UNIT – II

JOINING PROCESSES

SYLLABUS

Operating principle, basic equipment, merits and applications of : Fusion welding processes : Gas welding - Types – Flame characteristics; Manual metal arc welding – Gas Tungsten arc welding - Gas metal arc welding – Submerged arc welding – Electro slag welding; Operating principle and applications of : Resistance welding - Plasma arc welding – Thermit welding – Electron beam welding – Friction welding and Friction Stir Welding; Brazing and soldering; Weld defects: types, causes and cure

Introduction

The process of joining takes place by means of welding, riveting or by fastening nut and bolts. If a joint can be disassembled then joining method is called temporary joining method. If the same, cannot be disassembled without breaking it then the joint is called permanent joint. Normally in welding operation joining of metal pieces is done by raising their temperature to the fusion point so that they form a sort of pool of molten metal at the ends to the joined, sometimes, the pool is supplemented with a filler metal (wire or rod) which normally has almost same compositions as that of the work pieces. This way the pool forms a homogeneous mixture. It is allowed to get solidify to have a permanent joint. There is wide diversity in welding technology so its conventional definition can be modified as ―welding is a technique of joining similar and dissimilar metals and plastics by adopting ways which do not include adhesives and fasteners.‖

Selection of type of joints:

a) Type of joint required for an application is temporary or permanent.
b) Whether similar or dissimilar materials are to be joined in order to take care of the compatibility aspect as metallurgical incompatibility can be disastrous for performance of the joints
c) Physical, chemical metallurgical properties of materials to be joined.
d) Requirements of the service from the joint under special conditions of temperature, corrosion, environment, and reliability.
e) Type and nature of loading conditions (static and dynamic loading under tension, shear, compression, bending etc.)

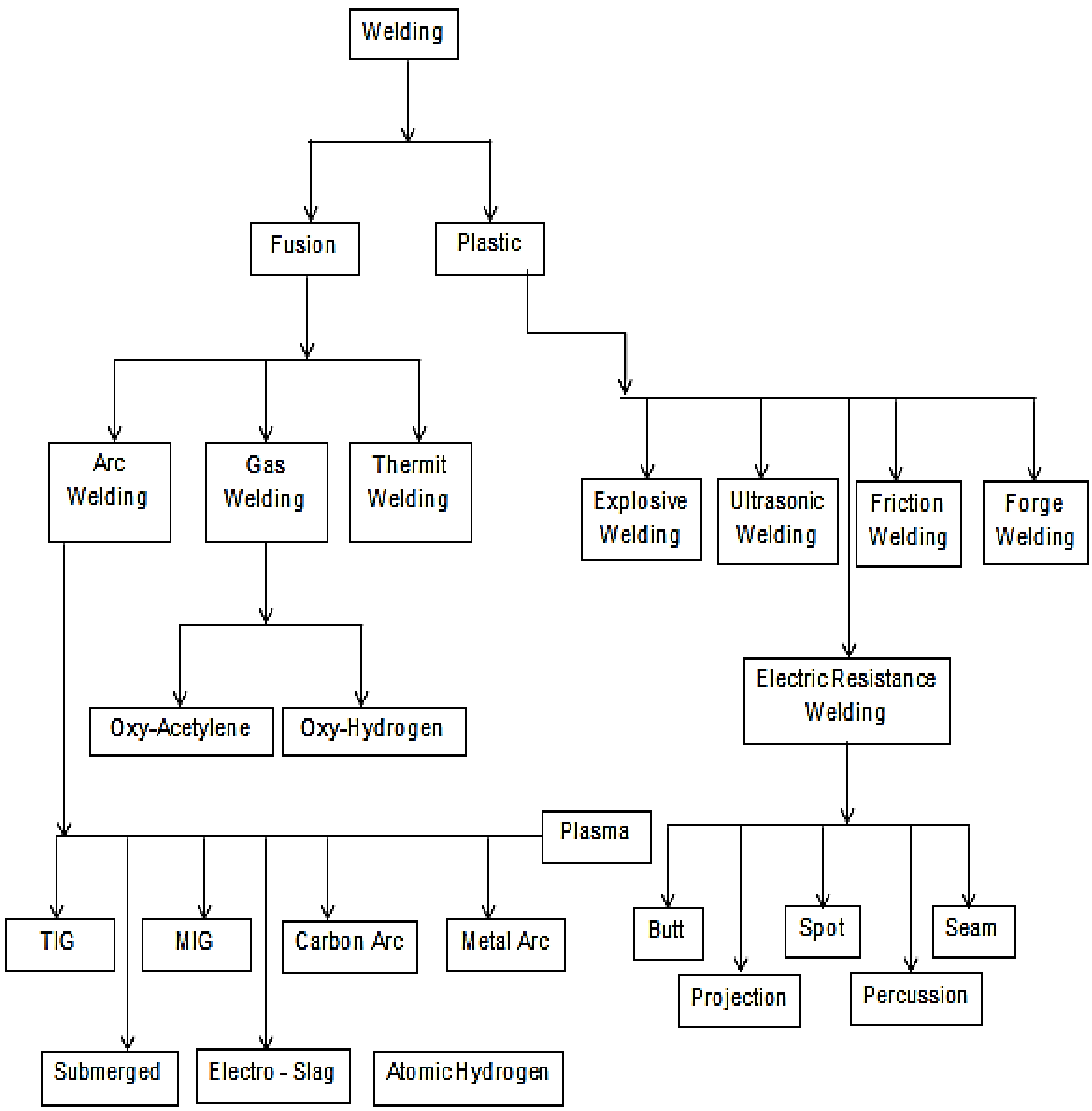
f) Economy or cost effectiveness is one most important factors influencing the selection of joint for manufacturing an engineering component

2.2 CLASSIFIATION OF WELDING PROCESSES

Welding process can be classified into different categories depending upon the following criteria:

(a) Liquid state welding (Fusion welding)

(b) Solid state welding (Pressure welding)



Welding process can be also classified as:

Autogeneous	:	During welding process, no filler metal is added to the joint interface. For example: solid welding process and electric resistance welding
Homogeneous	:	During welding process, filler metal is added and is of the same type as the parent metal. For Example: Arc welding
Heterogeneous	:	During welding process, filler metal is added and is of a different type from the parent metal. Example: Brazing and soldering

Advantages and Limitation of Welding

Advantages of welding are enlisted below:

1. Permanent joint is produced, which becomes an integral part of work piece.
2. Joints can be stronger than the base metal if good quality filler metal is used.
3. Economical method of joining.
4. It is not restricted to the factory environment.

Disadvantages of welding are enlisted also below:

1. Labour cost is high as only skilled welder can produce sound and quality weld joint.
2. It produces a permanent joint which in turn creates the problem in dissembling if of sub-component required.
3. Hazardous fumes and vapours are generated during welding. This demands proper ventilation of welding area.
4. Weld joint itself is considered as a discontinuity owing to variation in its structure, composition and mechanical properties; therefore welding is not commonly recommended for critical application where there is a danger of life.

Applications of welding

The welding is widely used for fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications besides shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations.

Specific components need welding for fabrication includes

(a) Transport tankers for transporting oil, water, milk etc.
(b) Welding of tubes and pipes, chains, LPG cylinders and other items.
(c) Fabrication of Steel furniture, gates, doors and door frames, and body

(d) Manufacturing white goods such as refrigerators, washing machines, microwave ovens and many other items of general applications

Electric 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 work piece. A line diagram indicating the whole process is shown in Figure 2.1.

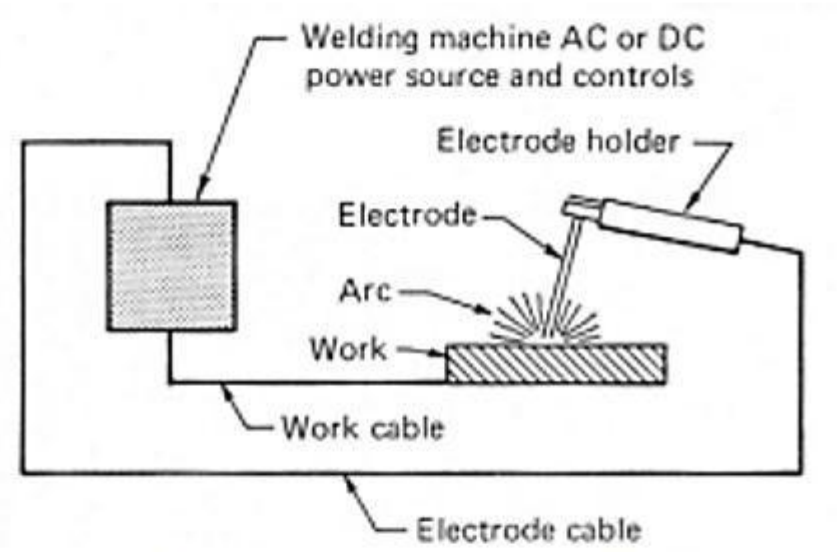


Fig.2.1 Process of Electric Arc Welding

Electric arc is generated when electrode is brought into contact with the work and is then quickly separated by a short distance approximately 2 mm. The circuit operates at low voltage and high current so arc is established in the gap due to thermo ionic emission from electrode (Cathode) to work piece (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^{o}C or higher. In this way a pool of molten metal consisting of work piece 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. Movement of the electrode relative to work piece is accomplished by either manually or by mechanical means in case of automatic welding machines. Better uniformity and good quality weldments are possible in case of automatic welding process.

Arc welding equipments are listed below. The equipments are categorized as facilitator, consumable and protecting equipments. Some of the equipment of arc welding is same as that are used in gas welding like flux, protecting devices and cleaning devices, etc.

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) Work piece
d) Filler metal

Protecting Equipment

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

Arc welding equipments are described below.

a) Power Source

Both AC (Alternative Current) and DC (Direct Current) can be used for welding. AC machines are recommended for ferrous metal and DC machines are recommended for other metals for better result. Main constituent of welding machine is transformer which converts the supply to low voltage and high current. For AC welding power is required at 80 to 110 volt and 50 to 80 ampere. For sustaining the established are power factor is kept low. In case of DC welding power is required at 8 to 25 volts and 50 ampere. Polarity is also are significant factor. Two types of polarities are possible in case of DC welding.

Straight Polarity

Electrode is made negative pole and work piece is made positive pole. It is also called as electrode negative.

Reversed Polarity

Electrode is made positive pole and work piece is made negative pole. It is called electrode positive too. As we know that two third of the total heat is generated at positive pole and only one third at negative pole. Polarity is decided according to the requirement of heat at either pole.

b) Welding Electrodes

These are also called welding rods. Two types of welding electrodes are generally used.

1) Consumable electrodes

2) Non-consumable electrodes.

Consumable electrodes

Consumable electrodes are the source of filler metal in case of arc welding. Consumable electrodes can further be classified into two categories

a. Coated electrodes
   - Light coated electrode
   - Heavily coated electrode
b. Bare electrodes.

Light coated electrode

Light coated welding electrodes have a definite composition. A light coating has been applied on the surface by washing, dipping, brushing, spraying, tumbling, or wiping. The coatings improve the characteristics of the arc stream. They are listed under the E45 series in the electrode identification system.

The coating generally serves the functions described below:

- It dissolves or reduces impurities such as oxides, sulfur, and phosphorus.
- It changes the surface tension of the molten metal so that the globules of metal leaving the end of the electrode are smaller and more frequent. This helps make flow of molten metal more uniform.
- It increases the arc stability by introducing materials readily ionized (i.e., changed into small particles with an electric charge) into the arc stream.
- Some of the light coatings may produce a slag. The slag is quite thin and does not act in the same manner as the shielded arc electrode type slag.

Heavily coated electrode

Heavy coated welding electrodes have a definite composition on which a coating has been applied by dipping or extrusion. The electrodes are manufactured in three general types: those with cellulose coatings; those with mineral coatings; and those whose coatings are combinations of mineral and cellulose. The cellulose coatings are composed of soluble cotton or other forms of cellulose with small amounts of potassium, sodium, or titanium, and in some cases added minerals. The mineral coatings consist of sodium silicate, metallic oxides clay, and other inorganic substances or combinations thereof. Cellulose coated electrodes protect the molten metal with a gaseous zone around the arc as well as the weld zone. The mineral coated electrode forms a slag deposit. The shielded arc or heavy coated electrodes are used for welding steels, cast iron, and hard surfacing.

Bare Electrodes

Bare welding electrodes are made of wire compositions required for specific applications. These electrodes have no coatings other than those required in wire drawing. These wire drawing coatings have some slight stabilizing effect on the arc but are otherwise of no consequence. Bare electrodes are used for welding manganese steel and other purposes where a coated electrode is not required or is undesirable.

Non-consumable Electrodes

They are made of tungsten or carbon. These do not melt in the process of welding and so called non-consumable electrodes. Their depletion rate is very low. In case of non-consumable electrodes metal and flux is supplied additionally. Generally non-consumable electrodes are used in MIG and TIG welding processes.

Electrode Coding

According to ISI coding system an electrode is specified six digits with a prefix letter ‗M' which is indicative of its suitability for metal arc welding. Explanation of six digits is given below.

E 70 1 8 -X

E	:	Indicates that this is an electrode
70	:	Indicates how strong this electrode is when welded. Measured in thousands of pounds per square inch.
1	:	Indicates in what welding positions it can be used
8	:	Indicates the coating, penetration, and current type used.
X		Indicates that there are more requirements.

WELDING POSITIONS

1 : Flat, Horizontal, Vertical (up), Overhead

2 : Flat, Horizontal

4 : Flat, Horizontal, Overhead, Vertical (down)

ADDITIONAL REQUIREMENTS

Suffix		Additional Requirement
1	:	Increased toughness (impact strength) for E7018 electrodes. Also increased ductility in E7024 electrodes.
M	:	Meets most military requirements - greater toughness, lower moisture content as received after exposure, diffusible hydrogen limits for weld metal.
-H4	:	Indicates the maximum diffusible hydrogen limit measured in millimeters per 100 grams (mL/100g).

Example: H4 = 4mL per 100 grams

The important functions Electrode coating are as follows:

1. Improve the electric conductivity in the arc region to improve the arc ignition and stabilization of the arc.
2. Formation of slag, which;
   (a) Influences size of droplet.
   (b) Protects the droplet during transfer and molten weld pool from atmospheric gases.
   (c) Protects solidified hot metal from atmospheric gases.
   (d) Reduces the cooling rate of weld seam.
3. Formation of shielding gas to protect molten metal.
4. Provide deoxidizers like Si and Mn in form of FeSi and FeMn.
5. Alloying with certain elements such as Cr, Ni, Mo to improve weld metal properties.
6. Improve deposition rate with addition of iron powder in coating.

Various constituents of electrode coating are cellulose, calcium fluoride, calcium carbonate, titanium dioxide, clay, talc, iron oxide, asbestos, potassium / sodium silicate, iron powder, ferro-maganese, powdered alloys, silica etc. Each constituent performs either one or more than one functions.

Electrode metallic core wire is the same but the coating constituents give the different characteristics to the welds. Based on the coating constituents, structural steel electrodes can be classified in the following classes;

Cellulosic Electrodes

Coating consists of high cellulosic content more than 30% and TiO_2 up to 20%. These are all position electrodes and produce deep penetration because of extra heat generated during burning of cellulosic materials. However, high spatter losses are associated with these electrodes.

Rutile Electrodes

Coating consists of TiO_2 up to 45% and SiO_2 around 20%. These electrodes are widely used for general work and are called general purpose electrodes.

Acidic Electrodes

Coating consists of iron oxide more than 20%. Sometimes it may be up to 40%, other constituents may be TiO_2 10% and $CaCO_3$ 10%. Such electrodes produce self-detaching slag and smooth weld finish and are used normally in flat position.

Basic Electrodes

Coating consist of $CaCO_3$ around 40% and CaF_2 15-20%. These electrodes normally require baking at temperature of approximately 250°C for 1-2 hours or as per manufacturer's instructions. Such electrodes produce high quality weld deposits which has high resistance to cracking. This is because hydrogen is removed from weld metal by the action of fluorine i.e. forming HF acid as CaF_2 generates fluorine on dissociation in the heat of arc.

Table 2.1: Coating Constituents and Their Functions

Coating Constituent	Functions	
	Main Functions	Other Functions
Cellulose	Gas former	Coating Strength and Reducing agent
Calcium Fluoride (CaF_2)	Slag basicity and metal fluidity, H_2 removal	Slag former
Clay (Aluminum	Slag former	Coating strength

Silicate)		
Talc (Magnesium Silicate)	Slag former	Arc stabilizer
Rutile (TiO_2)	Arc stabilizer, Slag former, Fluidity	Slag removal and bead appearance
Iron Oxides	Fluidity, Slag former	Arc Stabilizer, improved metal transfer,
Calcium Carbonate	Gas former, Arc stabilizer	Slag basicity, Slag former
Asbestos	Coating strength	Slag former
Quartz (SiO_2)	Slag fluidity, Slag former	Increase in current carrying capacity.

Sodium Silicate / Potassium Silicate	Binder, Arc stabilizer	Slag former
FeMn / FeSi	Deoxidizer	
Iron Powder	Deposition Rate	
Powdered Alloys	Alloying	

COMPARISON OF AC and DC WELDING MACHINES

Sl.No.	Category	A.C Transformer	D.C.Transformer
1	Efficiency range	80-85%	30-60%
2	Power consumption	Less	More
3	Cost	Low	High
4	Terminal connection	Positive and Negative are	Positive to work piece and

		changed	Negative to electrode
5	Operation	Noiseless	Noisy
6	Safely operation	No	Yes
7	Work piece	Only for ferrous material	Suitable for ferrous and non-ferrous
8	Electrode	Only coated electrode can be used	coated and bare electrode can be used
9	Maintenance	High	Low
10	Power factor	High	Low

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. Different combinations of gases can be used to obtain a heating flame. The popular gas combinations are oxy-hydrogen mixture, oxygen-acetylene, etc. different mixing proportion of two gases in a mixture can generate different types of flames with different characteristics.

Oxy-Acetylene Welding

Oxy-acetylene welding can use for welding of wide range of metals and alloys. 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

$$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O + Heat$$

On the basis of supply pressure of gases oxy-acetylene welding is categorized as high pressure welding in this system both gases oxygen and acetylene supplied to welding zone are high pressure from their respective high pressure cylinders. The other one is low pressure welding in which oxygen is supplied from high pressure cylinder but acetylene is generated by the action of water on calcium carbide and supplied at low pressure. In this case high pressure supply of oxygen pulls acetylene at the welding zone.

A comparison can be drawn between low pressure and high pressure welding. High pressure welding equipment is handy, supplies pure acetylene at constant pressure, with better control and low expenses as compared to low pressure welding.

Characteristics of the oxy-acetylene welding process include:

- The use dual oxygen and acetylene gases stored under pressure in steel cylinders,
- Its ability to switch quickly to a cutting process, by changing the welding tip to a cutting tip,
- The high temperature the gas mixture attains,
- The use of regulators to control gas flow and reduce pressure on both the oxygen and acetylene tanks,
- The use of double line rubber hoses to conduct the gas from the tanks to the torch,
- Melting the materials to be welded together,
- The ability to regulate temperature by adjusting gas flow.

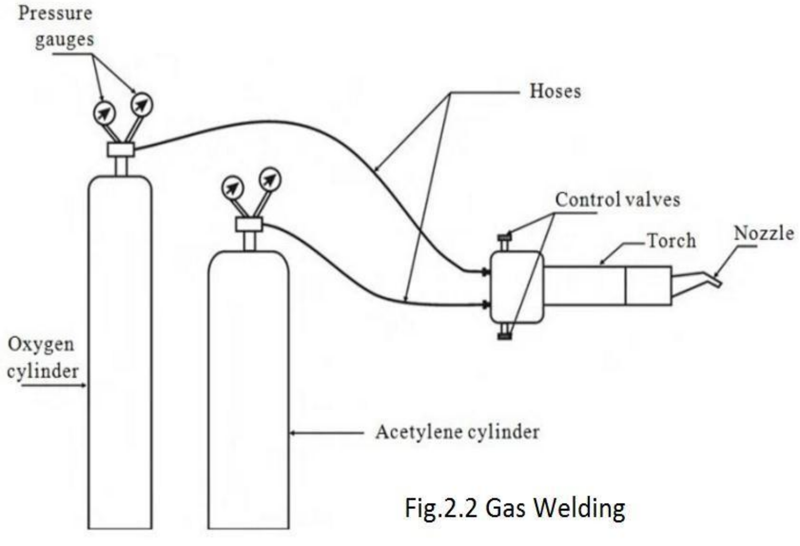


Fig.2.2 Gas Welding

Gas Welding Equipments

The following equipments are necessary for gas welding

1. Gas cylinders
2. Regulators
3. Pressure gauges
4. Rubber hoses
5. Welding torch
6. Safety goggles
7. Gloves
8. Spark lighter
9. Wire brush

1. Gas Cylinders

Oxygen and acetylene gases are stored in separate cylinders and used for gas welding. The colour of oxygen cylinder is black and the acetylene gas is stored in maroon cylinders. Oxygen is stored at a pressure of 125Kg/cm^2. Acetylene gas is stored at a pressure of 16 Kg/cm^2 in the cylinder.

2. Regulators

Separate regulators are fitted on both the cylinders. A regulator is used to control the working pressure of the gases. The working pressure of oxygen is 1Kg/cm^2 and acetylene is 0.15Kg/cm^2. Working pressure of these gases is altered according to the thickness of the metal parts of the joint.

3. Pressure Gauges

Two pressure gauges are fitted each on the oxygen cylinder and on the acetylene cylinder. One of the pressure gauges indicates the pressure of the cylinder and the other gauge indicates the working pressure of the specific gas.

4. Hoses

Separate hoses are used to connect the two cylinders with the welding torch through regulators. The colour of the hose from the oxygen cylinder is black and the one from the acetylene cylinder is red. These hoses carry the gases to the welding torch.

5. Welding Torch

Oxygen and acetylene reach the welding torch through the passages of hoses from the respective cylinders. These gases are mixed in the mixing chamber of the welding torch. Flame is produced at the tip of the torch when the gases are ignited. There are two control valves present in the torch to control the quantity of oxygen and acetylene. By this control, the grade of the flame can be altered. The size of the flame is altered to suit the thickness of the metal parts.

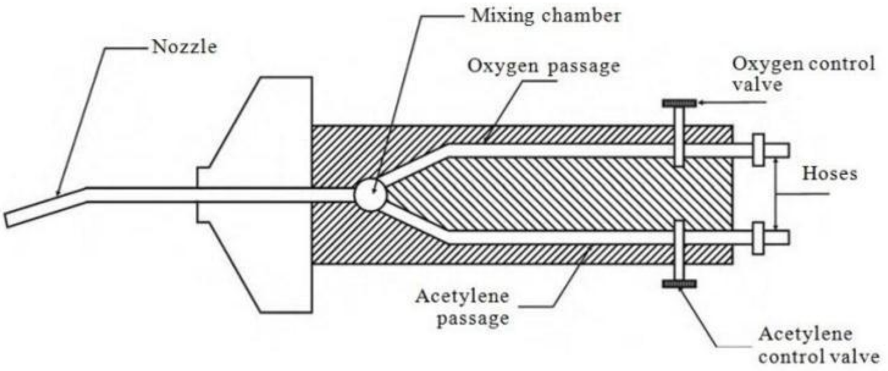


Fig.2.3 Welding Torch

6. Welding Gloves

Protective hand gloves are used by the operator to prevent possible damages that may be caused by high temperatures and metal splashes during welding.

7. Spark Lighter

Spark lighter is used to ignite the oxy-acetylene gas at the tip of the welding torch.

8. Wire Brush

Wire brushes are useful in cleaning the weld before and after the welding process.

Filler Rods Used in Gas Welding

Filler rods used in gas welding supply the additional metal in making joints. These rods are melted by the gas flame and deposited over the parts of the joint. Generally the filler rods are made of the same metal as that of the parts of the joint.

The diameter of the filler rod depends upon the thickness of the parts to be welded. The strength of the welding joint is increased by adding Nickel or Chromium in filler rods. A thin coat of copper is provided on the filler rods to prevent the molten metal from reacting with atmospheric oxygen. Flux may be applied either in powdered form or liquid form.

Advantages of Gas Welding

1. Applied for different classes of work
2. Welding temperature is controlled easily
3. The quantity of filler metal added in the joint can easily be controlled
4. The cost of the welding unit is less
5. The cost of maintenance is less
6. Both welding and cutting can be done

Limitations of Gas Welding

1. Intended for welding thin work pieces only
2. The process of welding is slow
3. The time taken by the gas flame to heat the metal is more when compared with electric arc
4. The strength of the joint is less
5. Great care should be taken in handling and storing gas cylinders

FLAME FORMATION AND ITS DIFFERENT TYPES

Flame is established by burning (controlled) of the two gases mixture at the outlet of blow pipe or torch. The proportion of gasses in the mixture is controlled by controlling the flow rate of each of the two gasses. Here, it should be clear that burning of acetylene generates heat and oxygen only supports acetylene in burning. Insufficient supply of oxygen leaves acetylene un burnt in atmosphere creating pollution and adding cost of waste acetylene. A general nomenclature of the flame established in oxy-acetylene welding is given in Figure 2.5. The flame can be divided in to three zones.

Zone ‗1‘ is very near to the outlet of torch, where oxygen reacts with acetylene and burning of two gases takes place.

Zone ‗2‘ produces carbon monoxide and hydrogen in ratio 2 : 1 by 45 volume. This zone gives the highest temperature of the flame. This zone is supposed to Welding consume the oxygen available here and contribute reducing properly to the flame.

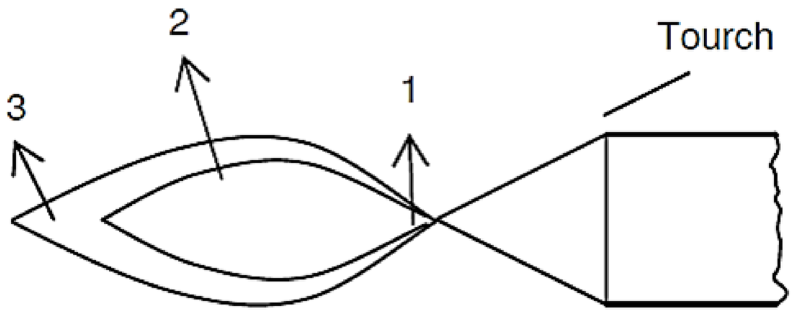


Fig.2.4 Flame establishment in oxy-acetylene welding

Zone ‗3‘ is the outermost zone of the flame. Temperature of this zone is comparatively low. This zone converts CO to CO_2 and H_2O vapours. On the basis of supply proportion of acetylene and oxygen, flames can be divided into three categories, neutral flame, carburizing flame and oxidizing flame. These are described here.

Neutral Flame

A neutral flame is obtained when amount of O_2 equal and C_2H_2 are mixed and burnt at the outlet of welding torch. The flame consists of two sharply defined zones inner white flame cone outer envelope of blue colour as shown in Figure 2.5. In this flame none of two gasses is supplied in excess. This flame is of white cone and has the maximum use for successful welding of many metals.

Carburizing Flame

This flame is obtained when excess of acetylene is supplied than which is theoretically required. This flame is identified by three zones the inner cone which is not sharply defined, an outer envelope as same in case of neutral flamed and middle zone surrounds inner one extended to outer envelope. It is white in colour due to excess acetylene. Larger the excess of acetylene larger will be its length. To get a neutral flame a systematic procedure is to make carburizing flame first and then increase oxygen supply gradually till the excess acetylene zone disappears. The resulting flame wills a carburizing flame. Its temperature generation range is 3100oC to 3300oC. It is used for the welding of metals where risk of oxidation at elevated temperature is more like aluminium, its alloys and lead and its alloys. The metals which have tendency to absorb carbon should not be welded by carburizing flame as they become brittle localized.

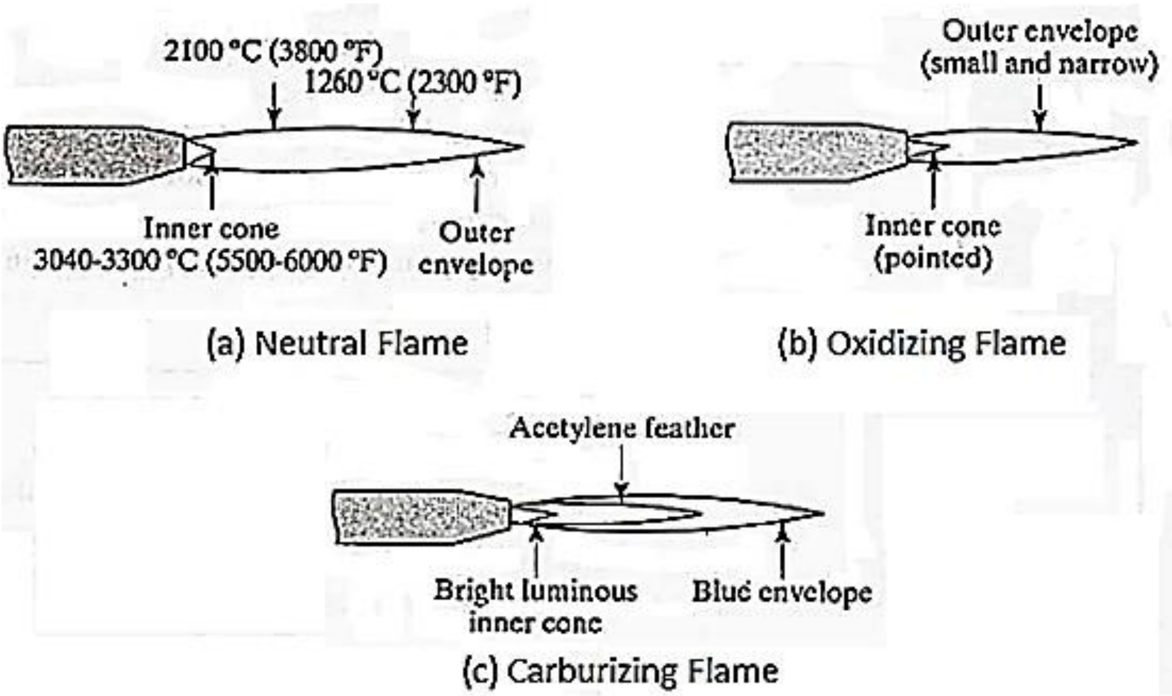


Fig.2.5 Various flame formation in Gas welding

Oxidizing Flame

This flame as an excess of oxygen over that required for a neutral flame. The ratio O_2 : C_2H_2 = 1.15 to 1.50. To have this flame set carburizing flame first convert it to neutral flame and then reduce the supply of acetylene to get oxidizing flame. Its inner cone is relatively shorter and excess oxygen turns the flame to light blue colour. It burns with a harsh sound. It is used for metals which are not oxidized readily like brasses and bronzes.

COMPARISON OF ARC WELDING AND GAS WELDING

Sl.No.	Arc welding	Gas welding
1	Electric arc is the source of heat.	Gas is the source of heat.
2	The arc temperature is about 4000 .	The gas temperature is about 3200 .
3	Filler rod functions as electrodes.	Filler rod is introduced separately.
4	Risk due to electric shock.	Risk due to gas pressure.
5	Arc welded joints have very high strength.	Gas welded joints have not much strength.
6	Brazing and soldering cannot be done using electric arc.	Brazing and soldering are done using gas.
7	Filler metal should be same as or an alloy of parent metal.	Filler metal need not be same as the parent metal.
8	This is a non-pressure fusion welding method.	This is also a non-pressure fusion welding method.
9	The filler rod metal should be selected as the same metal as that of the parts of the joint.	The filler rod metal can be different from that of the parts of the joint.

GAS TUNGSTEN ARC WELDING

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non consumable tungsten electrode and work piece. The tungsten electrode and the weld pool are shielded by an inert gas normally argon and helium. Figures 2.6 show the principle of tungsten inert gas welding process.

The tungsten arc process is being employed widely for the precision joining of critical components which require controlled heat input. The small intense heat source provided by the tungsten arc is ideally suited to the controlled melting of the material. Since the electrode is not consumed during the process, welding without filler material can be done without the need for continual compromise between the heat input from the arc and the melting of the filler metal. As the filler metal, when required, can be added directly to the weld pool from a separate wire feed system or manually, all aspects of the process can be precisely and independently controlled i.e. the degree of melting of the parent metal is determined by the welding current with respect to the welding speed, whilst the degree of weld bead reinforcement is determined by the rate at which the filler wire is added to the weld pool.

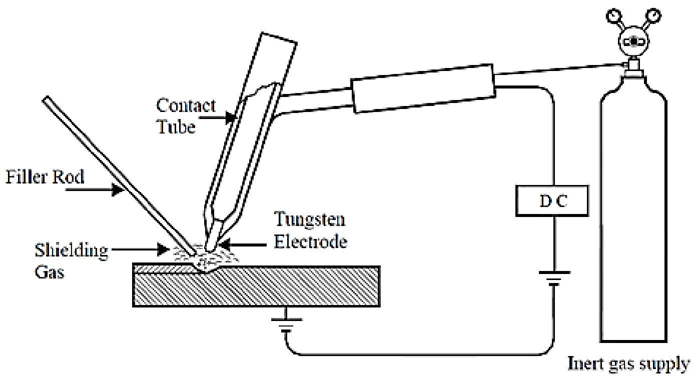


Fig.2.6 Gas Tungsten Arc Welding

In TIG torch the electrode is extended beyond the shielding gas nozzle. The arc is ignited by high voltage, high frequency (HF) pulses, or by touching the electrode to the work piece and withdrawing to initiate the arc at a preset level of current.

Selection of Electrode

D.C.Welding : 1 or 2 % of thoria

Thoria helps to improve electron emission which facilitates easy arc ignition

A.C.Welding : Pure tungsten or tungsten-zirconia

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source. AC is used only in case of welding of aluminum and magnesium and their alloys.

The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current shall flow, damaging the electrode. Open circuit voltage of power source ranges from 60 to 80 V.

Shielding Gases

- Argon
- Argon + Hydrogen
- Argon/Helium

Helium is generally added to increase heat input (increase welding speed or weld penetration). Hydrogen will result in cleaner looking welds and also increase heat input, however, Hydrogen may promote porosity or hydrogen cracking.

Argon or helium may be used successfully for most applications, with the possible exception of the welding of extremely thin material for which argon is essential. Argon generally provides an arc which operates more smoothly and quietly, is handled more easily and is less penetrating than the arc obtained by the use of helium. For these reasons argon is usually preferred for most applications, except where the higher heat and penetration characteristic of helium is required for welding metals of high heat conductivity in larger thicknesses. Aluminum and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections.

Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminum, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminum and copper. Helium argon mixtures may be used for low alloy steels, aluminum and copper.

Application

TIG welding can be used in all positions. It is normally used for root pass(es) during welding of thick pipes but is widely being used for welding of thin walled pipes and tubes. This process can be easily mechanised i.e. movement of torch and feeding of filler wire, so it can be used for precision welding in nuclear, aircraft, chemical, petroleum, automobile and space craft industries. Aircraft frames and its skin, rocket body and engine casing are few examples where TIG welding is very popular.

Benefits

- Superior quality welds
- Welds can be made with or without filler metal
- Precise control of welding variables (heat)
- Free of spatter
- Low distortion

Limitations

- Requires greater welder dexterity than MIG or stick welding
- Lower deposition rates
- More costly for welding thick sections

GAS METAL ARC WELDING (MIG WELDING)

This process also known as Shielded Inert Gas Metal Arc (SIGMA) welding, Metal Inert Gas (MIG) welding or Gas Metal Arc Welding (GMAW) uses a shielded arc struck between a bare metal electrode and the work piece. The metal electrode is provided in the form of a wire reel.

This process is based on the principle of developing weld by melting faying surfaces of the base metal using heat produced by a welding arc established between base metal and a consumable electrode. Welding arc and weld pool are well protected by a jet of shielding inactive gas coming out of the nozzle and forming a shroud around the arc and weld. MIG and TIG welding is primarily attributed to the variation in effectiveness of shielding gas to protect the weld pool in case of above two processes. Effectiveness of shielding in two processes is mainly determined by two characteristics of the welding arc namely stability of the welding arc and length of arc besides other welding related parameters such as type of shielding gas, flow rate of shielding gas, distance between nozzle and work-price. Consumption of the electrode during welding slightly decreases the stability of the arc.

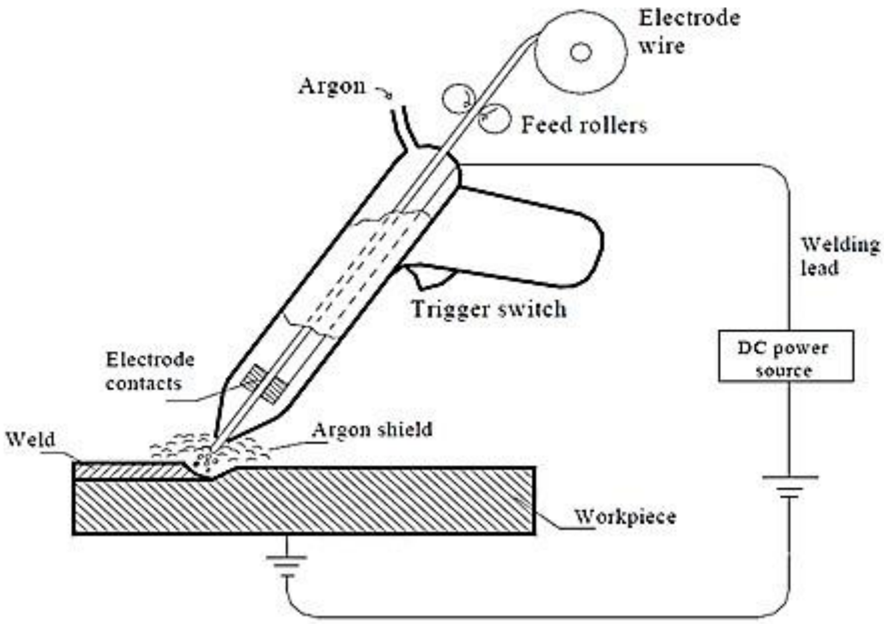


Fig.2.7 Metal Inert Gas (MIG) Welding

Metal inert gas process is similar to TIG welding except that it uses the automatically fed consumable electrode therefore it offers high deposition rate and so it suits for good quality weld joints required for industrial fabrication (Fig. 17.1). Consumable electrode is fed automatically while torch is controlled either manual or automatically. Therefore, this process is found more suitable for welding of comparatively thicker plates of reactive metals (Al, Mg, Stainless steel). The quality of weld joints of these metals otherwise is adversely affected by atmospheric gases at high temperature.

Characteristics of the MIG welding process

- Uses a consumable wire electrode during the welding process that is fed from a spool,
- Provides a uniform weld bead,
- Produces a slag-free weld bead,

- Uses a shielding gas, usually – argon, argon - 1 to 5% oxygen, argon - 3 to 25% CO2 and a combination argon/helium gas,
- Is considered a semi-automatic welding process,
- Allows welding in all positions,
- Requires less operator skill than TIG welding,
- Allows long welds to be made without starts or stops,
- Needs little cleanup.

Shielding Gas

The shielding gas, forms the arc plasma, stabilizes the arc on the metal being welded, shields the arc and molten weld pool, and allows smooth transfer of metal from the weld wire to the molten weld pool.

The primary shielding gasses used are:

- Argon
- Argon - 1 to 5% Oxygen
- Argon - 3 to 25% CO2
- Argon/Helium

CO_2 is also used in its pure form in some MIG welding processes. However, in some applications the presence of CO_2 in the shielding gas may adversely affect the mechanical properties of the weld.

Benefits

- All position capability
- Higher deposition rates than SMAW
- Less operator skill required
- Long welds can be made without starts and stops
- Minimal post weld cleaning is required
- MIG weld is not considered as clean as TIG weld
- The MIG arc is relatively longer and less stable than TIG arc

MIG Welding Problems

- Heavily oxidized weld deposit
- Irregular wire feed

- Burn back
- Porosity
- Unstable arc
- Difficult arc starting

Comparison on TIG welding and MIG welding

Sl.No.	TIG Welding	MIG Welding
1	Suitable to weld any metal.	Suitable to weld on Non-ferrous metal
2	Argon gas is used as primary shielding gas, Helium is Occasionally use.	Argon gas is used as primary shielding gas, Argon mixture with CO_2 is frequently used for dissimilar metal
3	Due to usage of non-consumable electrode, filler material is separately added	Filler metal is act as electrode
4	Difficult in operation	Simple and easy of operation
5	Suitable to operate on A.C. and D.C. supply	It is operate on D.C. supply only

SUBMERGED ARC WELDING

Submerged arc welding (SAW) is an arc welding process that uses a continuous, consumable bare wire electrode. The arc shielding is provided by a cover of granular flux consisting of lime, silica, manganese oxide, calcium fluoride and other compounds. The flux is fed into the weld zone from a hopper by gravity

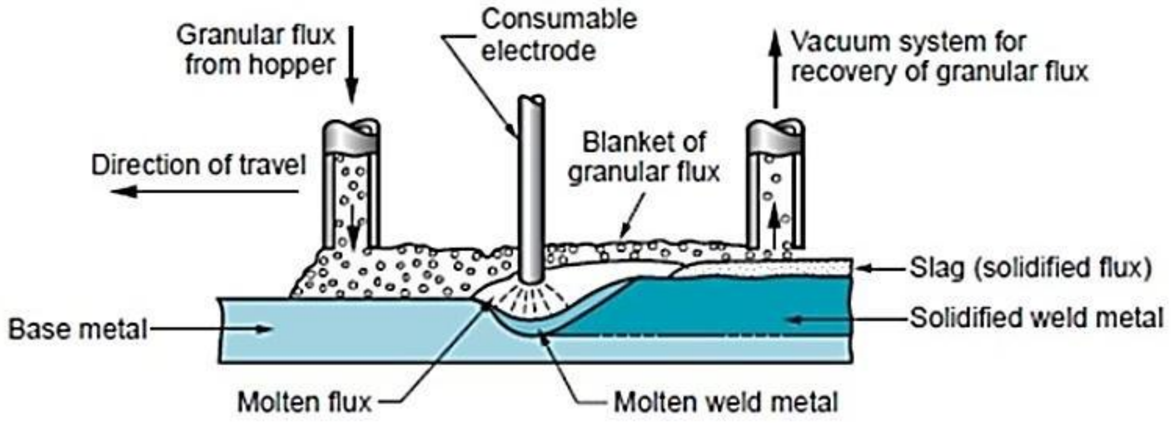


Fig.2.8 Submerged Arc Welding

flow through a nozzle. The thick layer of flux completely covers the molten metal. The electrode wire is fed automatically from a coil into the arc. The flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper, as shown in the figure.

The blanket of granular flux completely submerges the arc welding operation, preventing sparks, spatter and radiation that are so hazardous in other arc welding processes. The portion of the flux closest to the arc is melted, mixing with the molten weld metal to remove impurities and then solidifying on top of the weld joint to form a glasslike slag. The slag and infused flux granules on top provide good protection from the atmosphere and good thermal insulation for the weld area. This result in relatively slow cooling and a high-quality weld joint. The infused flux remaining after welding can be recovered and reused. The solid slag covering the weld must be chipped away usually by manual means. This process is widely used for automated welding of structural shapes, longitudinal and circumferential seams for large-diameter pipes, tanks, and pressure vessels. Because of the gravity feed of the granular flux, the parts must always be in a horizontal orientation.

The consumable electrode is a coil of bare round wire 1.5 to 10 mm in diameter, consumable electrode is fed automatically through a tube. Electric currents typically range from 300 to 2000A. The power supplies usually are connected to standard single-phase or three-phase power lines with a primary rating up to 440V.

Characteristics of submerged-arc welding

- The flux is fed into the weld zone from a hopper by gravity through a nozzle
- Prevents spatter and sparks;
- Suppresses the intense ultraviolet radiation and fumes characteristics of the SMAW.
- It acts as a thermal insulator by promoting deep penetration of heat into the work piece.
- The unused flux can be recovered, treated and reused.

Applications:

The weld made by Submerged-arc welding have high strength and ductility with low Hydrogen and Nitrogen content. It is suitable for welding low alloy steel, high tensile steel, LC and MC steels, high resisting steel, corrosion resistant steel, high strength steel and many of non-ferrous alloys.

Advantages:

- Smooth welds of high strength and ductility with low H2 and N2 content.
- Because of high current, high metal deposition, high welding speeds and good penetration are achieved.
- Due to high speeds less distortion will occur.
- Elimination of fumes and spatter.
- Absence of visible arc and ease of penetration.

Limitations:

- During welding process arc is not visible, judging the welding progress is difficult and so tools like jigs, fixtures and guides are required.
- Pre-placing of flux may not always possible.
- This welding process is limited to flat position.
- Flux is subjected to contamination that may cause weld porosity.
- Chlorine, Aluminium, Magnesium, Lead, Zinc cannot be welded.

ELECTROSLAG WELDING

Electro slag Welding is a welding process, in which the heat is generated by an electric current passing between the consumable electrode (filler metal) and the work piece through a molten slag covering the weld surface.

Prior to welding the gap between the two work pieces is filled with a welding flux. Electroslag Welding is initiated by an arc between the electrode and the work piece (or starting plate). Heat, generated by the arc, melts the fluxing powder and forms molten slag. The slag, having low electric conductivity, is maintained in liquid state due to heat produced by the electric current.

The slag reaches a temperature of about 3500°F (1930°C). This temperature is sufficient for melting the consumable electrode and work piece edges. Metal droplets fall to the weld pool and join the work pieces. The weld pool is contained within this space and—due to contact with the copper blocks—it cools, solidifies, and is shaped. Electro-Slag welds are started and finished on run-off plates. This is known as starting or finishing tabs—they improve the quality of the weld metal.

Circumferential seams can be welded by the electro-slag process, using special devices to overcome the difficulty of joining the start and finish of a weld. The bead on the reverse side can be moulded by a water-cooled copper chill-ring, a permanent steel-ring, or a travelling shoe. Pieces of variable cross-sections can be electro-slag welded using consumable electrode guides.

An A.C. or D.C. power source in the range 300-800 amps is suitable, as used for automatic and MMA processes.

Electroslag welding is capable of welding plates with thicknesses ranging from 50 mm to more than 900 mm and welding is done in one pass. The current required is about 600 A at 40 to 50 Volts although higher currents are used for thick plates. The travel speed of the weld is in the range from 12 to 36 mm/min. Weld quality is high. This process is used for large structural-steel sections, such as heavy machinery, bridges, ships and nuclear-reactor vessels.

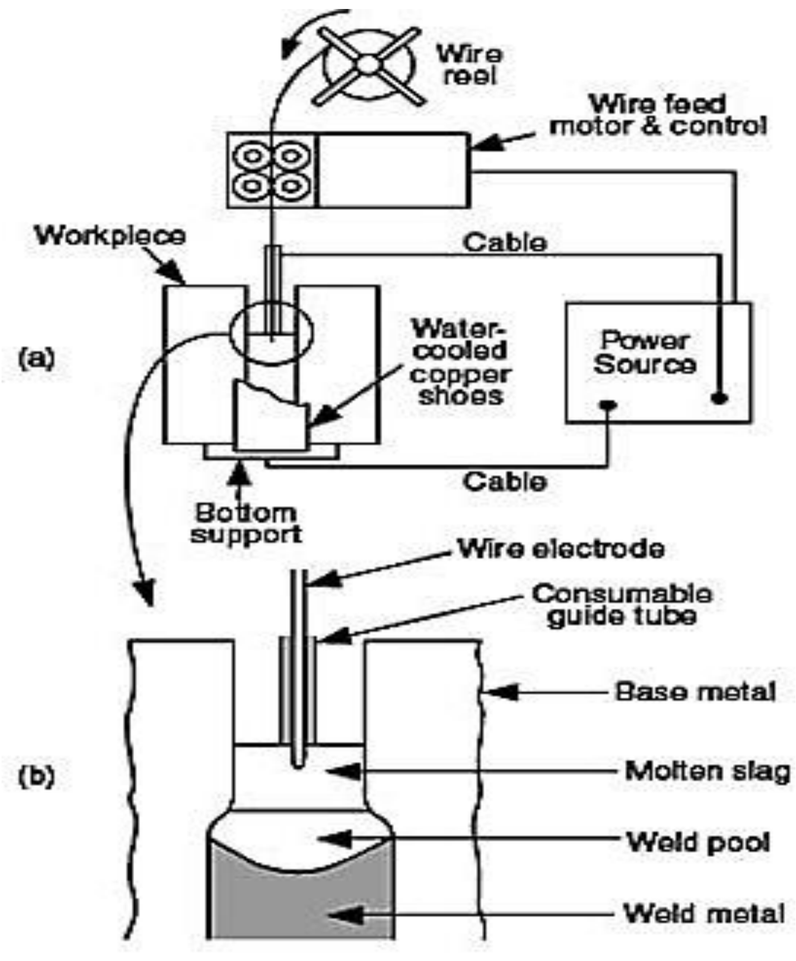


Fig.2.9 Electroslag welding

Advantages:

- High deposition rate - up to 20 kg/h
- Low slag consumption (about 5% of the deposited metal weight);
- Low distortion;
- Unlimited thickness of work piece.

Disadvantages

- Coarse grain structure of the weld;
- Low toughness of the weld;
- Only vertical position is possible.

RESISTANCE WELDING

Resistance Welding is a welding process in which work pieces are welded due to a combination of a pressure applied to them and a localized heat generated by a high electric current flowing through the contact area of the weld.

Different metals and alloys such as low carbon steels, aluminium alloys, alloy steels, medium carbon and high carbon steels can be welded by resistance welding. However, for high carbon contained steels, the weld bed can be harder (less brittle).

Resistance Welding (RW) is used for joining vehicle body parts, fuel tanks, and domestic radiators, pipes of gas oil and water pipelines, wire ends, turbine blades, railway tracks.

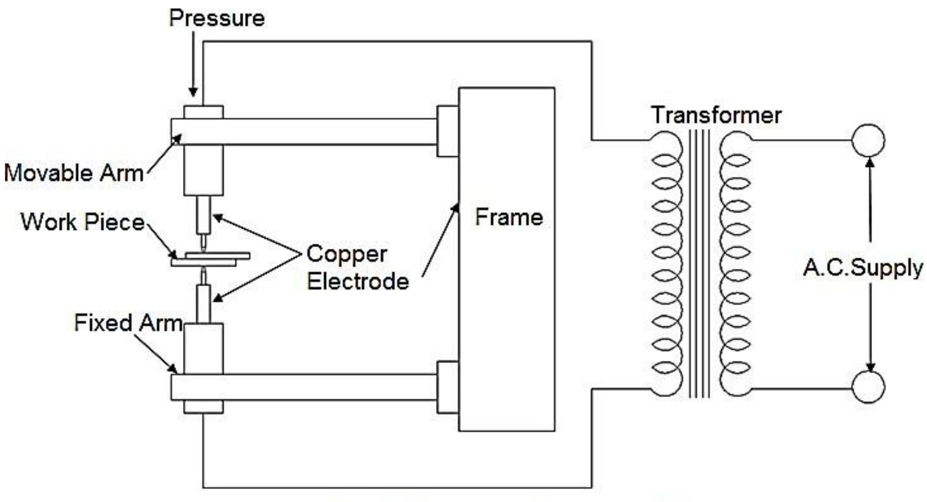


Fig. 2.10 : Resistance welding

Required heat is generated at the junction due to flowing current through it and resistance offered. The amount of heat generated is

Principle of resistance welding can be explained with the help of diagram shown in Figure. It consists of work piece to be welded, two opposing electrodes a mechanism to apply pressure to squeeze the work pieces, AC power supply to maintain the current, and a circuit breaker with times to stop the flowing current after a preset time.

Heat produced by the current is sufficient for local melting of the work piece at the contact point and formation of small weld pool (‖nugget‖). The molten metal is then solidifies under a pressure and joins the pieces.

Advantages:

- High welding rates;
- Low fumes;
- Cost effectiveness;
- Easy automation;
- No filler materials are required;
- Low distortions.

Disadvantages:

- High equipment cost;

- Low strength of discontinuous welds;
- Thickness of welded sheets is limited - up to 6 mm

TYPES OF RESISTANCE WELDING

- Butt welding
- Spot welding
- Seam welding
- Projection welding
- Percussion
- Stud welding

BUTT WELDING

Resistance butt welding is the simplest form of a group of resistance welding processes that involve the joining of two or more metal parts together in a localised area by the application of heat and pressure. The heat is generated within the material being joined by resistance to the passage of a high current through the metal parts, which are held under a pre-set pressure.

The process is used predominantly to make butt joints in wires and rods up to about 16mm diameter, including small diameter chain. The faces of the pieces to be joined may be flat and parallel or profiled in the case of larger sections. This reduces the initial contact area and further concentrates the heating at the interface. The components are clamped in opposing copper dies, with a small amount of stick-out, and abutted under pressure. Current is passed between the dies causing resistance heating of the weld area. The heat generated during welding depends on the current, the duration of the current, and the resistance. As the resistance is highest at the joint interface, heating is most intense in this area. When the material softens, it deforms under the applied load, giving a solid phase forge weld. No melting occurs. The current is terminated once a pre-set upset length has occurred, or the duration of the current is pre-set.

The joint is then allowed to cool slightly under pressure, before the clamps are opened to release the welded component. The weld upset may be left in place or removed, by shearing while still hot or by grinding, depending on the requirements.

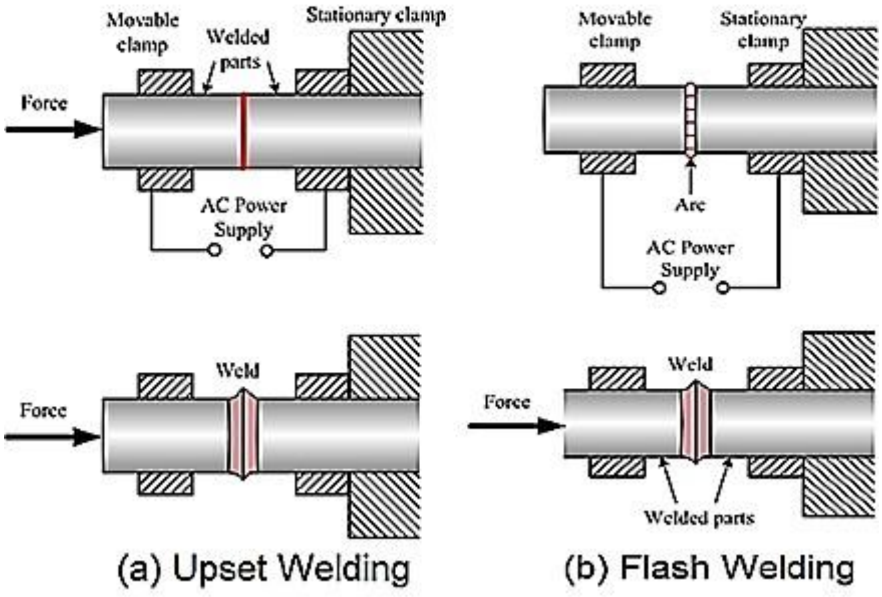


Fig. 2.11 : Butt Welding

Benefits

- Resistance butt welding is a high speed,
- It is clean process
- It is preferred to flash welding for many small components.

Drawbacks

There are some limitations on component size and geometry:

- Very thin or large sections are unsuitable.
- The risk of crushing fingers or hands
- Burns or eye damage from splash metal.

SPOT WELDING

Spot welding is one of the oldest welding processes. It can be used on very thin foils or thick sections but is rarely used above about 6mm thickness. It is used in a wide range of industries but notably for the assembly of sheet steel vehicle bodies. High quality welds can also be made in stainless steels, nickel alloys, aluminium alloys and titanium for aerospace application.

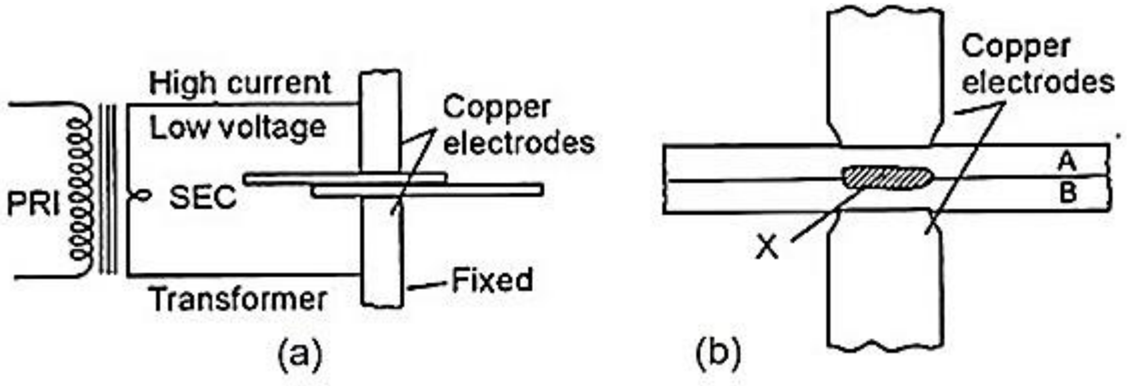


Fig. 2.12 : Spot Welding

Spot welding is one of a group of resistance welding processes that involve the joining of two or more metal parts together in a localised area by the application of heat and pressure. The heat is generated within the material being joined by the resistance to the passage of a high current through the metal parts, which are held under a pre-set pressure.

The process is used for joining sheet materials and uses shaped copper alloy electrodes to apply pressure and convey the electrical current through the work pieces. Heat is developed mainly at the interface between two sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget. The molten pool is contained by the pressure applied by the electrode tip and the surrounding solid metal.

Benefits

Spot welding offers a number of advantages over other techniques, including high speed, ease of automation and energy efficiency.

Drawbacks:

There are some limitations on material weldability but attention to correct setting up and good process control can solve most production problems. The main hazards are (i) the risk of crushing fingers or hands and (ii) burns or eye damage from splash metal. Little fume is produced but may need attention when welding coated steels or when oils or organic materials are present.

SEAM WELDING

In Resistance Seam Welding (RSEW), the electrodes are two rotating wheels as shown in the figure:

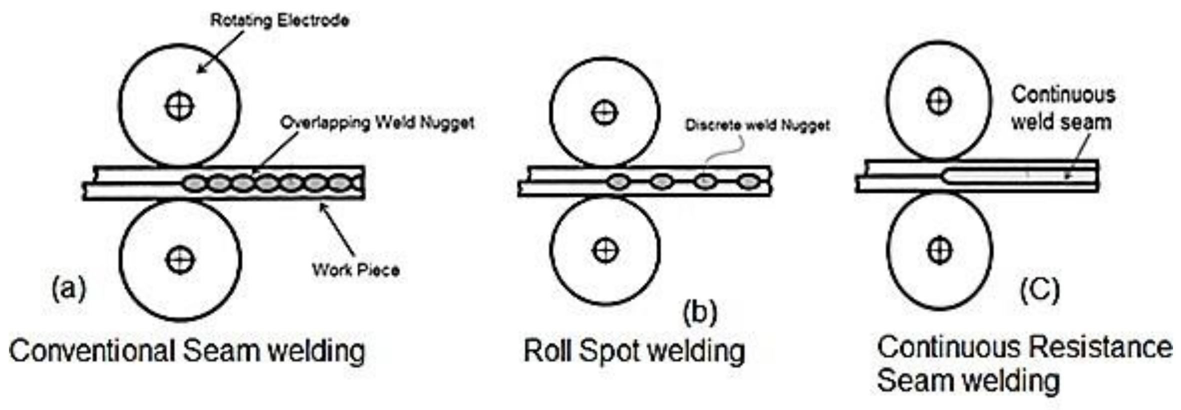


Fig.2.13 : Seam Welding

In the process of welding, a series of overlapping spot welds is made along the lap joint. The process is capable of producing airtight joints, and its industrial applications include the production of gasoline tanks, automobile mufflers, and various others fabricated sheet-metal containers.

The spacing between the weld nuggets in resistance seam welding depends on the motion of the electrode wheels relative to the application of the weld current. In the usual method of operation, called continuous motion welding, the wheel is rotated continuously at a constant velocity, and current is turned on at timing intervals consistent with the desired spacing between spot welds along the seam so that overlapping weld spots are produced. But if the frequency of current switching is reduced sufficiently, there will be spacing between the weld spots, and this method is termed roll spot welding. In another variation, the welding current remains on at a constant level so that a truly continuous welding seam is produced. These variations are depicted in the figure: Since the operation is usually carried out continuously, rather than discretely, the seams should be along a straight or uniformly curved line. Sharp comers and similar discontinuities should be avoided.

Advantages

- Gas tight as well as liquid tight joints can be made.
- The Overlap is less than spot or projection welding.
- The production of single seam weld and parallel seams can be got simultaneously.

Disadvantages

- The welding process is restricted to a straight line or uniformly curved line.
- The metals sheets having thickness more than 3mm can cause problems while welding.
- The design of the electrodes may be needed to change to weld metal sheets having obstructions.

Applications of RSEW

- Girth weld is possible in rectangular or square or even in circular shapes.
- Most of the metals can be welded (Except copper and some high percentage copper alloys)
- Butt welding can be done.

PROJECTION WELDING

In resistance projection welding (RPW), small projections are formed on one or both pieces of the base metal to obtain contact at a point which localize the current flow and concentrate the heat. Under pressure, the heated and softened projections collapse and a weld is formed. Projection on the upper component is pressed against the lower component by electrode force. The projection collapses and a fused weld nugget are formed with the application of current. This technique is of special value in mounting attachments to surfaces of which the back side is inaccessible to a welding operator.

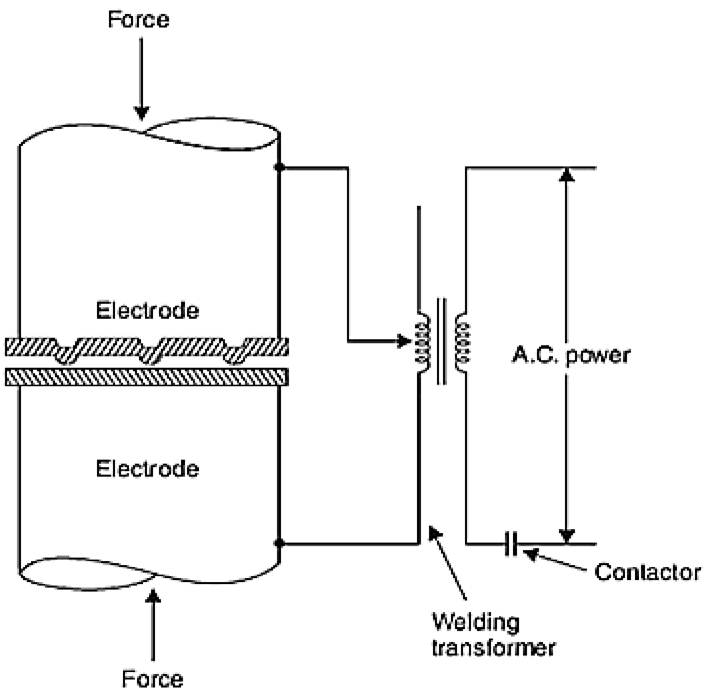


Fig.2.14 Projection Welding

Types of Projection Designs

There are typically three types of projection designs which are used for projection welding:

1) Embossed Projections
2) Stud-to-Plate Projections
3) Annular Projections

Advantages

- Simultaneous operation can be done i.e. more than one welds can be made.
- Projection welding has this advantage that it can weld metals of thickness which is not suitable for spot welding.

- Projection welding electrodes have a longer life when compared to spot welding electrodes.
- Resistance projection welding is not limited to sheet to sheet joints.
- Projection welding can be done in specific points which are desired to be welded.
- In difficult welding work projection welding gives a better heat balance.
- Projection welding saves electricity because it needs less current to produce heat. So it reduces the shrinkage and distortion defects.

Disadvantages

- All types of metals cannot be welded using projection method. Metal thickness and composition is a big question.
- All the metals are not strong enough to support the projections. Some brasses and coppers cannot be welded satisfactorily using projection welding.
- There is an extra operation which is called forming of projection.
- Projections need to have same heights for a appropriate welding.

Applications

- Resistance Projection welding is used in Automobile sector.
- Projection welding is used in refrigeration works (mass production of condensers, gratings, racks etc.)

PERCUSSION WELDING

Percussion welding is a variation or version of resistance welding, which is characterized by extremely short welding times and high welding currents. During this procedure, a joint is produced by a rapidly ignited arc and by the force which is generated by an electromagnet. Since only one 50 Hz half wave is used for the actual welding process, the welding time is always in the range of about 10 milliseconds. The weld current can reach values of about 100 kA.

The short welding time and the high welding current allow the combination of materials with high electrical and thermal conductivity. Also, large cross-section and thickness differences in the work pieces to be welded are no problem.

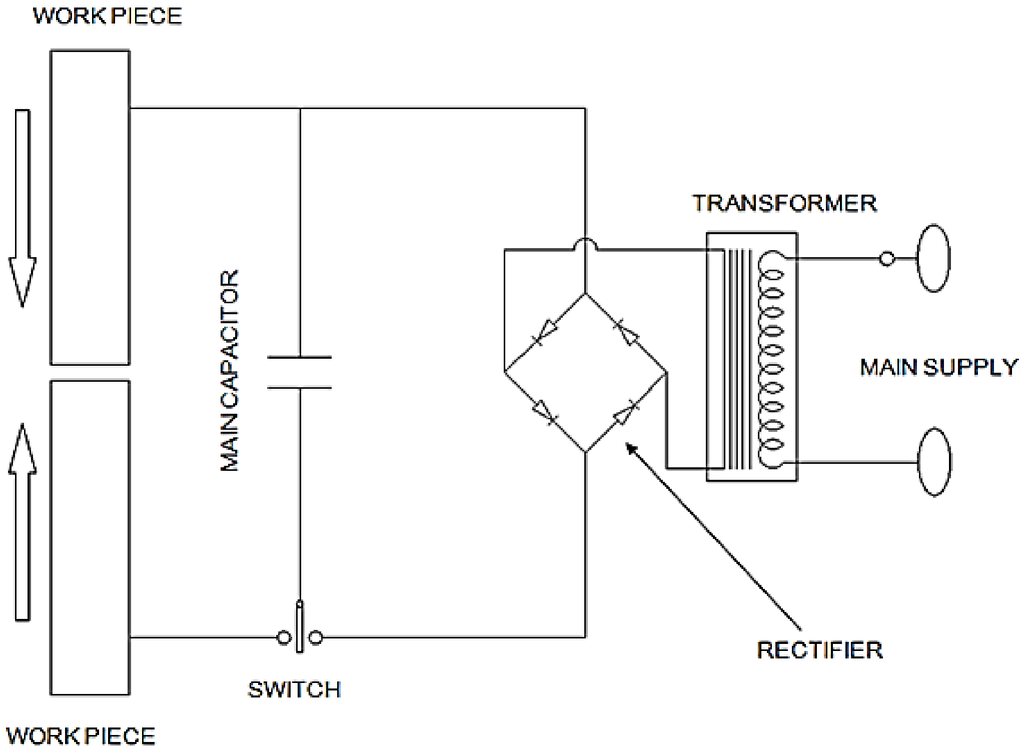


Fig.2.15 : Percussion welding

Process steps in Percussion Welding

1) The two materials to be welded are positioned with a preset air gap between them
2) A burst of RF energy ionizes the air gap.
3) Capacitor banks discharge, creating an arc that heats the two materials to a weldable temperature.
4) When the materials reach the proper welding state, electromagnetic actuators accelerate them together. The molten masses combine, metal to metal, and are forged together. As the weld cools, a complete alloy bond is formed.

In addition to the materials that can be processed on conventional resistance welding machines, the method is particularly suitable for the following combinations of materials and applications:

- Copper, tungsten, silver, molybdenum, nickel and their alloys
- Work pieces produced by powder metallurgy
- High-melting materials for high-voltage switchgear and control gear as well as power and heavy-duty switching devices

The components frequently used in power and high power switching devices in the field of electrical engineering can be made without the use of solder, flux or other welding and soldering consumables.

The main features of the method are

- The short welding time results in a very narrow heat affected zone
- A joint is created which is free from weld upset and nearly free from spatter
- Since the parts do not distort during the welding process and since there is nearly no material loss, minimum post weld machining or dressing is required, only.

STUD WELDING

Stud welding is an economical, rapid fixing method of metals used both in engineering and construction work in heavy sections. Stud means a protecting know-pin or a large-headed nails which can apply the fixing or fastening method of a variety of shapes and diameters to the parent plate.

The studs may be of circular or rectangular cross-section, plain or threaded (internally or externally) and vary from heavy support pins to clips or attachments used in component assembly.

Types of Stud welding:

(1) Drawn arc; and

(2) Capacitor discharge.

The Drawn arc method is generally used for heavier studs and plates. The Capacitor discharge method is for light gauge sheets. The operation depends upon the size, shape, and material of the stud and the composition and thickness of the metal parts.

Drawn arc process is used in both engineering and heavy construction work. The equipment consists of a D.C. power source controller and a hand-operated gun or holder. The hand-operated gun has an operating solenoid and return-spring within the gun-body which carries the operating adjustment switch. Studs are fluxed on the contact end, which is slightly pointed, and are supplied with ferrules. To operate the equipment, the welding current and time for the diameter of the stud are selected,

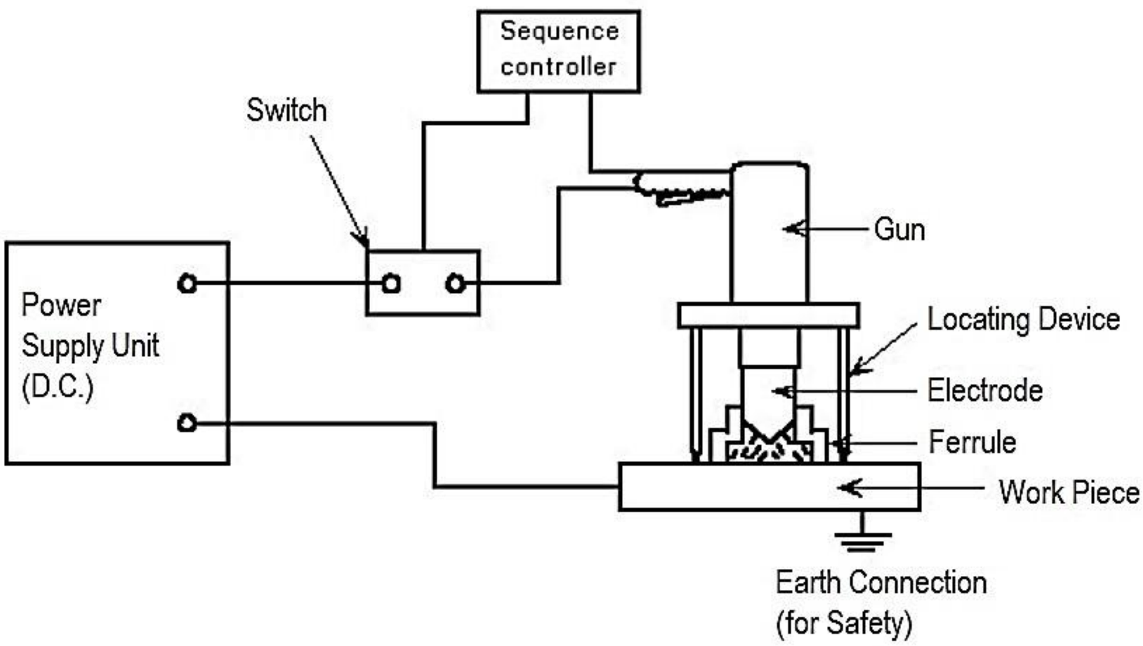


Fig.2.16 : Stude welding process

the stud is loaded into the proper chuck, the legs adjusted for length and the stud positioned on the plate. When the gun switch is pressed a low current flows between the pointed stud end and the work-piece and immediately the stud is raised, drawing an arc and ionizing the gap.

Studs from 3.3-20 mm and above in diameter can be used on the plate thicker than 1.6 mm and above. The rate of welding varies with the type of work, jigging, location, etc. In circular and rectangular cross-section for engineering and construction industries the weld can be made in mild steel, austenitic stainless steel, aluminium, and its alloys, etc.

In the capacitor process, a small projection on the end of the stud makes contact with the work-piece and the energy from a bank of charged capacitors is discharged across the contact. This melts the stud projection and produces a molten end of the stud and a shallow molten pool in the base metal. This completes the work-piece under controlled spring pressure.

Advantages:

- Fast attachment.
- No reverse marking.
- The welded joint is stronger than the parent material or the stud.
- Access is only required from one side.
- No holes hence no leaking or weakening of the sheet.
- Tamper proof.
- Pre-coated or painted material can be welded

Disadvantages

- It lacks the near-instant speed that the CD stud welding process offers. This factor could serve as a drawback for arc stud welding, resulting in a slight effect on productivity in certain fast-paced projects.
- Arc stud welds aren‘t ideal for use on thin metals,
- The amount of heat and current could leave behind discoloration on thinner work pieces.
- It is not suitable for smaller length of fasteners

PLASMA ARC WELDING (PAW)

It is a fusion welding process wherein the coalescence is produced by heating the work with a constricted arc established between a non-consumable tungsten electrode and work piece or between a non-consumable electrode and constricted nozzle. The shielding of the weld pool is obtained by the hot ionized gas produced by passing inert gas through the arc and constricted nozzle. Filler material may or may not be applied.

Principles of Operation:

In the PAW process, the work piece is cleaned and edges are prepared. An arc is established between a non-consumable tungsten electrode and work piece or between a non-consumable electrode and constricted nozzle. An inert gas is passed through the inner orifice surrounding the tungsten electrode and subsequently the gas is ionized and conducts electricity. This state of ionized gas is known as plasma. The plasma arc is allowed to pass through the constricted nozzle causing high energy and current density. Subsequently high concentrate heat and very high temperatures are reached. The low flow rate (0.25 to 5 l/min) of the orifice gas is maintained as excessive flow rate may cause turbulence in the weld pool. However the orifice gas at this flow rate is insufficient to shield the weld pool effectively. Therefore inert gas at higher flow rate (10- 30 l/min) is required to pass through outer gas nozzle surrounding the inner gas nozzle to protect the weld pool. A typical manual torch used in PAW is as shown in Fig. 4.5.2.

Plasma arc welding is of two types:

1) Non-transferred plasma arc welding process and
2) Transferred arc welding process.

In the former, the arc is established between the electrode and the nozzle and in the latter process the arc is established between the electrode and the work piece. The differences between these two processes are presented in the Table 2.1.

Operation:

In this process, arc cannot be initiated by touching the work piece as electrode is recessed in the inner constricted nozzle. Therefore, a low current pilot arc established in the constricted inner nozzle ad electrode. The pilot arc is generally initiated by the use of high frequency. AC or high voltage DC pulse superimposed on the main welding current. It cause the ionization of the orifice gas and high temperature which contributes to easy initiation of the main arc between the electrode and the work piece. After the initiation of the main arc, the pilot arc may be extinguished. This is followed by adding the filler material as in TIC welding process. Next, the welding torch is moved manually or automatically in the direction of welding. There are two techniques

1) Key hole technique
2) Non key hole techniques

In the key hole technique, due to constricted arc, high temperature and high gas flow, small weld pool with high penetration (up to 100%) width is obtained, resulting in complete melting of the base material beneath the arc. As the arc move forward, the material is melted and fills the hole produced due to arc force. The power supply and gas flow rate are turned off once the key hole is filled appropriately in the end of welding. The work piece is suitably cleaned after cooling

Table 2.1: Difference between the transferred and non-transferred arc welding processes

Sl.No.	Transferred plasma arc welding	Non-transferred plasma arc welding
1	Arc is established between electrode and Work piece	Arc is established between electrode and nozzle.
2	The work piece is part of the electrical circuit and heat is obtained from the anode spot and the plasma jet. Therefore, higher amount of energy is transferred to work. This is useful for welding.	The work piece is not part of the electrical circuit and heat is obtained from the plasma jet. Therefore, less energy is transferred to work. This is useful in cutting.
3	Higher penetration is obtained, so thicker sheets can be welded.	Less penetration is obtained, so thin sheets can be welded.
4	Higher process efficiency	Less process efficiency.

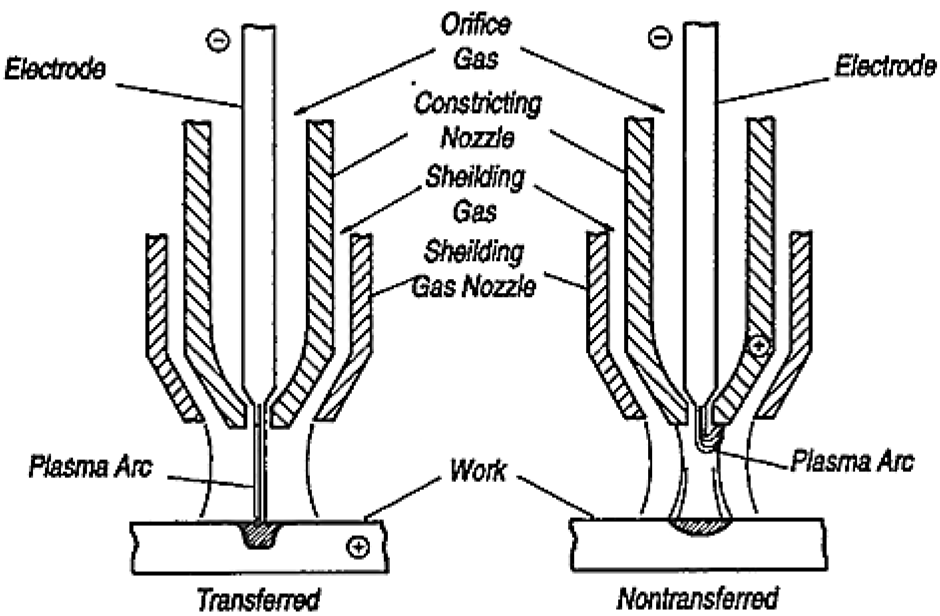


Fig. 2.17 : Plasma Arc welding

Equipment and Consumables:

Power source: A conventional DC current power supply with drooping V-I characteristics is required. Both rectifier or generator type power source may be used; however, rectifier type power source is preferred. The general range of the open-circuit voltage and current is 60-80V and 50-300A respectively.

Plasma torch: It consists of non consumable tungsten electrode, inner nozzle (constricting nozzle) and outer gas nozzle. The torch is water cooled to avoid heating of the nozzle. It is of two types: transferred arc and non transferred arc welding torch.

Filler material and shielding gases: Filler material used in this process is the same as those used in the TIG and MIG welding processes. The selection of the gases depends upon the martial to be welded. The orifice gas must be an inert gas to avoid contamination of the electrode material. Active gas can be used for shielding provided it does not affect the weld quality. In general, the orifice gas is the same as the shielding gas.

Applications of PAW:

This process is comparatively new and hence the potential of the process is yet to be understood/ accepted. This process can be used to join all the materials those can be welded by welding TIG process. Present applications of the process include:

- Piping and tubing of stainless and titanium,
- Submarine, aeronautical industry and jet engine manufacturing,
- Electronic components.

Advantages of PAW:

- Welding speed is higher.
- Penetration is more.
- Higher arc stability.
- The distance between torch and work piece does not affect heat concentration on the work up to some extent.

- Addition of filler material is easier than that of TIG welding process.
- Thicker job can be welded.
- Higher depth to width ratio is obtained resulting in less distortion.

Disadvantages of PAW:

- Higher radiations.
- Noise during welding.
- Process is complicated and requires skilled manpower.
- Gas consumption is high.
- Higher equipment and running cost.
- Higher open circuit voltage requiring higher safety measures to take.

ELECTRON-BEAM WELDING

Electron Beam Welding (EBW) is a fusion welding in which coalescence is produced by heating the work piece due to impingement of the concentrated electron beam of high kinetic energy on the work piece. As the electron beam impinges the work piece, kinetic energy of the electron beams converts into thermal energy resulting in melting and even evaporation of the work material.

Principles:

In general, electron beam welding process is carried out in vacuum. In this process, electrons are emitted from the heated filament called electrode. These electrons are accelerated by applying high potential difference (30 kV to 175 kV) between cathode and anode. The higher the potential difference, the higher would be the acceleration of the electrons. The electrons get the speed in the range of 50,000 to 200,000 km/s. The electron beam is focused by means of electromagnetic lenses. When this high kinetic energy electron beam strikes on the work piece, high heat is generated on the work piece resulting in melting of the work material. Molten metal fills into the gap between parts to be joined and subsequently it gets solidified and forms the weld joint.

Equipment:

An Electron Beam Welding set up consists of the following major equipment:

1) Electron gun,
2) Power supply,
3) Vacuum Chamber, and
4) Work piece handling device

Electron Gun: An electron gun generates, accelerates and aligns the electron beam in required direction and spots on the work piece. The gun is of two types:

(1) Self-accelerated
(2) Work accelerated.

The work accelerated gun accelerates the electron by providing potential difference between the work piece and cathode. In the self-accelerate gun, electrons are accelerated by applying potential difference between the cathode and the anode. The anode and cathode are enclosed within the gun itself. The control of electron density is better in this type of electron gun. A schematic diagram of an Electron Beam Welding is shown in figure. The major parts of a gun are briefly introduced in the following section.

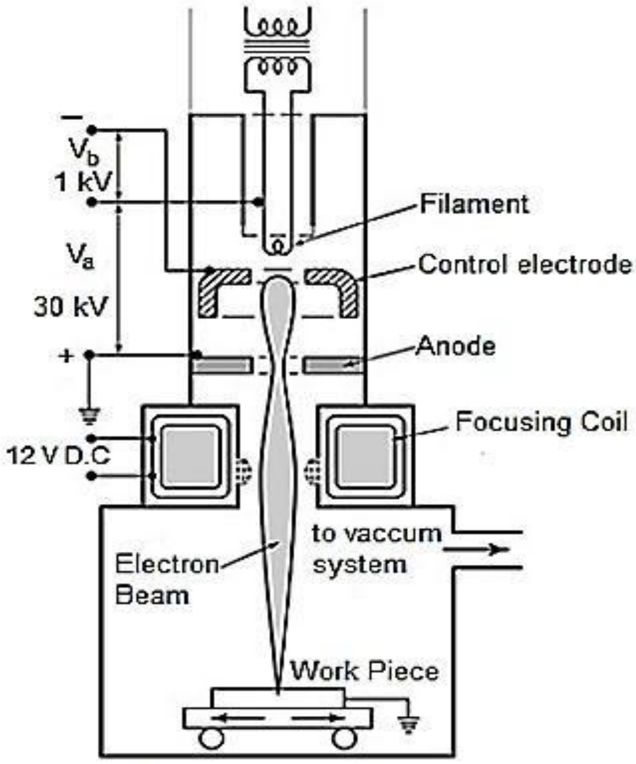


Fig. 2.18 : Electron Beam welding

Emitter / Filament:

It generates the electron on direct or indirect heating.

Anode:

It is a positively charged element near cathode, across which the high voltage is applied to accelerate the electrons. The potential difference for high voltage equipment ranges from 70-150 kV and for low voltage equipment from 15-30kV.

Grid cup:

Grid cup is a part of triode type electron gun. A negative voltage with respect to cathode is applied to the grid. The grid controls the beam.

Focusing unit:

It has two parts: Electron focusing lens and deflection coil. Electron focusing lens focuses the beam into work area. The focusing of the electrons can be carried out by deflection of beams. The electromagnetic lens contains a coil encased in iron. As the electrons enter into the magnetic field, the electron beam path is rotated and refracted into a convergent beam. The extent of spread of the beam can be controlled by controlling the amount of DC voltage applied across the deflection plates.

Electron gun power supply:

It consists of mainly the high voltage DC power supply source, emitter power supply source, electromagnetic lens and deflection coil source. In the high voltage DC power supply source the required load varies within 3-100 kW. It provides power supply for acceleration of the electrons. The current level ranges from 50-1000 mA.

In emitter power supply, AC or DC current is required to heat the filament for emission of electrons. However DC current is preferred as it affects the direction of the beam. The amount of current depends upon the diameter and type of the filament. The current and voltage varies from 25-70 A and 5-30 V respectively. The power to the electromagnetic lens and deflection coil is supplied through a solid state device.

Vacuum Chamber:

In the vacuum chamber pressure is reduced by the vacuum pump. It consists of a roughing mechanical pump and a diffusion pump. The pressure ranges from 100 kPa for open atmosphere to 0.13-13 Pa for partial vacuum and 0.13-133 mPa for hard vacuum. As the extent of vacuum increases, the scattering of the electrons in the beam increases. It causes the increase in penetration.

Work Piece Handling Device:

Quality and precision of the weld profile depends upon the accuracy of the movement of work piece. There is also provision for the movement of the work piece to control the welding speed. The movements of the work piece are easily adaptable to computer numerical control.

Advantages of EBW:

- High penetration to width can be obtained, which is difficult with other welding processes.
- High welding speed is obtained.
- Material of high melting temperature can be welded.
- Superior weld quality due to welding in vacuum.
- High precision of the welding is obtained.
- Distortion is less due to less heat affected zone.
- Dissimilar materials can be welded.
- Low operating cost.
- Cleaning cost is negligible.
- Reactive materials like beryllium, titanium etc. can be welded.
- Materials of high melting point like columbium, tungsten etc. can be welded.

- Inaccessible joints can be made.
- Very wide range of sheet thickness can be joined (0.025 mm to 100 mm)

Disadvantages of EBW:

- Very high equipment cost.
- High vacuum is required.
- High safety measures are required.
- Large jobs are difficult to weld.
- Skilled man power is required

Applications of EBW:

a. Electron beam welding process is mostly used in joining of refractive materials like columbium, tungsten, ceramic etc. which are used in missiles.
b. In space shuttle applications wherein reactive materials like beryllium, zirconium, titanium etc. are used.
c. In high precession welding for electronic components, nuclear fuel elements, special alloy jet engine components and pressure vessels for rocket plants.
d. Dissimilar material can be welded like invar with stainless steel.

THERMIT WELDING

The energy in the form of heat is liberated by a chemical reaction the reaction is called ―Exothermic‖ — which is the chemical reaction of Thermit welding.

Thermit is a chemical process welding which was previously termed ―Alumino -Thermit‖ because the chemical mixture was of iron oxide and powdered aluminium. Aluminium is a strong reducing agent—it combines with the oxygen from the iron oxide, reducing it to iron.

The Thermit consists of about five parts of aluminium to eight parts of iron oxide. If this mixture is placed in a fireclay crucible and ignited by means of a special powder, the action starts and continues throughout the mass of the mixture, giving out great heat.

The intense heat that results due to the chemical action not only melts the iron but raises the temperature to about 3,000°C. The high temperature of the iron results in excellent fusion of the parts to be welded. Good steel scrap, or a small percentage of manganese or other alloying elements may be added, thereby producing a good quality Thermit steel.

$$Fe_2O_3 + 2\,Al \longrightarrow 2\,Fe + Al_2O_3$$

$$3Cu_2O + 2\,Al \longrightarrow 6\,Cu + Al_2O_3$$

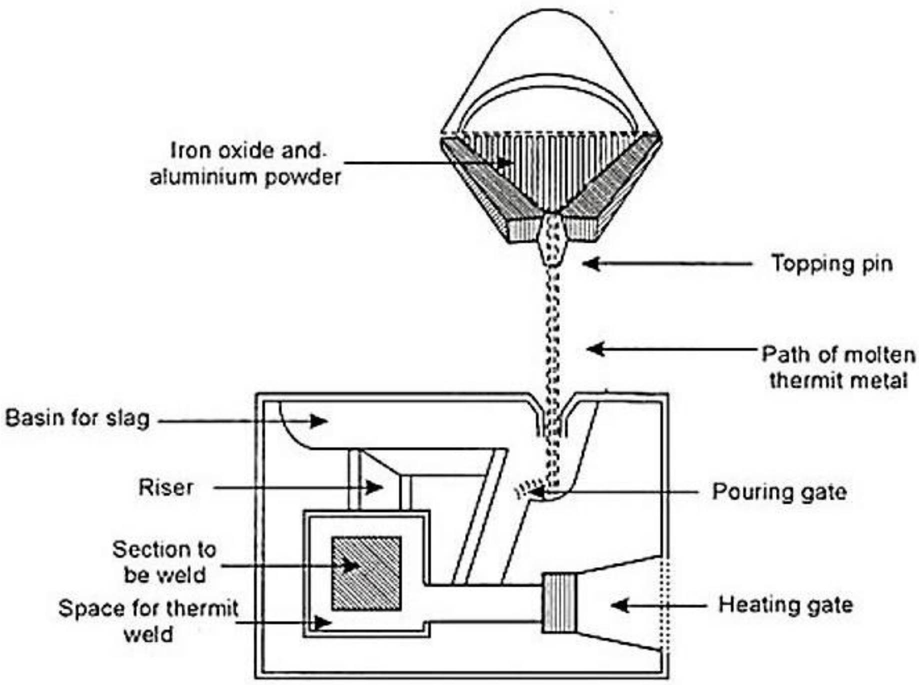


Fig.2.19 : Thermit welding process

Preparation of the Weld:

1. The edges of the work piece are cut flat and cleaned to remove dirt, grease and other impurities to obtain a sound weld. A gap of about 1.5-6mm is left between the edges of the two work pieces.

2. A wax heated to its plastic state is poured in the gap between the work pieces to be joined and allowed to solidify. Excess wax solidified around the joint is removed.
3. A mould box is placed around the joint and packed with sand providing necessary gates and risers. A hole or heating gate is made in the mould connecting to the joint.
4. The wax material is melted out by means of flame directed into the heating gate, so that it leaves a cavity at the joint which will later be occupied by the molten metal. The heating gate is then closed with a sand core or iron plug.
5. Exothermic reaction occurs to form molten iron and slag which floats at the top. The temperature resulting from this reaction is approximately 3000°C. The plug at the bottom of the crucible is opened and the molten metal is poured into the cavity. The molten metal acts as a filler metal, melts the edges of the joint and fuses to form a weld.
6. After the weld joint cools and solidifies, the mould is broken, risers are cut and the joint is finished by machining and grinding.

   Fig. 2.11 illustrates the weld process.

Types of Thermit welding

1. Wabbler Thermit
2. Plain Thermit
3. Cast iron Thermit
4. Forging Thermit

Wabbler Thermit

Wabbler thermit which is particularly alloyed to make a solid, wear resistant, Machinable Steel use for produce rolls and pinions within rolling mills.

Plain Thermit

Plain Thermit is a combination of Aluminium with Iron Oxide and is the base for every other Thermits

Cast Iron Thermit:

Beside by Ferro-Silicon, Plain Thermit with Mild Steel are add as a combination and is use for welding iron works

Forging Thermit

Beside by Nickel, Manganese, Plain Thermit with mild steel are other as a mixture and is use for welding iron works.

Advantages:

- Intended for finish welding of strengthens bars to be use in concrete construction.
- For welding new necks to rolling mill rolls with pinions.
- Used for welding large broken crankshafts
- Used for building up damaged wobblers
- For welding busted frames of machines
- For restore broken teeth on big gears

Disadvantages:

- Low deposition rate with operating factor
- Its cannot weld low melting point
- It has slag inclusion
- It is high skill factor
- Extremely high level of fumes

Application:

The process is especially useful in welding together large-sections such as locomotive frames, stem posts of ship and rudders, railway lines, and tramlines.

FRICTION WELDING

Friction Welding (FRW) is a solid state welding process which produces welds due to the compressive force contact of work pieces which are either rotating or moving relative to one another. Heat is produced due to the friction which displaces material plastically from the faying surfaces. The basic steps explaining the friction welding process are shown in Fig.4.4.1. In friction welding the heat required to produce the joint is generated by friction heating at the interface. The components to be joined are first prepared to have smooth, square cut surfaces. One piece is held stationary while the other is mounted in a motor driven chuck or collet and rotated against it at high speed. A low contact pressure may be applied initially to permit cleaning of the surfaces by a burnishing action. This pressure is then increased and contacting friction quickly generates enough heat to raise the abutting surfaces to the welding temperature.

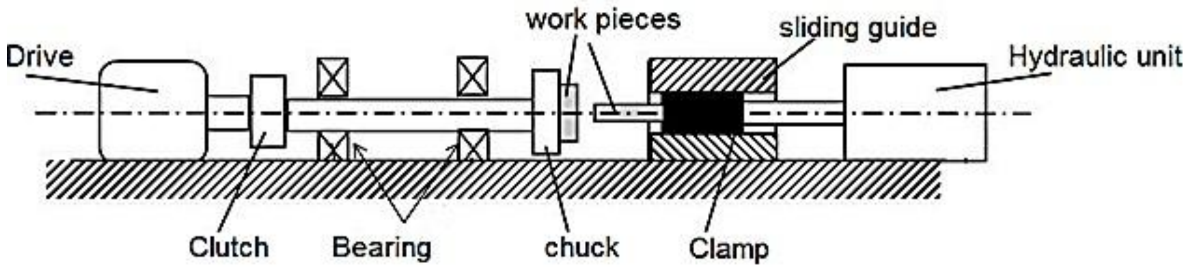


Fig.2.20 : Friction Welding

As soon as this temperature is reached, rotation is stopped and the pressure is maintained or increased to complete the weld. The softened material is squeezed out to form a flash. A forged structure is formed in the joint. If desired, the flash can be removed by subsequent machining action. Friction welding has been used to join steel bars upto 100 mms in diameter and tubes with outer diameter up to 100 mm. Inertia welding is a modified form of friction welding, where the moving piece is attached to a rotating flywheel. The flywheel is brought to a specified rotational speed and is then separated from the driving motor. The rotating assembly is then pressed against the stationary member and the kinetic energy of the flywheel is converted in to frictional heat. The weld is formed, when the flywheel stop its motion and the pieces remain pressed together. Since the conditions of the inertia welding are easily duplicated, welds of consistent quality can be produce and the process can be easily automated. The heat affected zones are usually narrow, since the time period is very short for heating and cooling. The radial and orbital FRW are shown in figure.

Advantages

1. No filler metal, flux or shielded gases are needed
2. is an environment-friendly process with generation of smoke, fumes or gases.
3. No material is melted so the process is in solid state with narrow HAZ
4. Oxides can be removed after the welding process.
5. The process is very efficient and comparatively very rapid welds are made.
6. The weld is strength is stronger than the weaker of the two materials being joined

Disadvantages

1. The process is restricted to joining round bars or tubes of same diameter
2. Dry bearing and non-forgeable materials cannot be welded. (i.e. one of the material must be ductile)
3. Preparation and alignment of the work piece may be critical for developing uniform rubbing and heating
4. Equipment and tooling cost are high
5. Free machining alloys are difficult to weld.

Application

- Tongs hold to critical aircraft engine components
- Automotive parts like engine valve and shock absorber
- Hydraulic piston rod and track roller in agricultural equipment.
- Friction welded assemblies are often used to replace expensive casting and forgings

FRICTION STIR WELDING

Friction-stir welding (FSW) is a solid-state joining process (the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the joint, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool), much like joining clay, or dough. It is primarily used on aluminium, and most often on extruded aluminium (non-heat treatable alloys), and on structures which need superior weld strength without a post weld heat treatment.

A constantly rotated non-consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface.

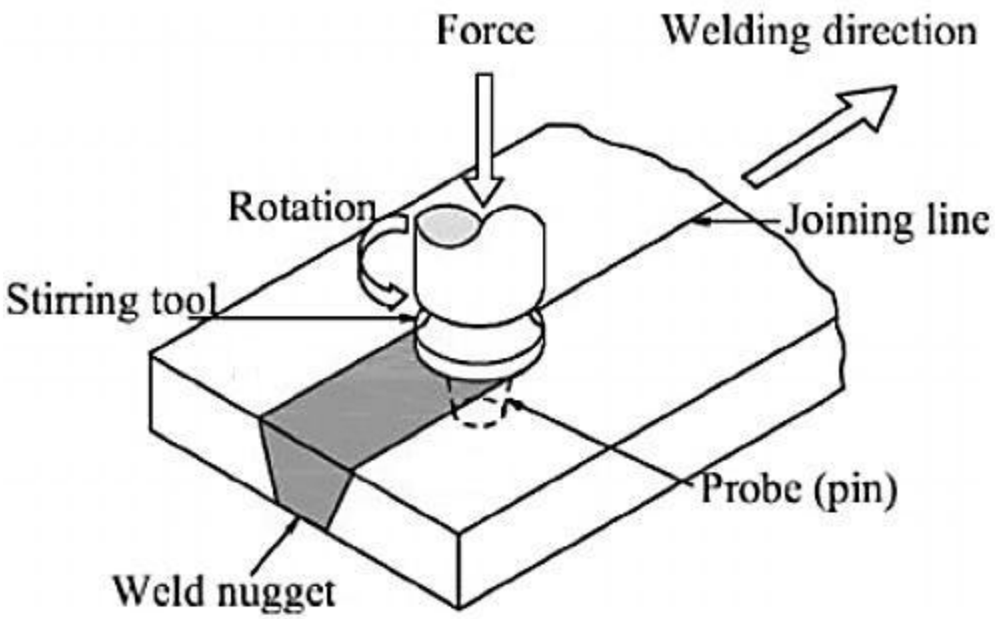


Fig. 2.21 Friction stir welding

Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld.

This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material.

Advantages:

- Good mechanical properties in the as-welded condition
- Improved safety due to the absence of toxic fumes or the spatter of molten material.
- No consumables — no filler or gas shield is required for aluminium.
- Easily automated on simple milling machines — lower setup costs and less training.
- Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
- Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
- Can use thinner materials with same joint strength.
- Low environmental impact.
- General performance and cost benefits from switching from fusion to friction.

Disadvantage

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.

BRAZING

The filler material cools down and solidifies forming a strong metallurgical joint, which is usually stronger than the parent (work piece) materials. The parent materials are not fused in the process.

Brazing is similar to Soldering. The difference is in the melting point of the filler alloy: brazing filler materials melt at temperatures above 840°F (450°C); soldering filler materials (solders) melt at temperatures below this point.

The difference between brazing and welding processes is more sufficient: in the welding processes edges of the work pieces are either fused (with or without a filler metal) or pressed to each other without any filler material; brazing joins two parts without melting them but through a fused filler metal.

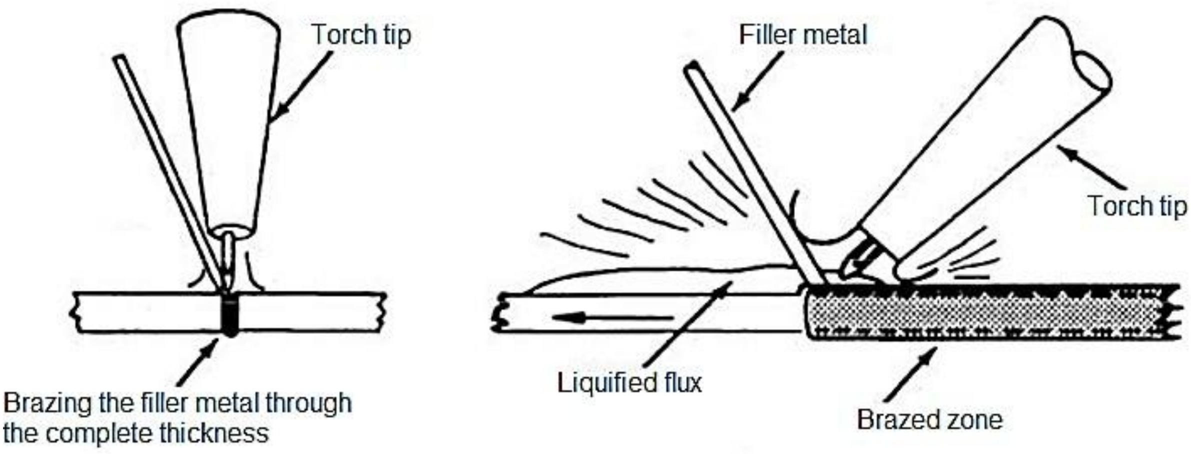


Fig.2.22 Brazing Process

Surface Cleaning and Brazing Fluxes

- Capillary effect is achieved by both: a proper Surface preparation and use of a flux for wetting and cleaning the surfaces to be bonded.
- Contaminants to be removed from the part surface are: mineral oils, miscellaneous organic soils, polishing and buffing compounds, miscellaneous solid particles, oxides, scale, smut, rust.
- The work pieces are cleaned by means of mechanical methods, soaking cleaning and chemical cleaning (acid etching).
- A brazing flux has a melting point below the melting point of the filler metal, it melts during the heating stage and spreads over the joint area, wetting it and protecting the surface from oxidation.
- It also cleans the surface, dissolving the metal oxides.
- It is important that the surface tension of the flux is: 1. Low enough for wetting the work piece surface; 2. Higher than the surface tension of the molten filler metal in order to provide displacement of the flux by the fused brazing filler. The latter eliminates the flux entrapment in the joint.
- The flux is applied onto the metal surface by brushing, dipping or spraying.

The more common types of filler metals used are

- Aluminum-silicon
- Copper
- Copper-silver
- Copper-zinc (brass)
- Copper-tin (bronze)
- Gold-silver
- Nickel alloy
- Silver
- Amorphous brazing foil using nickel, iron, copper, silicon, boron, phosphorus, etc.

Brazing methods

Torch brazing utilizes a heat of the flame from a torch. The torch mixes a fuel gas with Oxygen or air in the proper ratio and flow rate, providing combustion process at a required temperature.

The torch flame is directed to the work pieces with a flux applied on their surfaces. When the work pieces are heated to a required temperature, filler alloy is fed into the flame. The filler material melts and flows to the gap between the joined parts.

Torch brazing is the most popular brazing method.

Torch brazing equipment:

- Fuel gas cylinder with pressure regulator;
- Oxygen cylinder with pressure regulator;
- Welding torch;
- Blue oxygen hose;
- Red fuel gas hose;
- Trolley for transportation of the gas cylinders.

Furnace brazing	:	It uses a furnace for heating the work pieces.
Vacuum brazing	:	It is a type of furnace brazing, in which heating is performed in vacuum.
Induction brazing	:	Induction brazing utilizes alternating electro-magnetic field of high frequency for heating the work pieces together with the flux and the filler metal placed in the joint region.
Resistance brazing	:	Resistance brazing uses a heat generated by an electric current flowing through the work pieces.
Dip brazing	:	Dip brazing is a brazing method, in which the work pieces together with the filler metal are immersed into a bath with a molten salt. The filler material melts and flows into the joint.
Infrared brazing	:	Infrared brazing utilizes a heat of a high power infrared lamp.

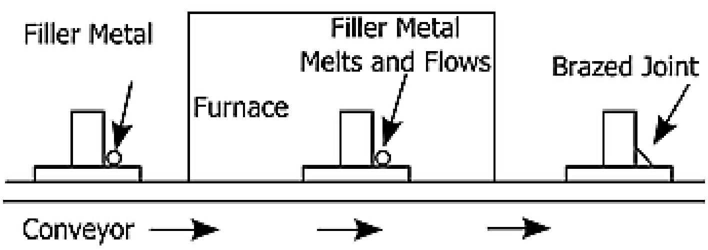


Fig.2.23 Furnace Brazing

Advantages of brazing

1. Low thermal distortions and residual stresses in the joint parts;
2. Microstructure is not affected by heat;
3. Easily automated process;

4. Dissimilar materials and thin wall parts may be joined;
5. High variety of materials may be joined;
6. Moderate skill of the operator is required.

Disadvantages of brazing

1. Careful removal of the flux residuals is required in order to prevent corrosion;
2. No gas shielding may cause porosity of the joint;
3. Large sections cannot be joined;
4. Fluxes and filler materials may contain toxic components;
5. Relatively expensive filler materials.

SOLDERING

Soldering is a method of joining two metal work pieces by means of a third metal (solder) at a relatively low temperature, which is above the melting point of the solder but below the melting point of either of the materials being joined. Flow of the molten solder into the gap between the work pieces is driven by the capillary force. The solder cools down and solidifies forming a joint. The parent materials are not fused in the process.

Soldering is similar to Brazing. The difference is in the melting point of the filler alloy: solders melt at temperatures below 840°F (450°C); brazing filler materials melt at temperatures above this point.

The difference between soldering and welding processes is more sufficient: in the welding processes edges of the work pieces are either fused (with or without a filler metal) or pressed to each other without any filler material; soldering joins two parts without melting them but through a soft low melting point solder.

Fluxes:

The function of fluxes is to remove the non-metallic oxide film from the metal surface during the heating and soldering operations, so that clean metals may make mutual metallic contact.

The flux does not constitute a part of the soldered joint. Commonly used fluxes in soldering joining process are Zinc chloride (Zncl2), ammonium chloride (NH4cl and hydrochloric acid (Hcl).

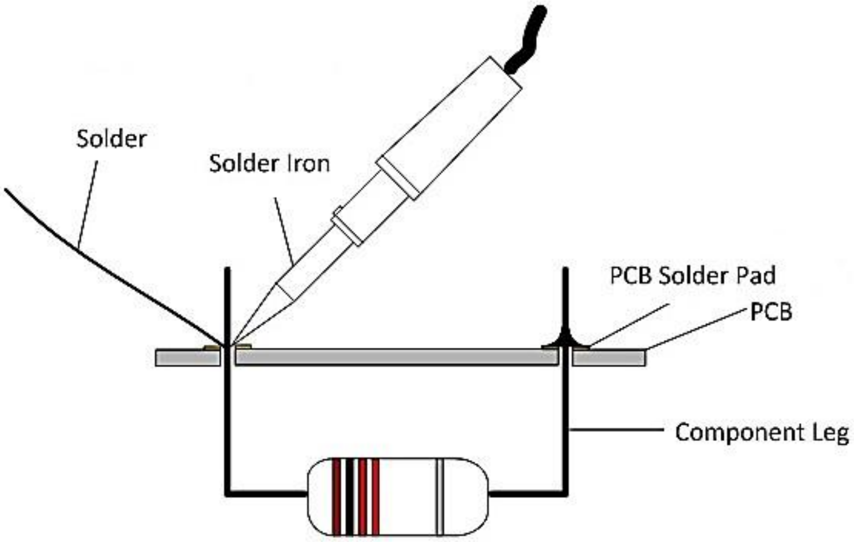


Fig. 2.24 Soldering Process

Soldering Methods

Hand soldering

Iron soldering utilizes a heat generated by a soldering iron.

Torch soldering utilizes a heat of the flame from a torch. The torch mixes a fuel gas with oxygen or air in the proper ratio and flow rate, providing combustion process at a required temperature.

The torch flame is directed to the work pieces with a flux applied on their surfaces. When the work pieces are heated to a required temperature, solder is fed into the joint region. The solder melts and flows to the gap between the joined parts. Hand soldering is used in repair works and for low volume production.

Wave soldering

The method uses a tank full with a molten solder. The solder is pumped, and its flow forms a wave of a predetermined height. The printed circuit boards pass over the wave touching it with their lower sides. The method is used for soldering through-hole components on printed circuit boards.

Reflow soldering

In this method a solder paste (a mix of solder and flux particles) is applied onto the surface of the parts to be joined and then are heated to a temperature above the melting point of the solder. The process is conducted in a continuous furnace, having different zones: preheating, soaking, reflow and cooling. The joint forms when the solder cools down and solidifies in the cooling zone of the furnace.

Advantages of soldering

1. Low power is required;
2. Low process temperature;
3. No thermal distortions and residual stresses in the joint parts;
4. Microstructure is not affected by heat;
5. Easily automated process;
6. Dissimilar materials may be joined;
7. High variety of materials may be joined;
8. Thin wall parts may be joined;
9. Moderate skill of the operator is required.

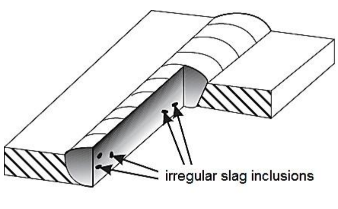
Disadvantages of soldering

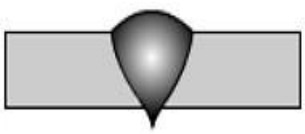
1. Careful removal of the flux residuals is required in order to prevent corrosion;
2. Large sections cannot be joined;
3. Fluxes may contain toxic components;
4. Soldering joints cannot be used in high temperature applications;
5. Low strength of joints.

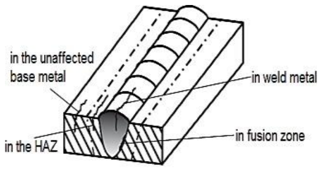
Comparison of welding soldering and brazing

Sl.No.	Welding	Soldering	Brazing
1	Welding joints are strongest joints used to bear the load. Strength of the welded portion of joint is usually more than the strength of base metal.	Soldering joints are weakest joints out of three. Not meant to bear the load. Use to make electrical contacts generally.	Brazing joints are weaker than welding joints but stronger than soldering joints. This can be used to bear the load up to some extent.
2	Temperature required is 3800°C in welding joints.	Temperature requirement is up to 450°C in soldering joints.	Temperature may go to 600°C in brazing joints.
3	To join work pieces need to be heated till their melting point.	Heating of the work pieces is not required.	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 sill required are in between other two.
6	Heat treatment is generally required to eliminate undesirable effects of welding.	No heat treatment is required.	No heat treatment is required after brazing.
7	No preheating of workpiece is required before welding as it is carried out at high temperature.	Preheating of workpieces before soldering is good for making good quality joint.	Preheating is desirable to make strong joint as brazing is carried out at relatively low temperature.

Sl.No	Defects	Causes	Remedies
1	Porosity	• Porosity is the entrapment of small volumes of gas in solidifying weld metal • It may arise from damp consumables or metal or, from dirt, particularly oil or grease, on the metal	• Drying consumables • Cleaning, degreasing material being welded • Electrode or filler metals with higher level of deoxidants • Sealing air leaks, reducing excess shielding gas flow
2	Slag inclusions  (e) Slag Inclusion	• These are irregularly shaped, not spherical like porosity	• Position work and/or change electrode/flux to increase slag control • Better slag removal between passes • Dress weld surface smooth if it is likely to cause slag traps • Remove heavy mill scale on plate

3	Lack of Fusion  lack of fusion between weld and base metal	• Lack of fusion is caused by incorrect welding conditions	• Procedure for complete fusion should be verified by testing • Increased energy input • Correct electrode angle and work position
4	Overlap	• Overlap is an imperfection at the weld toe or root caused by metal flowing onto the surface of the base metal without fusing to it	• Adjust electrode manipulation to ensure fusion of base metal • Limit size of fillet to 9-mm leg length
5	Undercut	Undercut is an irregular groove at the weld toe in the parent metal or previous pass caused by • excessive weaving • melting of top edge of fillet weld with high current	• Weld in flat position • Change shielding gas to one which produces better wetting • Terminate welds so they don‘t finish at a free edge
6	Excessive penetration  Excessive Root Penetration	Excessive penetration is caused by • Incorrect assembly or preparation Edge preparation too thin to support weld under bead Excessive root gap • Energy input too high • Lack of operator skill	• Control of preparation • backing bars

7	Crack  (b) Crack	These are developed due to shrinkage during solidification of weld metal , high arc travel speeds fast cooling rates, too concave or convex weld bead	Avoid producing too large a depth to width ratio Avoid high welding speeds Provide sufficient time for cooling