Joining Processes

Joining two or more elements to make a single part is termed as a joining or fabrication process. Joining process include mechanical joining by means of bolts, screws or rivets; adhesive bonding by employing synthetic glues such as epoxy resins, welding, brazing and soldering.

Choice of a particular process depends on type of assembly (permanent, semi-permanent or temporary); materials, economy, type of service (heavy loading, light loading, high temperature etc).

Joining by adhesive bonding is done using adhesives such as thermosetting resins, thermoplastic resins, silicone resins and elastomers. Elastomers such as natural rubbers when mixed with thermosettting resins reduce brittleness and provide toughness for shock resistance.

Welding

Welding is the most extensively used joining method. In welding, the joining takes place through atomic bonding. Atomic bonding may be solid state, liquid state or solid liquid state.

For the bonding to take place heat or pressure or both heat and pressure are to be applied at the joints.

In fusion welding heat is applied at the joints and in pressure type welding pressure also applied apart from heat.

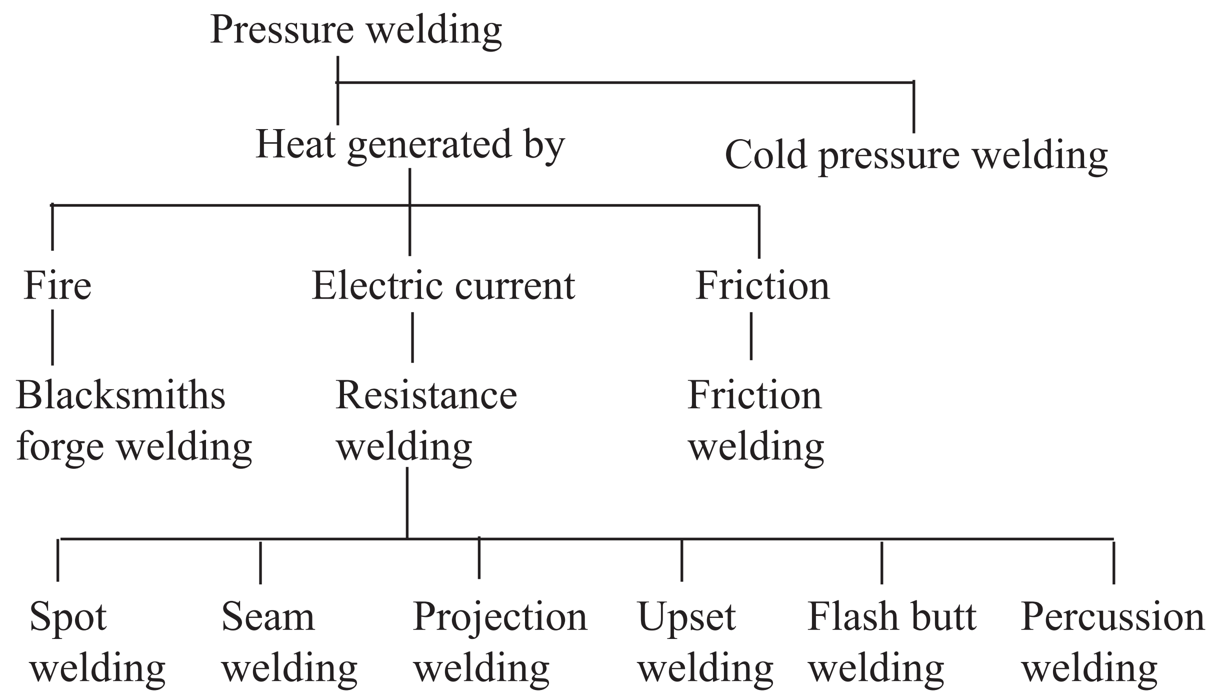
In all weding process, except cold welding process, heat is applied for the bonding to take place. Therefore there should be one heat source.

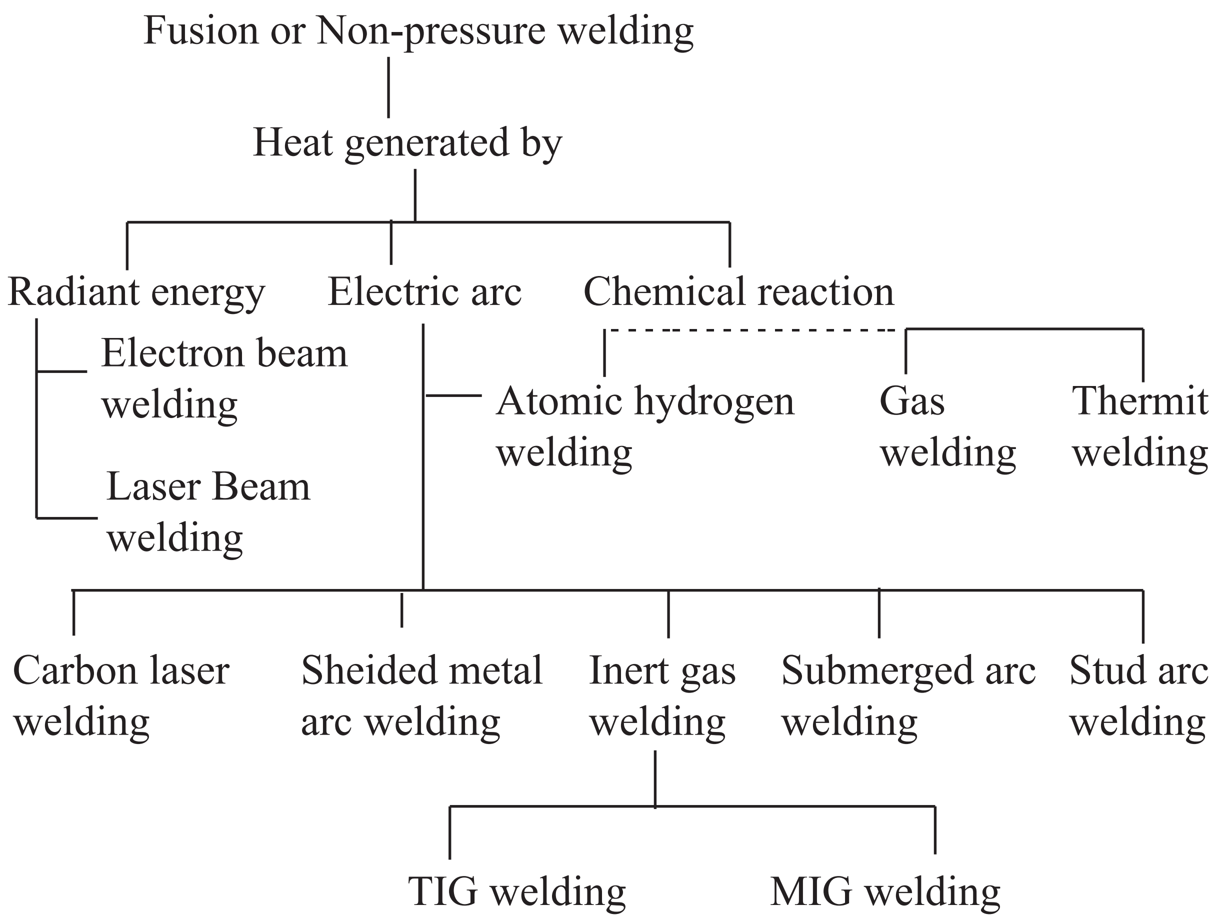
Fusion welding is a non pressure liquid state welding. Bonding takes place in a metallurgical fusion process where interface of two parts are brought above melting point and then allowed to solidify.

Electric arc welding, Induction welding, gas welding, thermit welding etc are examples of fusion welding.

Forge welding, resistance welding, friction welding and cold pressure welding are examples of pressure type welding.

Classifications of welding processes are shown in the figures.


Pressure welding
Heat generated by
Cold pressure welding
Fire
Electric current
Friction
Blacksmiths forge welding
Resistance welding
Friction welding
Spot welding
Seam welding
Projection welding
Upset welding
Flash butt welding
Percussion welding


Fusion or Non-pressure welding
Heat generated by
Radiant energy
Electric arc
Chemical reaction
Electron beam welding
Laser Beam welding
Atomic hydrogen welding
Gas welding
Thermit welding
Carbon laser welding
Sheided metal arc welding
Inert gas welding
Submerged arc welding
Stud arc welding
TIG welding
MIG welding

Solid State Welding

Cold welding, friction welding, diffusion welding, forge welding etc are examples of solid state welding. Cold welding includes welding, ultrasonic welding and explosive welding.

In fusion welding process melting of metal takes place. Therefore there should be a source of heat. In electric arc welding, electric resistance welding and induction welding heat is generated by thermo chemical actions.

In gas welding and thermit welding heat is generated by thermo chemical actions.

In new generation welding processes such as electron beam welding, laser beam welding etc radiant energy is the source of heat for welding.

Electric Arc Welding

Electric arc welding is a fusion welding process. Welding heat is obtained from an electric arc between the work (or base metal) and electrode.

Electric arc is produced when two conductors in an electric circuit, which are touched together are separated by a small distance, such that there is sufficient voltage in the circuit to maintain the flow of current through the gaseous medium. Temperature produced is 6000ºC to 7000ºC.

The depression created on the base metal due to the arc is called crater.

DC or AC current can be used for arc welding. DC voltage required is 60 to 80 V for striking the arc and 15 to 25 V for maintaining the arc. For AC current they are 80 to 100 V and 30 to 40 V respectively.

AC Welding Equipment

1. AC Machines
   (i) Transformer
   (ii) Alternater engine driven by motor or engines
2. DC Machines
   (i) Transformer with rectifier
   (ii) DC genetator driven by motor or engine

Transformer sets are more commonly used in AC welding. As there is no moving parts power comsumed and noise are less. Also maintenance cost is low and efficiency is more.

Specification of Arc Welding Machines

1. Maximum rated open circuit voltage
2. Rated current in amperes
3. Duty cycle

American welding society (AWS) defines duty cycle as the percentage time in a ten minute period that a welding machine can be used at its rated output overloading. Normally 40% duty cycle is suggested (Indian Standard specifies 5 minutes as the cycle time).

Types of Welding Electrodes

1. Non consumable
2. Consumable

Non consumable type of electrodes are made of carbon, graphite or tungsten. Carbon and graphite electrodes are used in DC welding only tungsten can be used for both AC and DC welding. As this electrode is not consumed arc length is constant and it is stable and easy to maintain. Separate filler rods are used in this case.

There are three types of consumable electrodes

1. Bare electrodes
2. Fluxed or lightly coated electrodes
3. Coated or extruded/shielded electrodes

Types of Electric Arc Welding Process

1. Carbon arc welding
2. Shielded metal arc welding
3. Flux cored arc welding
4. Gas metal arc welding
5. Gas tungsten arc welding
6. Submerged arc welding
7. Atomic hydrogen welding
8. Plasma arc welding
9. Stud welding
10. Electro slag welding

Carbon Arc Welding

In carbon arc welding carbon or graphite electrodes are used. If required filler material also is used. Shielding is not generally used. So carbon arc welding is used in metals that are not sufficiently contaminated by oxygen and nitrogen in the atmosphere (copper alloys, brass, bronze, Aluminium alloys etc.)

Shielded Metal Arc Welding (SMAW)

This method is also known as manual metal arc welding. This is the most generally used welding type. Coated electrodes are used in this type of welding. Shielding is obtained from the decomposition of the coating. The ingredients in the vaporized coating creates a protective gas atmosphere over the weld puddle. As the coating melts at a slower rate than the metal this welding rod will be having a concave end. This helps to concentrates the heat from the arc. The flux coating helps removal of impurities through formation of slag. The electrode diameter depends upon the thickness of the metal being welded and the type of the joint.

Welding current is determined on the basis of the electrode diameter.

Welding current = k.d amperes

Where d is diameter in mm

K = constant

= 45 to 60 for ordinary steel electrodes

= 18 to 22 for graphite

= 5 to 8 for carbon

Voltage depends only on the arc length. It is given by

$V = k_1 + k_2$ volts

Where k_1 = 10 to 12 and k_2 = 2 to 3

L = arc length in mm

Minimum arc voltage, V_{min} = (20 + 0.041) volts.

Arc length depends upon the kind of electrodes used, its coating, its diameter, current used and position of welding. Shorter arc lengths are used for overhead and vertical positions.

An arc length of 0.6 to 0.8 times the electrode diameter can produce stable arcs and high quality welding.

Flux Cored Arc Welding

In this method a hollow tubular electrode inside which the flux is provided, is used. Continuous welding is possible as the electrode can be supplied in coils.

Gas Metal Arc Welding (GMAW)

This is also known as metal inert gas (MIG) welding. In this method an inert gas such as Argon is used for shielding the welding area. Consumable electrode is fed through a welding gun through which the inert gas also is supplied for shielding weld area. Electrode is supplied in coils and continuous welding is possible. Other inert gases are helium and carbon dioxide.

Gas Tungsten Arc Welding (GTAW)

This process is also known as tungsten inert gas welding (TIG welding). This is similar to mig welding. But a non-consumable electrode of tungsten is used.

A filler metal may or may not be used. In the tungsten electrode 1 to 2% thorium and zirconium are added to improve electron emission, arc stability, arc striking and current carrying capacity etc. TIG welding was originally developed for welding magnesium which is highly oxidizing. Now it is used for welding, aluminium and its alloys, stainless steel, cast iron, silicon bronze, titanium, nickel, copper and carbon steels. This method is suitable for welding thinner metals, below 6 mm thick. Both AC and DC can be used. DCEP is not used as this tend to melt electrode due to overheating. For more penetration DCEN is preferable. For metals like magnesium and aluminium high frequency AC supply is used which break up the surface oxides.

Submerged Arc Welding (SAW)

Submerged arc welding is generally used for welding thick plates which require straight welds in flat position. In this method arc electrode is continuously fed from reals. The arc and the welding occurs inside a blanket of granular flux which is continuously fed ahead of the electrode. The granular flux shields the weld area from atmosphere. Molten flux acts as a cleanser, absorbing impurities from the molten metal and producing the slag which floats on top of molten metal. The flux may also contain powder metal alloying elements. In order to prevent molten metal running out of the joints, water cooler backup plates are used.

Electro Gas Welding

This process is a development of electro-slag welding. The main difference with the electro-slag welding is that no flux is fed into the joint and the heat is produced by electric arc through out. An inert gas is fed into the joint for shielding the arc. This process is used for welding 20 to 80 mm thickness plates.

Non-conventional Welding

Cold welding, diffusion welding explosion welding, resistance welding etc can be grouped under non-conventional welding.

Cold Welding

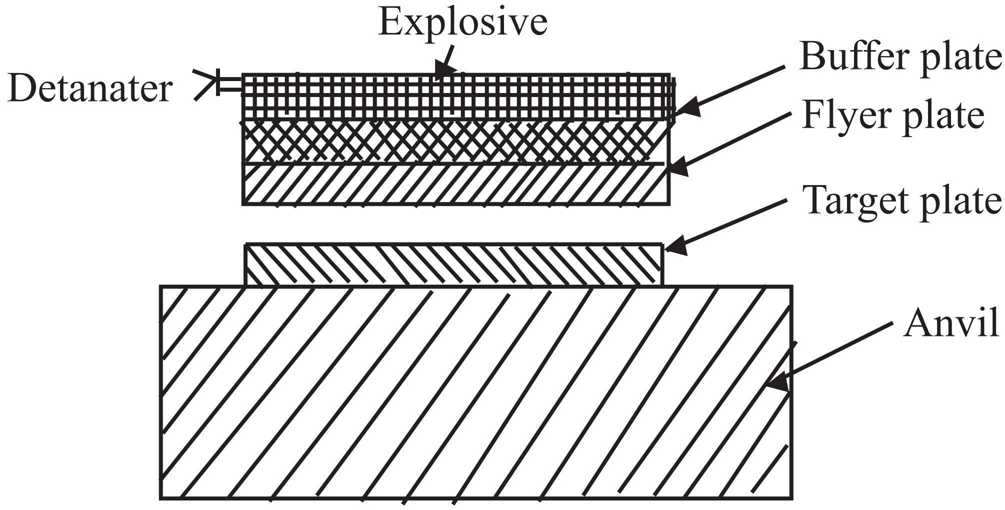
Cold welding is a solid state welding done at room temperature under pressure. Coalescence of the metal parts occur due to the deformation under the great pressure applied by roller or die.

Diffusion Welding

In diffusion welding process, strength of the joint is obtained primarily from diffusion of the atoms across the interface. It is a solid stste welding process where coalescence of the parts occur by the application of pressure under elevated temparatures. Generally the temperature is above 0.5 times the melting point.

Explosion Welding

Explosion welding or explosive welding is a solid state welding where the parts are joined by high velocity movements produced by a controlled detonation.



When the explosive is detonated, the flyer plate moves to the target plate under great velocity and bounding occurs with the target plate or base plate. This method is used for metal cladding of heat exchanger tube plates etc.

Atomic Hydrogen Welding

In automic hydrogen welding arc is produced between two tungsten electrodes. A stream of hydrogen passes to the weld area through nozzles through which the electrodes are held. High temperature of the arc breaks up the hydrogen molecules into hydrogen atoms absorbing heat from molecules into hydrogen atoms absorbing heat from the arc (421.2 KJ/mol). The hydrogen atoms are highly reactive. They combine with atmospheric oxygen to form water vapor and form hydrogen molecule at the surface to be welded releasing intense heat necessary for melting of the metal. Because of its reactivity hydrogen atoms also breaks the oxides on the base metals allowing formation of a clean weld. Hydrogen also acts as a shielding gas. As the molten metals becomes highly fluid atomic hydrogen welding is used only for flat positions. The main advantage of this process is its ability to provide high heat concentration. Thin metal sheets or smaller diameter wires can be welded using this mehod because of its lower thermal efficiency compared to direct arc processes. Aluminium, stainless steel sheets etc are welded using this method.

Plasma Arc Welding

In plasma arc welding, welding is done using a plasma jet. Plasma is a gas sufficiently ionized, containing positive and negative ions and with very high temperature and conducts current freely. In plasma welding argon gas and tungsten electrode is used. Argon gas is used for producing the plasma jet as well as acting as a shielding gas. Plasma jet is created when the arc is passed through a constrictive nozzle. As a result of this, the plasma jet will take a narrow columnar shape with unique properties ideal for welding. The plasma welding torch has passages for orifice gas, shield gas and water for cooling.

There are two methods of plasma welding

1. Transferred plasma arc
2. Non-transferred plasma arc

In both cases electrode is negative. In transferred arc work is positive and non-transferred arc the nozzle is connected as positive.

Stud Arc Welding

Stud arc welding is an arc welding process used for welding studs to flat metal surfaces. A stud welding gun is used for this purpose. An arc is produced between the work and end of the stud held in the gun. When the stud end and work spot melts the stud is pressed and alowed to cool. The whole cycle of operations are automatically controlled.

Electro Slag Welding

Electro slag welding is used for welding thick plates, structures for turbine shafts, boiler parts ets. In this process the plates to be welded are held in a vertical position with a gap of 15 to 30 mm. Filler wires and flux are fed automatically.

Electric Resistance Welding

In resistance welding heat required for welding is produced by means of electrical resistance at the joint of two parts to be joined. Low voltage (4 to 12 V) and high current is applied. Heat generated during time, t is given by

$$H = I^2R\,t\,k$$

When I = current in amperes

R = Resistance in ohms

t = time in secs

k = constant to account for loss by conduction and radiation

Types of resistance welding

1. Spot welding
2. Seam welding
3. Projection welding
4. Butt welding
5. Percussion welding

In **Spot welding** the tips of two solid cylindrical electrodes are placed on either side of the lap joint of two sheet metals and high current is passed across the point of contact. Heat generated melts the metals locally at the point of contact when pressure is applied. Low voltage and high current is applied during a very short time.

Seam welding is a specilized case of spot welding. In this case rotating disc type electrodes are used. Therefore a continuous weld is obtained. The seam is made of continuous overlapping spot welds. If the spot welds are spaced it is known as **roll spot welding.**

Projection welding is another variation of spot welding. One sheet is provided with a number of projections to help to locate the current at predetermined spots. These projections are obtained by embossing.

Upset butt weldingis a butt joint welding. Heat is generated at the contact area between the two plates. The joint get slightly upset due to the pressure applied. It is used for joining ends of rods or similar pieces.

Welding Defects

For a strong welding joint the welding should have minimum defects.

The following defects are noticed in welding

1. Porosity
2. Slag inclusions
3. Incomplete penetration
4. Underfilling
5. Undercutting
6. Inclusions
7. Cracks
8. Lamellar tears

Porosity is caused by the gases such as oxygen, nitrogen and hydrogen absorbed during melting.

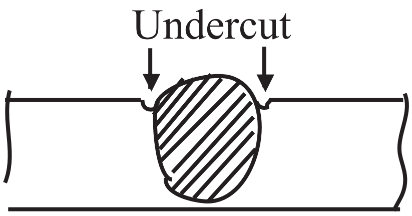
As the molten metal is cooled solubility of the gases is decreased and they try to escape. If escaping is not possible they remain with in the weld causing porosity.

In inclusion slag, scale or dirt may get entrapped in the weld deposit during welding. Contaminated base plate, non-uniform melting of electrode coating, high melting point or high viscosity of slag or insufficient deoxidizing of the metal in the weld etc can cause inclusions. Slag inclusion can occur in a multipass welding if the slag solidified in the previous pass is not cleaned before the next pass.

Incomplete fusion or lack of fusion may occur if the temperature of the base metal is not raised to its melting point and due to faulty welding conditions. When the gap is not totally filled by molten metal, it leads to incomplete fusion.

Underfilling occurs when proper amount of molten metal is fed to the gap.

In **Undercutting** an undercut is a groove formed adjacent to the toe of the weld. Under cutting may be caused by excessive heating, improper positions of electrode or torch tip or non-uniform feed of filler rod. Unercutting reduces fatigue strength of the joint.



Cracks

Cracks may occur in or near the weld. Cracks can be micro cracks, macro cracks or wide cracks (fissures) depending upon the size. Micro cracks will be visible only through a microscope. Macro cracks can be seen by unaided eye or through a low power magnifier. Cracks that occur at low temperature (around 200ºC) is known as cold cracks.

Cracks that occur when the metal is very hot is known as hot cracks. Depending upon location and direction, cracks can be toe crack, under bead crack, longitudinal crack, transverse crack etc.

Lamellar Tears

Lamellar tears are caused by non-metallic inclusion such as sulphides and oxides. These inclusions are elongated by rolling process. This generally happens in plates of low ductility in the thickness direction.

Lamellar tears are more dominant in T and corner joints where fusion boundary is parallel to the rolling plane.