Chapter-IV: Welding

- Joining two or more elements to make a single part is termed as a fabrication process. Welding is one of the fabrication processes.
- A large number of industrial components are made by fabrication processes. Common examples are aircraft and ship bodies, bridges, building trusses, welded machine frames, sheet metal parts etc.
- It may be called a secondary manufacturing process.

The **welding** is a process of joining two similar or dissimilar metals by **fusion** (application of heat), with or without the application of **pressure** and with or without the use of **filler metal.**

Weld-ability of a metal is the ability (or the ease) of the metals with which two similar or dissimilar metals are joined by fusion with or without the application of pressure and with or without the use of filler metal.

> **Fuse**: meaning: 1. To mix (constituent elements) together by or as if by melting; blend.

The **fusion,** (*means:* The act or procedure of liquefying or melting by the application of heat OR the act or operation of melting or rendering fluid by heat; the act of melting together; as, the fusion of metals), of metal takes place by application of heat. The heat may be obtained from electric arc, electric resistance, chemical reaction, friction or radiant energy. The importance of fusion is clear from the observation that without melting and mixing of the two metals pieces the joining will not be successful.

Base Metal: The metal to be joined or cut is termed as the base metal.

Filler metal: It is the metal (in the form of wire or rod) added to supplement the molten metal pool to make a good and strong joint.

Power Or Heat sources

The sources of power for welding operation may be combustion of gas and coal, electric arc, electric resistance, chemical reaction. The gas and electricity are most used power sources. The gas welding can be performed for thin section and without much expenditure. In case of electric power sorce welding is suitable for thick sections and provides clean joints but heavy and costly equipment is required. The welding process using the chemical reaction as power source can be carried out at remote locations where it is not practicable to carry heavy equipments i.e. railway track welding.

Classification of welding process

The welding processes may be classified on the basis of

(i) **Metals joined and filler material,**

Autogenous Welding

The process of joining similar metals by melting the edges together, without the addition of filler metal, is called autogenous welding.

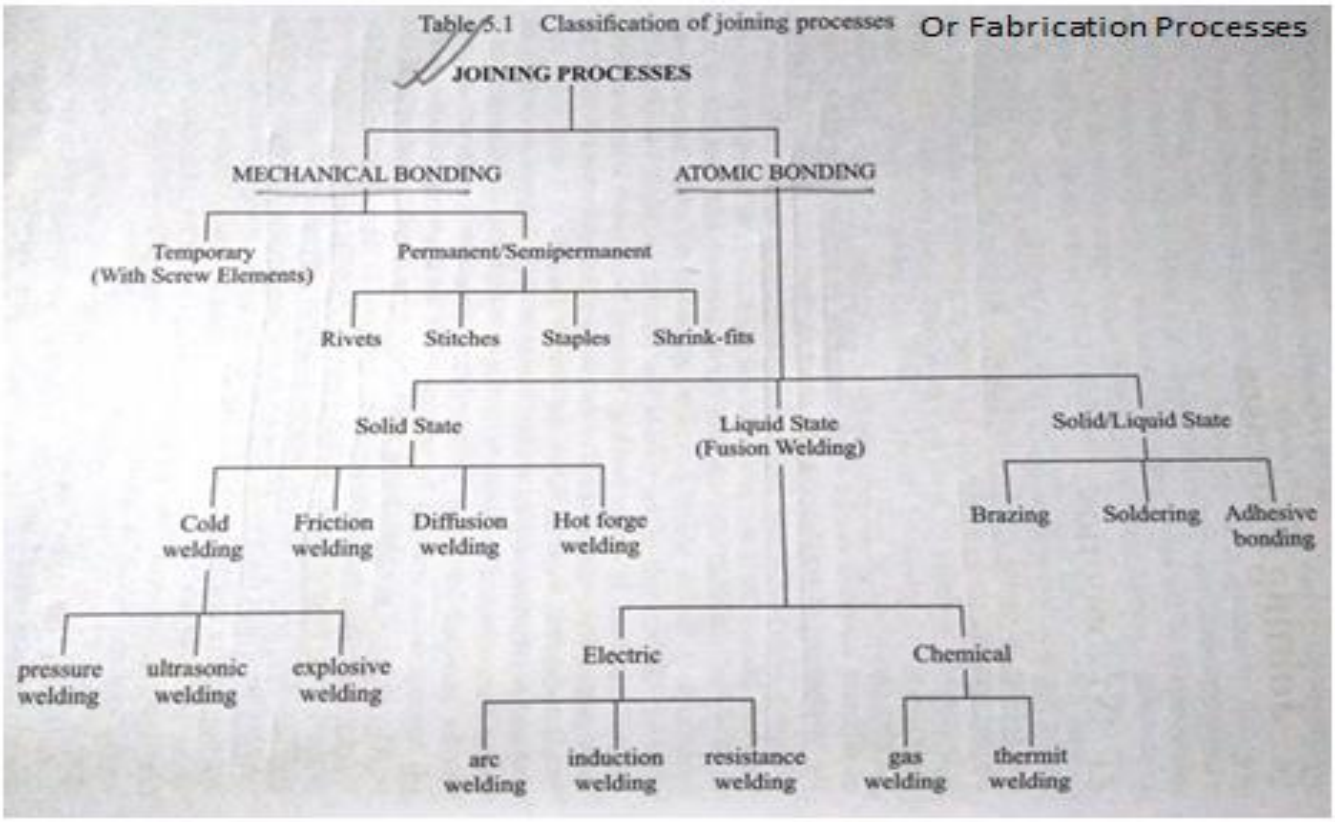
Homogeneous Welding

The process of joining similar metals with the help of filler rod of the same metal is called homogeneous welding.

Heterogeneous Welding

The process of joining dissimilar metals using filler rod is called heterogeneous welding.

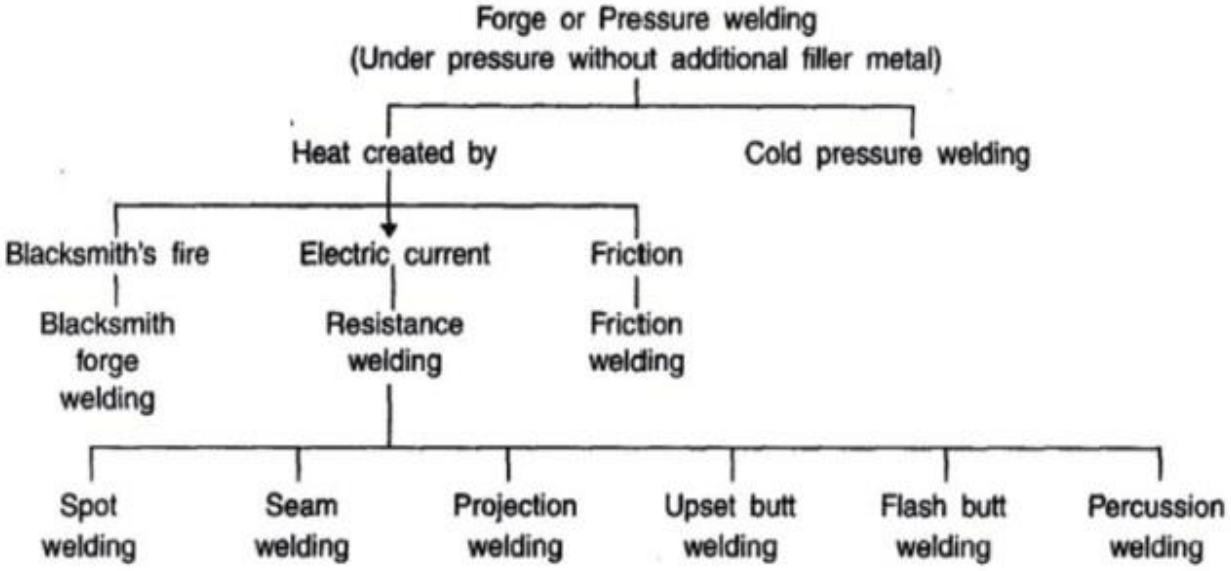
Table 5.1 Classification of joining processes Or Fabrication Processes

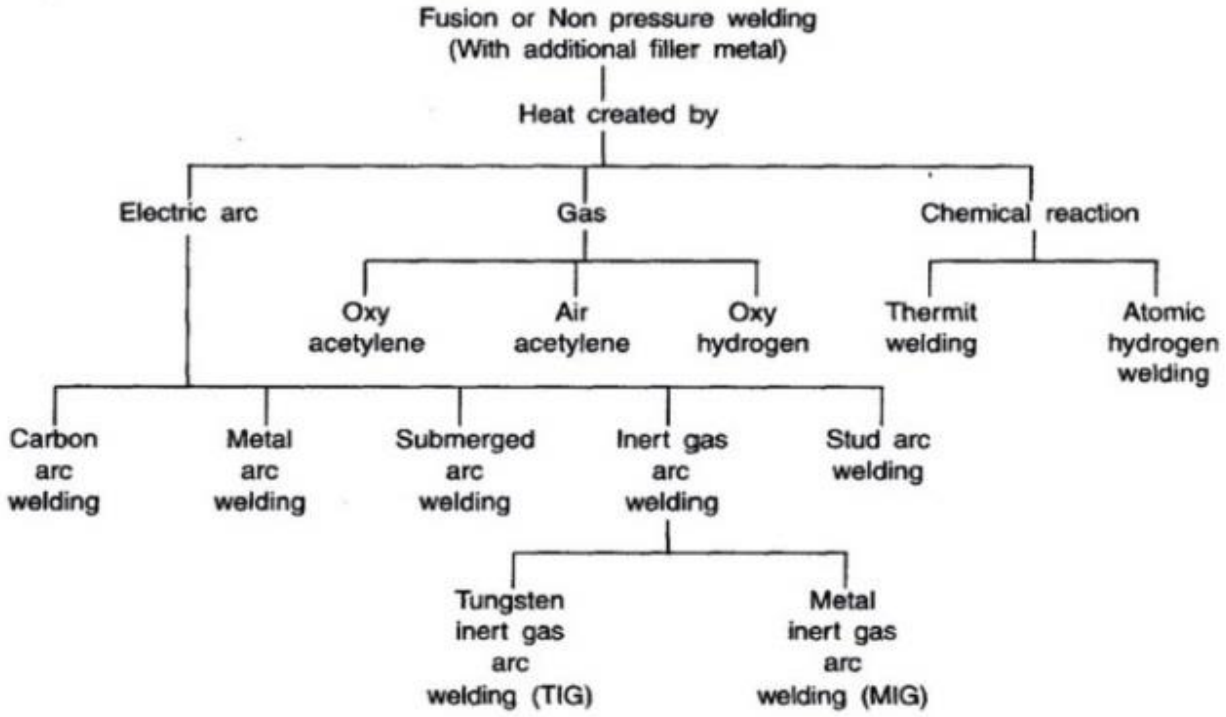


(ii) **The state of metals at the time of welding**, i.e. if the metals are heated to the melting temperature then the welding is called as **fusion welding**, and in case the metal is heated only upto such a temperature to bring it to plastic state then welding is called as **solid state** or **pressure welding**.

Solid state welding: In forge or pressure welding, the work-pieces are heated to plastic state and then, the work-pieces are joined together by applying external pressure on them. The examples are:
1. Forge welding, 2. friction welding, 3. ultrasonic welding, and 4. Spot welding, 5. Seam welding, 6. Projection welding, 7. Resistance butt welding, 8. Flash butt welding 9. Percussion welding, etc.

Fusion or Non-pressure Welding: In this welding, the material at the joint is heated to a molten state and then allowed to solidify. The filler material may or may not be added. The examples are:
1. Air-acetylene welding, 2. Oxy acetylene welding, 3. Arc Welding, 4. Carbon arc welding, 5. Shielded metal arc welding, 6. TIG (Tungsten Inert Gas) welding, and 7. MIG (Metal Inert Gas) 8. Thermit welding 9. Laser beam welding, etc


Forge or Pressure welding
(Under pressure without additional filler metal)
Heat created by
Cold pressure welding
Blacksmith's fire
Electric current
Friction
Blacksmith forge welding
Resistance welding
Friction welding
Spot welding
Seam welding
Projection welding
Upset butt welding
Flash butt welding
Percussion welding


Fusion or Non pressure welding
(With additional filler metal)
Heat created by
Electric arc
Gas
Chemical reaction
Oxy acetylene
Air acetylene
Oxy hydrogen
Thermit welding
Atomic hydrogen welding
Carbon arc welding
Metal arc welding
Submerged arc welding
Inert gas arc welding
Stud arc welding
Tungsten inert gas arc welding (TIG)
Metal inert gas arc welding (MIG)

ADVANTAGES OF WELDING

a) A good weld is as strong as the base metal.
b) A large number of metals/alloys can be joined by welding.
c) Repair by welding is very easy.
d) Welding can be easily mechanized.
e) Portable welding equipment is available.
f) General welding equipment is not very costly.
g) Total joining cost is less in case of welding joint.

DISADVANTAGES OF WELDING

a) Welding produces the harmful radiation, fumes and spatter.
b) A skilled welder is required.
c) Welding heat produces metallurgical changes.
d) Cost of equipment (initial cost) is high.
e) Edge preparation is required before welding.
f) More safety devices are required.
g) Jigs and fixtures are required to hold the parts to be welded

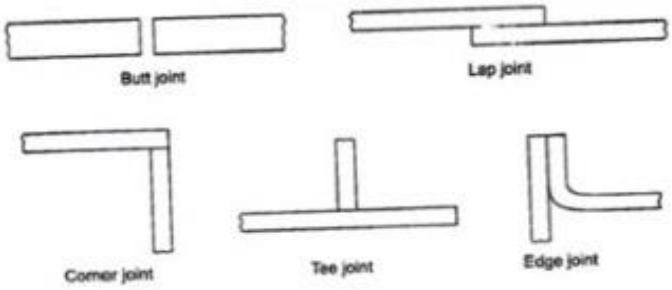
Applications of welding

a) Automobile construction.
b) Railroad equipment.
c) Ships.
d) Aircraft construction.
e) Building construction.
g) Pressure vessels.
h) Storage tanks.
i) Piping and pipe lines.
j) Fabrication of jigs, fixtures and machine tools.
k) Repair of broken and damaged parts.
l) Household furniture.
m) Material handling equipments etc.

WELDING AS COMPARED TO RIVETING AND CASTING

a) Welding is more economical and is a much faster process as compared to both casting and riveting.
b) As compared to riveting and casting, fewer persons are involved in a fabrication process.
c) Welding involves less cost of handling.
d) Welding produces less noise as compared to riveting.
e) Welding designs involve less cost and are flexible also (we can change easily).
f) Cost of pattern making, storing, maintenance, repairs is eliminated.
g) Welding structures are comparatively lighter.
h) Welding can be carried out at any point on a structure, but riveting requires enough clearance.
i) Drilling holes to accommodate rivets weakens a riveted structure.
j) Welding can produce a 100% efficient joint, which is difficult to make by riveting.

Types of welded joints



The following are the five basic types of joints commonly used in fusion welding:

1. **Lap Joint**. The lap joint is obtained by overlapping the plates and then welding the edges of the plates.

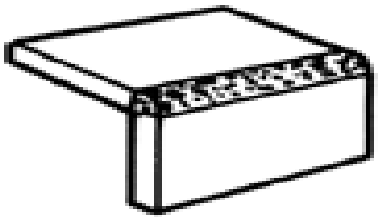
2. **Butt Joint**. The butt joint is obtained by welding the ends or edges of the two plates.

3. **Corner Joint**. The corner joint as shown in Fig. is obtained by joining the edges of two plates whose surfaces are at an angle of approx. 90 degrees to each other.

4. **Edge Joint**. The edge joint as shown in Figure is obtained by joining two parallel plates. It is economical for plates having thickness less than 6 mm.

5. **T-Joint**. The T-joint as shown in Figure, is obtained by joining two plates whose surfaces are approximately at right angles to each other. These joints are suitable upto 3 mm thickness.

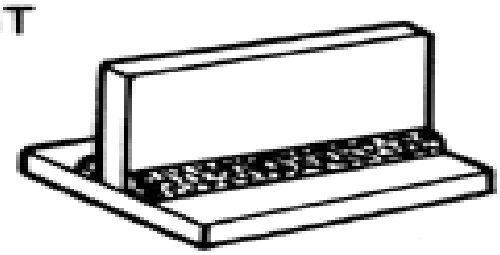
BUTT JOINT



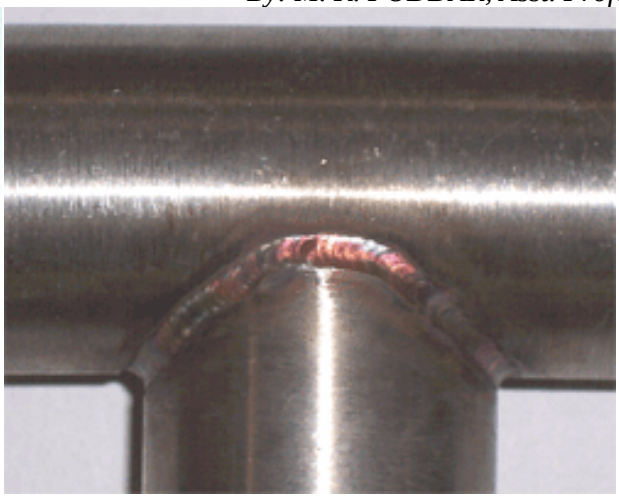
CORNER JOINT

EDGE JOINT

LAP JOINT



TEE JOINT



Gas Welding

- It is a fusion welding in which strong gas flame is used to generate heat and raise temperature of metal pieces localized at the place where joint is to be made. In this welding metal pieces to be joined are heated. The metal thus melted starts flowing along the edges where joint is to be made. A filler metal may also be added to the flowing molten metal to fill up the cavity at the edges. The cavity filed with molten metal is allowed to solidify to get the strong joint.

Oxy-Acetylene Welding

- Acetylene mixed with oxygen when burnt under a controlled environment produces large amount of heat giving higher temperature rise. This burning also produces carbon dioxide which helps in preventing oxidation of metals being welded. Highest temperature that can be produced by this welding is 3200oC. The chemical reaction involved in burning of acetylene is

$$2C2H2 + 5O2 = 4CO2 + 2H2O + Heat$$

Chemical reactions: In welding process the acetylene gas reacts with oxygen in two stages and produces heat. The reactions are written as:

1. First reaction: $2C_2H_2 + 2O_2 \longrightarrow 4CO + 2H_2$
2. Second reaction: $4CO + 2H_2 + 3O_2 \longrightarrow 4CO_2 + 2H_2O$
3. The combination of above two $2C_2H_2 + 5O_2 \longrightarrow 4CO_2 + 2H_2O$ reactions:

GAS WELDING TOOLS AND EQUIPMENTS

- **Tools and Equipment**

(a) Gas cylinders (two)

(b) Hose pipes and valves

(c) Cylinder pressure gauge

(d) Outlet pressure gauge

(e) Pressure regulators

(f) Blow pipe or torch and spark lights

(g) Welding screens

(h) Goggles, screens, gloves and apron

(i) Wire brush, trolley, chipping hammer.

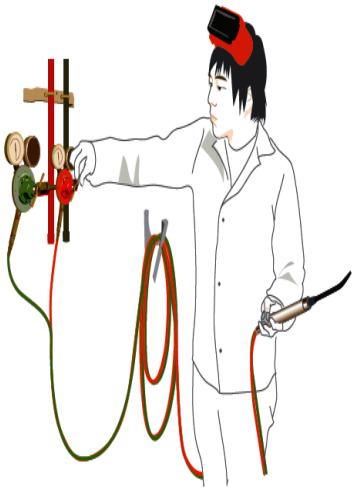
- **Consumables**

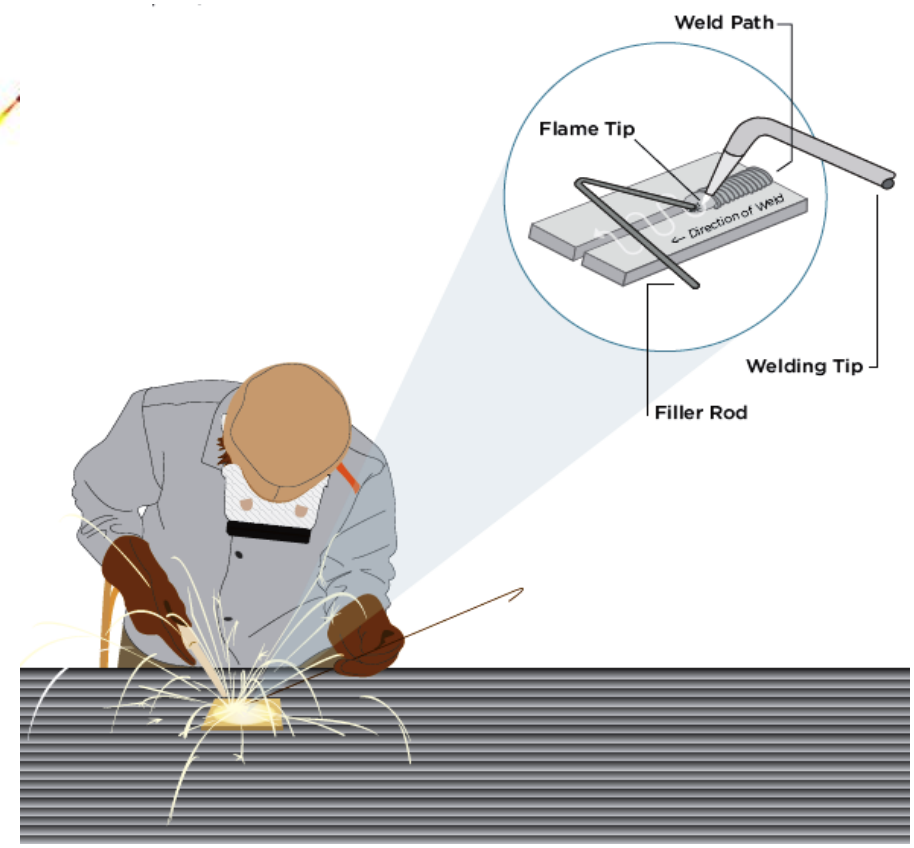
(a) Oxygen gas

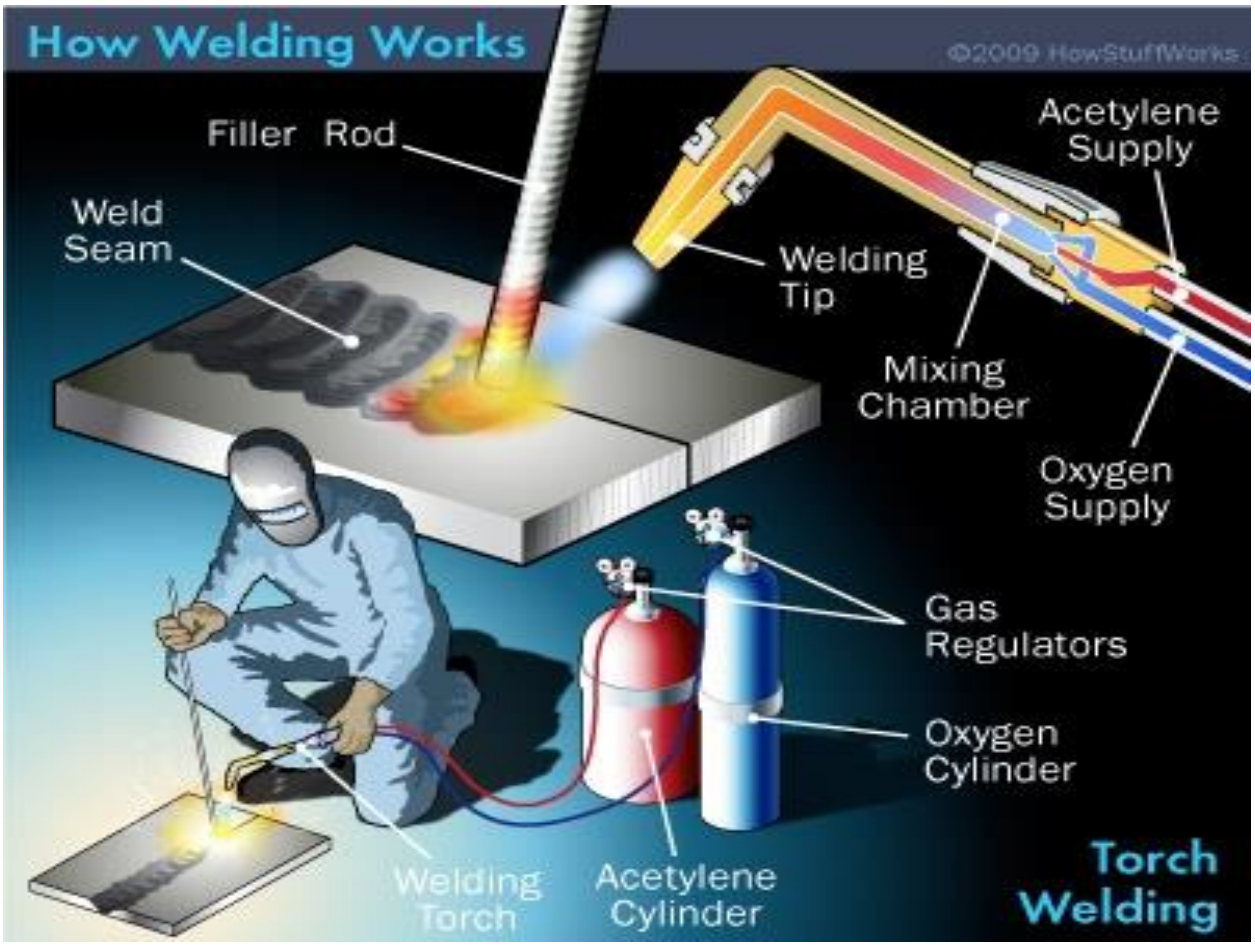
(b) Acetylene gas

(c) Filler Metal (rod or wire)

(d) Fluxes.






How Welding Works
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Filler Rod
Weld Seam
Welding Tip
Acetylene Supply
Mixing Chamber
Oxygen Supply
Gas Regulators
Oxygen Cylinder
Welding Torch
Acetylene Cylinder
Torch Welding

Principle of operation

The acetylene gas is mixed with oxygen in correct proportions in the welding torch and ignited, the flame is produced which is sufficiently hot to melt and join (upon cooling) the parent metal. Temperature of flame is about 2800-3400°C. A filler rod is generally added to build up the seam for greater strength.

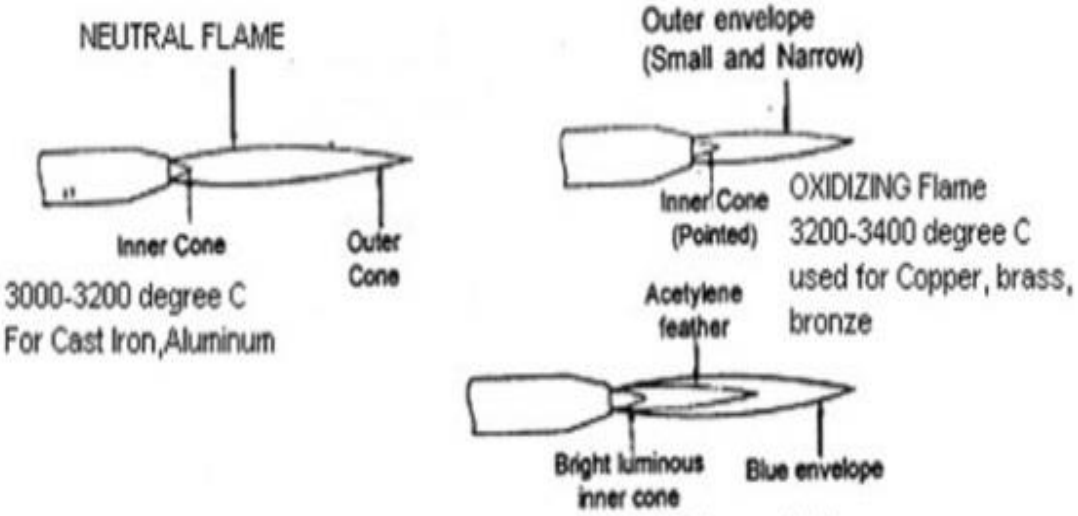
Oxy-acetylene welding may be classified as:

High Pressure Oxy-acetylene Welding: In case of high pressure Oxy-acetylene gas welding, the acetylene gas is supplied from the acetylene cylinder (Painted maroon) in compressed form. The acetylene is dissolved in the porous mass soaked in acetone. The oxygen gas is supplied from the commercial cylinders (Painted black) in both types of gas welding.

Gas Welding Torch

Low Pressure Oxy-acetylene Welding: In case of low pressure Oxy-acetylene gas welding, the acetylene gas is supplied from the generator at low pressure. In the generator calcium carbide stone is added in the chamber in which water is already present. Calcium carbide stone reacts with the water and produce acetylene gas. This gas can be easily collected from the top of the water and can be used for welding purpose.

Types of welding flames: depending upon the proportions of acetylene and oxygen the three types of flames are:



1. Neutral flame

a) A neutral flame is produced when oxygen to acetylene ratio is 1.1 to 1.
b) The temperature is of the order of about (3000-3200°C).
c) The flame has nicely defined inner cone (light blue in colour) and is surrounded by outer envelope which is dark blue in colour than the inner cone.
d) It is called neutral because it will **not oxidize or carburise** the metal.
e) It is used for welding of Copper, Cast iron, Al.

2. Oxidizing flame

After the neutral flame, if the supply of oxygen is further increased, the result will be an oxidizing flame.

a) Its inner cone is more pointed and outer flame envelope is much shorter.
b) It burns with a loud roar.
c) The temperature is of the order of about 3400°C (because of excess of O_2 so complete combustion takes place).
d) This flame is harmful for steels, because it oxidizes the steels.
e) Only in the welding of **copper and copper based alloys**, oxidizing flame is desirable, because in those cases a thin protective layer of slag forms over the molten metal

3. Reducing flame

If the volume of oxygen supplied to the neutral flame is reduced, the resulting flame will be a carburising or reducing flame i.e. rich in acetylene.

a) In this flame, **acetylene feather** exists between the **inner cone** and **outer envelope**.
b) Temperature is of the order of about 2800°C (less because it does not completely consume the available carbon).
c) Metals that tend to absorb carbon should not be welded with reducing flame.
d) Carburizing flame contains more acetylene than a reducing flame.
e) Carburizing flame is used for the welding of lead and for carburizing (surface hardening) purposes.
f) Reducing flame is used, with low alloy steel rod, for **welding high carbon steel**.

Flux is a chemical cleaning agent, flowing agent, or purifying agent. Fluxes may have more than one function at a time. They are used in both extractive metallurgy and metal joining. During welding process the metal is heated/ melted in air, oxygen from the air combines with the metal to form oxides which results in poor quality, low strength welds and in some cases may even make welding impossible.

Purpose of flux The role of a flux in **joining processes** (welding, soldering & brazing) is multiple as:

a) It dissolves of the oxides on the metal surface, which facilitates wetting by molten metal, and
b) Acts as an oxygen barrier by coating the hot surface, preventing its oxidation.
c) In some applications molten flux also serves as a heat transfer medium, facilitating heating of the joint by the soldering tool or molten solder.
d) It improves the fluidity of the metal and capillary action
e) Examples of flux are sodium carbonate, borax and ammonium chloride.

Advantages of Gas Welding	Disadvantages of Gas Welding
It can be applied to a wide variety of manufacturing and maintenance situations	Flame temperature is less than the temperature of the arc
Rate of heating and cooling of weld deposit and job is slow	Refractory metals (e.g. tungsten, molybdenum, tantalum etc.) and reactive metals (titanium and zirconium) cannot be gas welded.
No electric current is required	Gas flame takes a long time to heat up the metal than an arc
Equipment is having less cost	Heat affected zone is wider
Operator is having better control because sources of heat and filler metals are separate	
Cost and maintenance of the welding equipment is low	

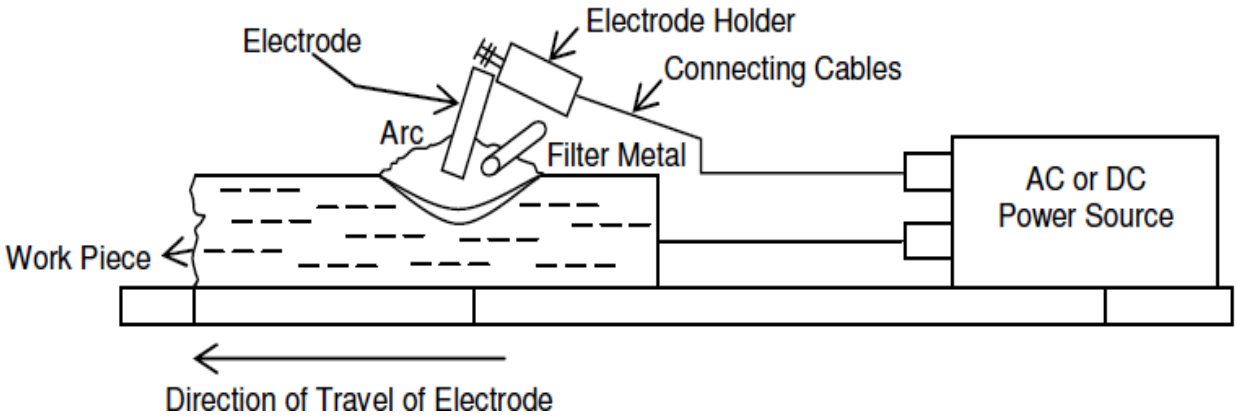
Arc Welding

- Electric arc welding is one of the fusion welding processes in which coalescence of the metal is achieved by the heat from an electric arc between an electrode and workpiece, mostly without the application of pressure and with or without the use of filler metal depending upon the thickness of base metal

Arc welding Principle

Electric arc is generated when electrode is brought into contact with the work and is then quickly separated by a short distance approximately (0.8mm to 2 mm). The circuit operates at low voltage and high current so arc is established in the gap due to thermoionic emission from electrode (Cathode) to workpiece (Anode). The arc is sustained due to continuous presence of a thermally ionized column of gas. This arc produces at temperature of the order of 5500 ℃ or higher. In this way a pool of molten metal consisting of workpiece metal and filler metal

is formed in the welding zone. The electrode is moved along the joint with perpendicular zig-zag motion. The solidified molten weld pool makes the strong welded joint.



ARC WELDING EQUIPMENT

The equipments are categorized as facilitator, consumable and protecting equipments.

Facilitator Equipment Welding

(a) Power source (welding machine)
(b) Electrode holder
(c) Work table
(d) Cables (for connection)
(e) Finishing devices like chipping, hammer, wire brush, etc.

Consumable Equipment

(a) Electrode
(b) Flux
(c) Workpiece
(d) Filler metal

Protecting Equipment

(a) Welding shields
(b) Goggles
(c) Screens
(d) Gloves
(e) Apron

What is arc and How an arc is formed?

The arc is like a flame of intense heat that is generated as the electrical current passes through a highly resistant air gap. **Procedure**: The arc is formed (after switching ON the electric arc welding machine and connecting the electrodes) by striking the end of the welding rod on the work piece and a spark is produced, simultaneously the gap (approximately 0.8 to 2 mm) is maintained between the welding rod and work piece, this result in the continuous arc and heats the workpiece.

Advantages and disadvantages of **arc welding**

Advantages	Limitations or disadvantages
Most efficient way to join metals	Manually applied, therefore high labor cost.
Lowest-cost joining method	Need high energy causing danger
Affords lighter weight through better utilization of materials	Not convenient for disassembly.
Joins all commercial metals	Defects are hard to detect at joints
Provides design flexibility	

Applications of arc welding

a) Used for fabrication work and repairs
b) Used in ship building, pipe lines, bridge construction, tanks, boilers, etc
c) Domestic repairs and making of doors/ gates.
d) Manufacture

Comparison of A.C. and D.C. arc welding

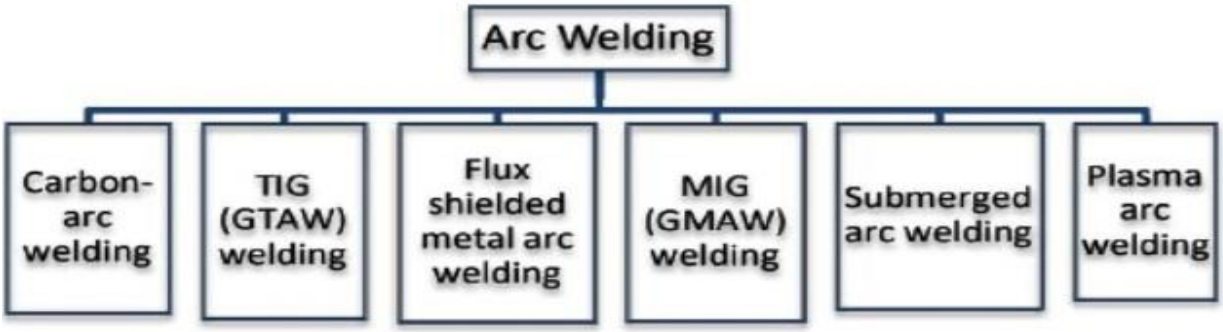
Alternating Current (from Transformer)	Direct Current (from Generator)
More efficiency	Less efficiency
Power consumption less	Power consumption more
Cost of equipment is less	Cost of equipment is more
Higher voltage – hence not safe	Low voltage – safer operation
Not suitable for welding non ferrous metals	suitable for both ferrous non ferrous metals
Not preferred for welding thin sections	preferred for welding thin sections
Any terminal can be connected to the work or electrode	Positive terminal connected to the work

Electrode

The electrode used for providing heat input in arc welding are of two type, consumable and non-consumable electrodes

Consumable electrode: when arc is obtained with a consumable electrode, the weld metal under the arc melts as also the tip of electode. The molten metal from electrode and that obtained from base metal gets mixed under the arc and provide the necessary joint after solidification. Electrode also acts as a filler rod to provide the filler metal metal into the joint. It may be made from steel, cast iron, copper, bronze or aluminum.

Non-Consumable electrode: Non consumable electrode made of carbon, graphite or tungsten. Carbon and grapgite electode used in DC welding, whereas tungsten electrode is used for both AC and DC welding. The filler metal required has to be deposited through a separate filler rod.



Carbon-arc welding

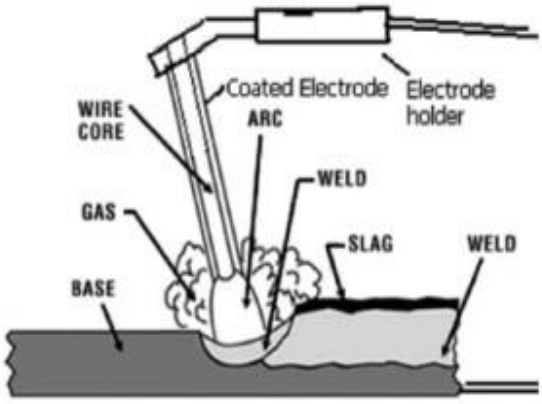
In carbon arc welding the arc is established between the work piece and the carbon electrode the filler material may be used separately.

Metal arc welding

In metal arc welding the arc is established between the work piece and the metal electrode which acts as the filler material also.

Metal arc welding Procedure

a) The work piece is connected to one terminal of the welding machine.(Positive terminal in case of straight polarity)
b) The electrode is attached to the electrode holder.
c) The machine is switched 'ON' and current adjusted.
d) The metal electrode is struck to the workpiece and a gap of 0.8-1.2 mm is maintained to establish the arc.
e) The developed arc melts the metals and forms a pool of molten metal, called puddle. The molten metal forms a joint on cooling and solidification.
f) The joint is complete on solidification.



Metal Arc welding with coated electode

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