relatively low temperature, the metallurgical damage to base metal is minimized

Disadvantages:

- Strength of the joint is relatively low than welding
- Since entire area of brazing need to heated, it consumes more heat than soldering.
- Flux used in soldering is often corrosive, hence joint must be cleaned properly.

Soldering

Soldering is very much similar to brazing and its principle is same as that of brazing. The major difference lies with the filler metal, the filler metal used in case of soldering should have the melting temperature **lower than 450 ^{0}C**. The surfaces to be soldered must be pre-cleaned so that these are faces of oxides, oils, etc. An appropriate **flux** must be applied to the surfaces and then are heated. **Filler metal called solder** is added to the joint, which distributes between the closely fitted surfaces. Strength of soldered joint is much lesser than welded joint and les than a brazed joint.

Types of Solder:

Most of the solder metals are the alloy of tin and lead. These alloys exhibit a wide range of melting point so different type of soldering metal can be used for variety of applications.

Soft Solder: It is a alloy of 63 % of tin and 37 % of lead. The melting point of this solder is 150 ^{0}C to 190 ^{0}C.

Hard Solder: It is alloy of lead 4% and silver 96 %. The melting point of this solder is 350 ^{0}C to 900 ^{0}C.

Flux: It is applied to the joint with the help of a Soldering and Brazing brush before soldering. It avoids oxidation of molten metal, helps in flow of molten solder into the joint and so maintains strength of the joint.

The main functions performed by fluxes are :

- remove oxide films and tarnish from base part surfaces,
- prevent oxidation during heating, and
- promote wetting of the joining surfaces.

Advantages:

- It is simple and economic process
- Since it is done at relatively low temperature, the metallurgical damage to base metal is minimized
- Soft soldered joint can be dismantled by simple heating.

Disadvantages:

- Strength of the joint is relatively low
- Flux used in soldering is often corrosive, hence joint must be cleaned properly.

Comparison between welding, brazing and soldering

Sl. No.	Welding	Soldering	Brazing
1.	It is a high temperature process wherein the base metals are heated above their melting temperature.	Low temperature process. Base metals are not melted.	The base metals are not melted, but broadly heated to a suitable temperature.
2.	Filler metal used is of the same material as that of the base metal.	Filler metal is not the same as that of the base metal.	Filler metal is not the same as that of the base metal.
3.	Joint is formed by the solidification of the molten filler metal with the molten base metal.	Joint is formed by means of diffusion of the filler metal into the base metal.	Joint is formed by means of diffusion of the filler metal into the base metal associated with surface alloying.
4.	Strength of welded joint is much stronger than the base metal.	Strength of the soldered joint is comparatively low.	Strength of the brazed joint lies between that of welded and soldered joint.
5.	Since welding takes place at high temperatures, the metal adjacent to the weld portion called the *heat affected zone* is affected to a large extent.	There is no heat affected zone, as the process is carried at low temperatures.	Although base metals are heated, the heat affected zone is not too much when compared to welding.
6.	Welded joints require certain finishing operations like grinding, filing etc.	Joints can be used as is, without any finishing operations.	In some cases, brazed joints require finishing operations.
7.	Welding produces stronger joints. Hence the process is used for fabrication and structural applications	Joint formed is comparatively weak & hence used in light sheet metal applications & electronic industries.	Used in arts, jewelry works and in some industries.