1

Introduction to Welding Engineering

1.1. History and Development of Welding

The first historical reference about welding is given in Bible and Tubal-Cain was the first smith who forged the instruments of bronze and iron. About 5000 years back the forge, hammer, anvil, bellows and fire heaters were used for forging. It was in the year 1887 that Thomas Fletcher of Warrington invented various blow pipes for burning hydrogen or coal gas with air or oxygen. The bicycle frames were manufactured with the help of these blow pipes. This type of blow pipe is used even today where acetylene gas is used in place of hydrogen or coal gas.

In 1892, acetylene gas was first discovered by Thomas Leopold Wilson of North Carolina. In 1886, two Frenchmen, the Brins brothers formed a company for the liquefaction of air from which pure oxygen was obtained. The only acetylene welding blow pipe was invented by Fouche and Picard. Volta, after whom the term volt is named, demonstrated in 1800 that the electric arc could be used for melting iron wire and the process of fusion of metals by electricity was born.

A swedish marine engineer thought of protecting the arc with an inert gas. This gas, he produced by applying a flux to the electrode. The flux melts and vaporises in the intense heat of the welding arc, protects the molten metal from the air and can be used to add alloying elements to the welding wire.

Many advances have been made since these early days. Automation has added to them, welding arcs and cutting flames, electronically guided arc, gas combined with electricity in hydrogen, helium and argon arcs. New methods have been added, the notable among them is the plasma arc welding.

1.2. Welding Processes

Machines, Boilers, Pressure Tanks etc. are made of iron steel, aluminium etc. They are either cast or are made in different part and then joined together. This joining can be done by mechanical or thermal joint. Mechanical joint is achieved by rivetting, bolts and nuts or by threaded screws. Thermal joint is achieved by the process of welding.

Welding consists of fusion or uniting of two or more pieces of metal by the application of heat and sometimes of pressure. Welding involves more sciences and variables than any other industrial process. The principal sciences involved in welding are Physics, Chemistry and Metallurgy. Of these, the Physics problems involve heat, mechanics, elasticity plasticity electricity, and magnetism. Testing and research work in this field require a knowledge of optics including polarised light, *X*-rays, *X*-ray diffraction, crystal theory and the constitution of matter. The process can be defined according to :

(*a*) The method of joining.

(*b*) The surface to be welded.

Further, it can be differentiated as to whether it is

(*a*) By hand

(*b*) By machine.

Also, whether it is

(*a*) By fusion

(*b*) Pressure.

Many welding processes have been developed which differ widely in the manner in which the heat is applied and in the type of equipment used. Some processes require hammering, rolling, or pressing to effect the weld; others bring the metal to a fluid state and require no pressure. Processes using pressure require bringing the surfaces of the metal to a temperature sufficient for cohesion to take place. This is nearly always a sub-fusion temperature. However, if the fusion temperature is reached, the molten metal must be confined by surrounding solid metal. No additional weld metal is required in welds of this type.

Most welds are made at fusion temperature and require addition of weld metal in some form. In welding of dissimilar metals, it is often possible to make a satisfactory bond by bringing only one of the metals to a fusion temperature.

Welds are also made by casting, in which case the metal is heated to a high temperature and poured into the cavity between the two pieces to be joined. In this method, the heat in the weld metal must be sufficient to cause it to fuse properly with the parent metal.

Most of the developments of modern welding have taken place since the First World War due to the demands of industry of more rapid means of fabrication and assembly of metal parts. Welding processes are employed extensively in the manufacture of automobile bodies, machine frames, high-speed rail road cars, structural work, aircraft, tanks and general machine repair.

In oil industry, welding is extensively used in refineries and in-pipe-line fabrication. The largest single use of welding during war has been in ship-building; in peace time it is the fabrication of metal structures.

Competition of welding has also been felt in casting industry because many machine parts which were formerly cast are now made up of steel members welded together. Such construction has the advantage of being lighter and stronger than cast iron. Similarly, gas cutting had its influence on forged products. Many parts are now accurately cut from thick steel plates. Hence, the cost of expensive dies is saved. Today, there is hardly any industry which is not affected in some or the other way by welding and cutting processes.

Firstly, welding processes were all limited to wrought iron and low carbon steel, which are easily welded and have a wide welding range. As carbon content increase or as alloying elements are added, welding range decreases, and good welds become increasingly different. Development of new electrodes and new welding techniques has, however, altered greatly the concept of weldable material. If proper equipment and materials are used, practically all alloy steels can now be welded.

Cast iron at first presented serious difficulties due to its low ductility, poor fusion and tendency to crack on cooling. Now, most of these difficulties have been overcome by proper methods and selection of suitable welding materials. Such non-ferrous metals as copper, aluminium, brass, bronze, monel metal, and nickel can be welded successfully, although special precautions have to be usually taken for preventing oxidation.

1.2.1. General Conditions for Welding. Welding is facilitated if surfaces are cleaned and freed from foreign matter by wire brushing, sand blasting, or machining. Impurities tend to weaken a weld, causing metal to be either brittle or filled with gas or slag inclusions. They also cause poor cohesion of the metals.

Tendency toward oxidation increases with temperature. At high temperatures used in many welding processes, oxidation of weld metal is likely to have serious weakening effects in the weld. In some processes, this influence is counteracted by the use of a flux, which removes the oxides and permits perfect cohesion of metals.

In electric arc process, flux is coated on the electrodes and, when melted, forms a protective coating of slag over the weld metal and a non-oxidising atmosphere.

In gas welding and forge welding flux is usually added in powder form. Other processes eliminate any oxidation tendency by creating a non-oxidising atmosphere at the point where the welding is done.

As oxidation takes place rapidly at high temperature, speed in welding is important. Some processes are naturally quicker than others, but work should be done as rapidly as possible.

1.2.2. Classification of Welding Processes. The welding processes can be classified as under :

(*A*) Gas Welding.
(*B*) Arc Welding.
(*C*) Resistance Welding.
(*D*) Induction Welding.
(*E*) Thermit Welding.
(*F*) Forge Welding.
(*G*) Braze Welding.
(*H*) Flow Welding.
(*I*) Cold Welding.

The above processes can further be sub-divided as :

(*A*) *Gas Welding*

(*i*) Oxy-Acetylene Welding.
(*ii*) Air-Acetylene Welding.
(*iii*) Oxy-Hydrogen Welding.
(*iv*) Pressure Welding.

(*B*) *Arc Welding*

(*a*) Carbon Electrode
↓
Shielded | Unshielded

(i) Shielded carbon arc welding	(i) Carbon arc welding (ii) Twin-carbon arc welding
(ii) Inert gas carbon arc welding	

(b) Metal Electrode

↓

Shielded	Unshielded
(i) Shielded metal arc welding	(i) Stud welding
(ii) Impregnated-tape metal arc welding	(ii) Bare metal arc welding.
(iii) Atomic hydrogen welding	
(iv) Inert gas metal arc welding	
(v) Submerged arc welding	
(vi) Shielded stud welding.	

(*C*) *Resistance Welding*

(*i*) Spot welding
(*ii*) Seam welding
(*iii*) Projection welding
(*iv*) Flash welding
(*v*) Upset welding
(*vi*) Percussion welding.

(*D*) *Induction Welding*

(*E*) *Thermit Welding*

(*i*) Pressure thermit welding
(*ii*) Non-pressure thermit welding

(*F*) *Forge Welding*

(*i*) Hammer welding
(*ii*) Die welding
(*iii*) Roll welding.

(*G*) *Brazing*

(*i*) Torch brazing
(*ii*) Furnace brazing
(*iii*) Induction brazing
(*iv*) Resistance brazing
(*v*) Dip brazing
(*vi*) Block brazing.

1.3. Introduction of Various Welding Processes

(1) **Gas Welding.** Heat may be generated by electrical, chemical or mechanical means. Of all the gases which are available for combustion with oxygen, the burning of acetylene in oxygen results in the highest temperature. Another combination which results in a high temperature is the burning of hydrogen in oxygen. This flame

has been used for the welding of low melting point metals such as aluminium. The temperature of the oxy-acetylene flame is about 3200°C, which is ample for the welding of steel.

Oxyacetylene welding is a fusion-welding process ; the coalescence of metals is produced by an oxygen-accetylene flame. Extreme heat is concentrated on the edge or on the edges and surface of the pieces of metal being joined until the molten metal flows together. Whether a filler metal should be used to complete the weldment is determined by the type of joint design.

Filter metal as added by inserting it into the molten puddle of the base metals. The puddle then then solidifies making the weld bead (Fig. 1.1). The extremely high heat depends on the mixture of two types of gaseous substances, oxygen and acetylene. Oxygen supports higher combustion ; acetylene being the fuel for combustion.

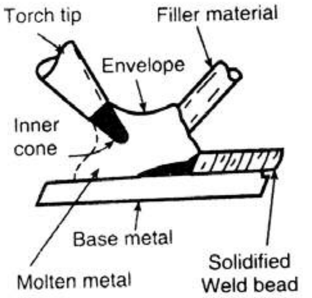

Fig. 1.1. Oxygen-acetylene welding.

(2) **Arc Welding.** Of the electrical methods for the generation of heat, there are two of great importance, the electric arc and electrical resistance. Arc welding had its beginning with the electric dynamo which was invented in 1877. Since then, the field of arc welding has grown to one of great importance. Electric arc welding was first used for connecting the various parts of storage battery plates. Auguste de Meritens, a French inventor established this process in 1881. The electric arc is a particularly suitable source of energy for welding since its heat is effectively concentrated. The energy input may be supplied from efficient electrical generators and transformers with suitable controls and response characteristics. Inert or special atmospheres may be used, if desired. The welding arc column is characterised by a nearly constant temperature of the order of 6000 ± 300° C abs. throughout the length and diameter of the arc column.

Application of arc welding depended naturally upon the development of electricity. Hence, the improvements in dynamos and generators in 1880 permitted the advancement of arc welding. N.V. Bernado developed the first actual arc welding, which was defined as joining of metals by melting and fusing them with the help electrodes. He created a mechanism which used carbon electrodes, producing an arc between the carbon electrode and the metal edges to be welded and thus heating the metal to a fusible state. Carbon arc welding improved tremendously as a result of the development of better carbon electrodes, making them electrically more consistent. However, this method has been almost completely replaced by newer welding processes.

In 1895, N.G. Slavianoff tried a metallic electrode, but he experienced little success because he used bare metal electrodes. In 1905, the success of the metallic electrode was assured as a result of the invention of the flux coated electrodes.

Since 1905, there have been few new developments in shield arc welding; the major development being the production of portable machines and automatic welding machines.

These days, shielded arc welding is accomplished by producing an electric arc between the work to be welded and the electrode tip. Advantages of this type of welding arc: (*i*) less heat loss, and (*ii*) less oxidation as compared to oxy-acetylene flame. Due to rapid development in the equipment, which makes this method suitable for a variety of purposes, the practice of making welds electrically is rapidly increasing. Shielded arc welding is done mostly with metallic electrodes.

In case of *inert gas arc welding,* the inert gases are not absorbed the any extent by molten metal and have little effect on the resulting weld. However, they do have a definite usefulness in welding as a shielding medium, *i.e.* the exclusion of chemically active gases from contact with the molten metal. Inert gas atmospheres also have considerable effect on the electrical behaviour of the welding arc. Doan has shown that in atmospheres of the relatively inert gases *e.g.*, argon and helium, high voltages are necessary in order to sustain arc. Molten metal generally can and often does, absorb upto 0.005% (by weight) of hydrogen. The absorption of hydrogen occurs automatically. The atomic form may be obtained by the dissociation of water vapour, hydrocarbons or molecular hydrogen by the welding heat or in the electric arc. Hydrogen retained in solution in weld metal causes localised embrittlement around inclusions or defects in low or medium strength metals and severe general embrittlement in very high strength welds. Hydrogen diffuses from the weld metal into the heat affected zone of the base metal during the welding and cooling period. If the hardenability of the base metal and the rate of cooling of the weld produce a fully hardened heat affected zone cracks may occur in this zone. The amount of hydrogen retained in weld metal is controlled by solubility limits and by the reactions liberating gaseous products.

(3) **Resistance Welding.** In case of resistance welding processes the required heat, at the joints to be welded, is generated by the resistance offered through the work parts to the relatively short-time flow of low-voltage, high density electric current. Force is always applied before, during and after the application of current to assure a continuous electrical circuit and to forge the heated parts together. The maximum temperature achieved is ordinarily above the melting point of the base metal.

Resistance welding was first used in 1886. It was developed by Elihu H. Thompson and was called Butt welding because it consisted of placing the metal pieces to be welded into a large clamp, which brought the edges of the metal together and at the same time a heavy current was passed through the two metals. At the joint of the metals, the resistance of the metal to the electric current produced high heat fusing the pieces together.

When the current passes through the metal, the greatest resistance is at the point of contact. Hence, the greatest heating effect is at the point where the weld is to be made. Alternating current is generally used, coming to the machine with usual commercial voltages.

A transformer in the machine reduces the voltage 4 to 12 volts and raises the amperage sufficiently to produce a good heating current. Amount of current necessary is 5 to 7 kV per square cm of area to be united, based on a time of about 10 seconds. For other time intervals, power varies inversely with time. Necessary pressure to effect the weld varies from 300 to 600 kg/cm^2.

Resistance welding is essentially a production process used for joining light gauge metals, which can be lapped. Usually, equipment is suitable for only one type of job, and work must be moved to the machine. The process is especially adapted to quantity production and includes a large amount of welding done at the present time.

It is the only process, which permits a pressure action at the weld, while allowing an accurately regulated heat application. Also, the operation is extremely rapid. Weldability of a given metal depends to some extend on its melting point. Practically, all metals can be welded by resistance welding, although some few, *e.g.,* tin, zinc and lead can be welded only with great difficulty.

In all resistance welding, three factors requiring consideration are expressed in the formula:

$$\text{Heat} = I^2RT$$

where I = Welding current in amperes,

R = Resistance of metal being welded,

T = Time.

Amperage of secondary or secondary current is determined by the transformer.

To provide possible variation of secondary current, the transformer is equipped with a regulator on the primary side to vary the number turns on the primary coil. This may be seen in the Fig. 1.1.

For good welds, these three variables, *viz.,* current, resistance, and time must be carefully controlled and determined by the factors, *viz.;* material thickness, kind of material and electrode size.

Timing of welding current is very important. After the pressure has been applied, there should be an adjustable delay until the weld starts. Current is then turned on by the timer and held a sufficient for the weld. It is then stopped, but the pressure remains until the weld cools, thus any tendency for the electrodes to arc is eliminated and also the weld is protected from discoloration.

The pressure on the weld is obtained manually, by mechanical means, by air pressure, by springs, or by hydraulic means. Its application is controlled and co-ordinated with the application of welding current.

Resistance welding may be sub-divided as:

(*i*) Spot welding,

(*ii*) Projection welding,

(*iii*) Seam welding,

(*iv*) Butt welding,

(*v*) Percussion welding.

(4) **Induction Welding.** The metal can be heated internally by passing an electric current through it. If the current is supplied by connecting the metal to a battery or generator, the method is known

as 'Resistance Heating'. If the current is produced or induced in the metal itself, the process is called 'Induction Heating'.

When a conductor is placed in a magnetic field that is changing with time, an electromotive force is generated within the conductor. If the ends of the conductor are joined so that a closed circuit is formed, a current will flow. The magnitude of voltage is proportional to the rate of change of the magnetic field. If the rate of change or frequency of the field is rapid, large voltages can be generated. Frequencies above 300 cycles per second are used in the industrial field of electrical heating. The heating is caused by the high frequency current, no matter how the current is produced.

Frequencies of 3000 cycles per second are often used for melting of small pots of metal. The metals are brought to a melting point in very few minutes through the current induced by the windings of the inductor coil. Still higher frequencies upto about 200,000 cycles per second can be produced by spark-gap equipment. Above this range, the generators are limited to electronic oscillators. The circuit used in induction heating is shown in the figure. Section R represents schematically the mercury-tube rectifier used to convert 50 cycle output of the high voltage transformer to the direct current utilised by the oscillator circuit S. Section T is a portion of the circuit consisting of the inductor coil surrounding the work or metal to be heated.

In induction welding , a high frequency induced current is made to flow through the edges of the parts to be joined. These edges suddenly melt and form narrow strips of liquid metal. Because of their cohesive properties, these strips of molten metal flow together an form a bead that bridges the joint. The entire operation is carried out in a few hundredths of a second. The heating of the metal is caused by I^2R losses, I being the induced high frequency current.

The first fundamental requirement of induction welding is that the parts to be joined must constitute a closed path or short-circuited turn. Thin-walled cylinders or discs are the most ideal shapes for welding. The areas being heated are determined by the geometry of the parts as well as by the shape and proximity of the inductor coil.

Since high frequency currents flow mainly on or near the surface of metals and since only the part of the metal that carries the current is heated, the weld is limited to shallow areas. In fact, the depth of penetration of the current is proportional to $\sqrt{\frac{l}{f}}$, f being the frequency of the induced current. Thus, the higher the frequency, the more pronounced is the skin effect. If the frequency is lowered, the current penetrates deeper and a larger volume of metal is heated. More power is needed to bring this increased volume of metal to welding temperatures. It has been found that an oscillator having a frequency of about 400 kilocycles per second is satisfactory power generator for welding ferrous alloys.

The conversion of 50 cycle power into heat energy within the work is carried out in several steps. The first is in the rectifier unit, which converts the 50 cycle power to high-voltage direct current. The second is in the oscillator unit which in generates high frequency power from the direct current. The third step is in the coupling of the high frequency power to the work itself. The power can be controlled at various points along the system.

Advantages of Induction Welding

(*i*) The process is of high efficiency. In a well-designed installation as much a 50% of the energy drawn from the line appears in the form of heat in the work.

(*ii*) In making annular welds, and induction welding installation drawing a maximum of 100 kW will weld parts that would require as much as 1000 kVA, if done on a projection welding machine.

(*iii*) The induction welding equipment can operate from a balanced 3-phase power system, whereas the projection welding machine is usually operated on single-phase.

(*iv*) Induction welding is by nature a mass production system. Only a few hundredths of a second are required to complete a weld, and since it is not necessary to make electrical connections to the parts to be welded, the output of the system depends largely on how fast the parts can be placed in welding position.

(*v*) Maintenance is low because electrodes do not touch the parts and hence do not have to be refaced as in the annular projection weld.

(*vi*) Small vessels containing materials that would be damaged by an arc or flame can be safely welded by induction welding.

(*vii*) Steel ranging in thickness from 0.25 mm to about 3 mm can be successfully welded by this method.

Disadvantages of Induction Welding

(*i*) It is a very costly process requiring large investment in equipment.

(*ii*) It has the limited scope of welding.

(*iii*) Copper, aluminium and other high conductivity metals are not well adapted to induction welding methods.

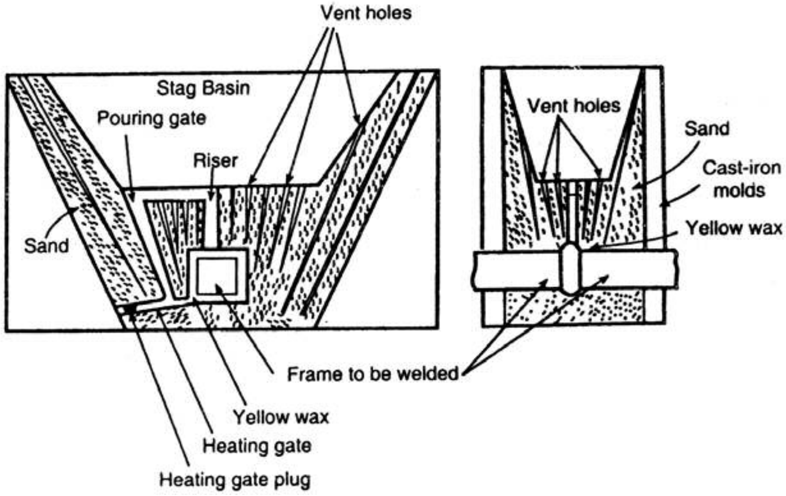

Fig. 1.2. Non-pressure thermit welding.

(5) **Thermit Welding**. It is the only welding process employing an exothermal chemical reaction for the purpose of developing a high temperature. It is based on the fact that aluminium has a great affinity for oxygen and can be used a reducing agent for many oxides.

It comprises of a group of welding processes wherein colescence is produced be heating with superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminium, with or without the application of pressure. Filler metal when used, is obtained from the liquid metal. Basic thermit is a mechanical mixture of finely divided aluminium and iron oxide in form of magnetic iron scale. The proportions are, roughly, thee parts of iron scale to one of aluminium. This mixture reacts according to the chemical formula:

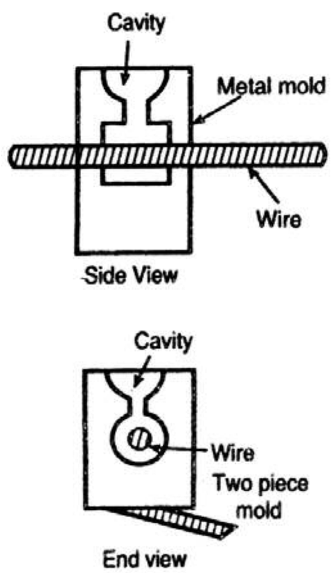

Fig. 1.3. Aln mino thermit welding.

$$8Al + 3\ Fe_3O_4 = 9Fe + 4Al_2O_3$$

The temperature resulting from the reaction is computed to be more than 2800°C. Due to the chilling effect of the crucible, however, the temperature of the liquid steel as poured into the mould for welding is slightly lower and has been measured at approximately 2500°C. The reaction is non-explosive and relatively slow, requiring about 30 seconds. No hazard is incurred in handling or storing the mixture as an initial temperature of 1200°C is needed for ignition. To start the reaction, a special ignition powder called 'Starting Thermit' is employed.

In the pressure-welding process no weld metal is deposited and only the heat of metal and the slag resulting from the reaction and utilised. The parts to be welded arc butted tightly together and enclosed in a removable mould, which provides space between the inner surface of the mould and the parts. The products of the reaction are then poured into the mould in such a manner that the slag enters the mould first. The slag cools rapidly in contact with the metal parts and provides a layer of brittle glasslike material so that the thermit steel which follows does not fuse with or adhere to the surface of the parts. The thermit steel generally lies in the lower half of the mould with the alumina or slag in the upper half and both give their heat to the ends of the pieces reach a welding heat, whereupon the pieces are forced together by means of clamps to make the pressure butt weld. The mould is then removed and the thermit steel and knocked off from around the weld.

In making a weld by this process, the first step is the lining up of the parts and the cutting of a parallel-sided gap at a point where

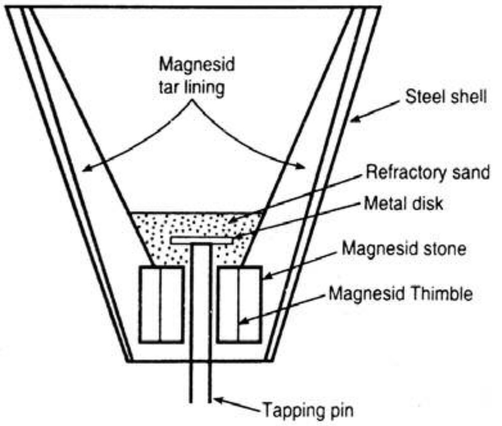

Fig. 1.4. Thermit crucible.

the weld is to be made, width of the gap depending on the size of the section. Around the break or joint, a wax pattern is formed and a refractory sand mould is built, which provides an annular space at the weld. The part is then preheated by means of kerosene and air blown into the mould through an opening. Preheating, which continues until the parts reach red heat, serves to burn out the wax pattern and to dry out the mould.

Reaction is started by means of a small starting thermit placed on top of the thermit in a specially designed crucible. When the reaction is computed, the crucible is tapped, allowing the thermit steel to run into the mould. Thus, steel having great superheat and being held in place between and around the ends of the parts to be welded, gives up its superheat to these parts, fusing and solidifying with them upon cooling.

A typical range of analysis of the steel produced by forging thermit and employed for welding is:

Carbon 0.25 to 0.35%

Manganese 0.40 to 0.60%

Silicon 0.09 to 0.20%

Sulphur 0.03 to 0.04%

Phosphorus 0.04 to 0.05%

Aluminium 0.07 to 0.18%.

A thermit weld of this composition has an average tensile strength of about 4800 kg/cm^2 with a yield strength of about 2400 kg/cm^2. In fact, although thermit weld metal resembles a cast steel it actually has physical properties closely approaching those of forged steel. Most commonly used thermits for welding ferrous metals are:

(*i*) **Plain thermit,** a mixture of finely divided aluminium and iron oxide which is the basis of all thermit mixtures.

(*ii*) **Forging thermit.** It is plain thermit with the addition of ferro-manganese and mild steel punchings and is used in welding steel.

(*iii*) **Cast iron thermit.** It consists of plain thermit with addition of ferro-silicon and mild steel punchings, used for welding cast iron.

(*iv*) **Wabbler thermit.** It consists of plain thermit with manganese and carbon additions and designed to produce a hard wearresistant machinable steel for building up worn wabbler ends of rolls and pinions in steel mills.

In *Thermit pressure welding,* the ends of joints to be welded are pressed together, and a mould is built around the joint. After the reaction starts, the slag is poured in first forming a glasslike surface around the joint, , and then the superheated metal added. When heat from slag and metal brings the joint upto welding temperature, the weld is made by pressure, similar to the procedure followed in resistance butt welding.

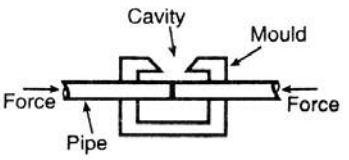

Fig. 1.5. Pressure thermit.

There is no limit to the size of weld, which can be made by thermit welding. It is employed primarily for repairing large parts that would be difficult or uneconomical to weld by other methods.

(6) **Forge Welding.** It comprises of a group of process wherein the parts to be welded are brought to suitable temperature by means of external heating and the weld is completed by pressure or blows. In all the forge-welding processes, the parts to be welded are brought to a welding temperature by means of a furnace. Pressure is applied after the parts have been properly heated. Heating must be slow because of unequal section thicknesses.

The materials most commonly joined by forge welding are wrought iron which can be obtained in the form of bars rounds, pipes, tubing, sheets and plates and low carbon steels (carbon not exceeding 0.2%) which are similarly available in a various forms. Low carbon steel and wrought iron are recommended for this type of welding because these have a large welding temperature range. This range decreases rapidly as the carbon content increases. High carbon steels and alloy steels require considerable more care in controlling temperature and producing welds.

The processes grouped under forge welding are hammer welding, die welding and roll welding. The essential difference among the three forge welding processes is in the manner in which the pressure is applied:

(*i*) In hammer welding, it is by blows of a hand hammer or machine hammer.

(*ii*) In die welding, it is either by means of a mandrel or tube rolls.

(*iii*) For roll welding , it is by means of plate rolls.

Forge welding is naturally rather slow, and there is considerable danger of an oxide scale forming on the surface. Tendency to oxidise can be counteracted somewhat by using a thick fuel bed and by covering the surfaces with a flux material which dissolves the oxides.

Clean silica sand borax in combination with sal ammonia are the two common fluxes used in forge welding. Borax, having a comparatively low fusion point, is used on high-carbon steel. It can be placed on the steel at low temperature, after chamfering, consequently supplying a protective coating or sprinkled on the steel while heating. It serves a double purpose, lowering the melting point of the oxide and preventing further oxidation.

Silica sand is cheaper than borax and can be used on the low carbon steels. It is generally sprinkled on the metal when the welding temperature is approached. Fluxes are not necessary in forge welding of wrought iron an very low-carbon steel because it is possible to melt the oxide without burning or melting the metal.

Large work may be welded in hammer forges driven by air. Such equipment is especially valuable for forming and shaping work in the plastic state and has the additional advantage of refining the grain size when worked above the critical temperature of the metal. Welded steel pipe is made mechanically by running the preheated steel strips through rolls, which form the pipe to size and apply the necessary pressure for the welding.

(7) **Brazing.** It is one of the oldest processes for joining metals by use of heat. A filler metal which melts at a temperature below the melting point of the base metal or parts to be joined is always used because the term brazing implies that the joint is made without melting the base metal.

In brazing, a non-ferrous alloy is introducing in liquid state, between the pieces of metal to be joined and allowed to soliding. Filler metal having a melting temperature of over 450°C, but lower than melting temperature of parent metal, is distributed between the surfaces by capillary attraction.

Braze welding is similar to ordinary brazing except that the filler metal is not distributed by capillary attraction.

In both, special fluxes are used for removing surface oxide and giving to the filler metal the fluidity which is necessary for wetting the joint surfaces completely.

Commonly used brazing metals and alloys are:

(*i*) Copper—Melting point 1083°C

(*ii*) Copper alloys (Brass and bronze alloys)—Melting points 870°C to 1230°C

(*iii*) Silver alloys—Melting points 620°C to 830°C

(*iv*) Aluminium alloys—Melting temperatures 550°C to 975°C.

In brazing of two pieces of metal, the joint must first be cleaned of all oil, dirt, or oxides mechanically or chemically and pieces properly filled together with proper clearance for filler metal. Borax, either alone or in combination with other salts is commonly used as a fluxing material.

(8) **Soldering.** Soldering differs from brazing in that lower temperature filler metal (below 450°C) are used in the joint. Soft solders are metals or alloys, having a melting range of 150 to 350°C, used for joining most common metals, which melt at temperatures below the melting points of the base metal and in all cases below 450°C. The soldered joint depends for its strength on alloying with the base metal and upon mechanical bonding between the parts.

Soft solders are made up of tin, tin-lead or lead with or without the addition of antimony, silver, arsenic or bismuth to impart special properties. These metals or alloys behave differently than the so-called 'Hard Solders (Silver Brazing Materials)'. The strength of the joint is determined by the adhesive quantities and the strength of these alloys.

(*i*) The joint strength obtainable is lower and may deteriorate rapidly if exposed to high temperatures or to corrosive conditions.

(*ii*) Continued stress reversals which may be produced by vibration or a constant load which may cause creep, also results in a very rapid drop in the joint strength.

Soft solders are obtainable commercially in the form of wire (or string), bars, powders or ingots.

Electric connections, wire terminals and similar small parts are typical of the joints made by soft soldering. A form of soldering known as 'wiping' is used in making lead pipe connections.

Fluxes for Soldering

The functions of a flux are (*i*) to clean the joint area (*ii*) prevent oxidation and (*iii*) lower the surface tension of the solder, thus increasing its wetting properties. Fluxes can be classified as under:

1. **Non-corrosive fluxes.** Rosin and rosin alcohol are truly non-corrosive fluxes. This type of flux requires that the parts be chemically or mechanically cleaned, yet not polished brightly since the flux has little or no cleaning power and low wettability.

A small addition of glycerine will increase the wetting properties of the flux. The addition of a small amount of lactic acid will increase the efficiency of the flux on the brass parts. The addition of a small amount of turpentine to the flux will help to reduce this stain caused by rosin.

2. **Mild fluxes.** Citric acid in water is a low cost slightly corrosive flux. If this flux is used for dip soldering, the acid should be dissolved in alcohol to reduce spatter. The addition of glycerine or sulfonated alcohol will increase the wetting action and further reduce the spatter. Levulinic acid in alcohol is widely used as flux on terne plate and tin plate in the can industry.

3. **Corrosive fluxes.** Zinc chloride and ammonium chloride (sal ammoniac) are the best known corrosive fluxes used in various soldering. They must be used singly or combined in various solvents. They are quick acting and help to produce efficient joints quickly. Zinc cut in hydrochloric (muriatic) acid, is most commonly used by tinners and repairmen in their work.

The parts to be soldered should be free from all oxide, scale, oil and dirt to insure sound joints. A flux is generally used to secure good joints except in some cases on aluminium. The material may be heated in any of several different ways:

(*i*) The most common method is to use a heated soldering iron, melting the solder directly on to the iron and heating the parts by conductivity through the molten solder or by physical contact with the iron.

(*ii*) The largest number of production irons are electrically heated.

(*iii*) In isolated locations, gas or charcoal furnaces or torches may be used.

(*iv*) Dip soldering is also a fast and efficient method of sodering light parts.

(*v*) Induction heating and resistance heating are also utilised for soldering.

Strictly speaking, soldering does not fall under the category of welding and as such shall not be dealt with in details in this book.

9. **Cold-pressure welding.** It is a method of joining non-ferrous metals by applying pressure to cause metals to flow in a manner to produce a weld. Before making a weld, the surfaces or parts to be joined must be wire-brushed thoroughly at a surface speed around 16 metres per second to remove oxide films on the surface. Other methods of cleaning appear to be satisfactory.

In making a weld, pressure is applied over a narrow strip so that the metal can flow away form the weld on both sides. It may be applied either by impact or with a slow squeezing action. Both the methods are equally effective. Pressure required for aluminium ranges from 2000 to 2800 kg/cm^2.

Spot welds by this method are rectangular in shape an in terms of gauge thickness are approximately $t \times 5t$ in size. Ring welds and continuous seam welds can also be made. Greatest success of this method of welding has been with aluminium and copper. However, zinc, lead, nickel and monel can also be joined by this method.

Some of the methods used in case of hand welding which are same for gas or electric welding are designated according to the axis of the weld:

(*i*) Flat position

(*ii*) Horizontal position

(*iii*) Vertical position

Out of these, the vertical position and overhead position welding are difficult. They require a good deal of practice and a good welder can do them quickly and efficiently. The flat and horizontal position welding are comparatively easier.

In case of pipe welding, only gas welding is used and a circular seam is used for the same. The details of gas, electric and other types of welding will be dealt in details in the following chapters of the book.

Questions

1. How did welding develope ?
2. Classify welding process ?
3. Give a brief introduction to:

(*i*) Gas welding
(*ii*) Arc welding
(*iii*) Resistance welding
(*iv*) Induction welding
(*v*) Thermit welding
(*vi*) Soldering
(*vii*) Brazing
(*viii*) Braze welding
(*ix*) Cold pressure welding.

4. What are the advantages and disadvantages of induction welding?
5. What are the most commonly used thermits ? Give their applications.
6. What are different fluxes employed in soldering? Give their properties.
7. What are the general conditions for welding?
8. What are the most commonly used brazing alloys?

Objective Types Questions

Correct answer be ticked (√)

Q.1. Metal parts cand be joined together permanently by
(*a*) Bolts and Nuts (*b*) Threaded screws
(*c*) Welding

Q.2. The process of welding consists of:
(*a*) Fusion (*b*) Pressure
(*c*) Both

Q.3. In the process of elective welding which of the following methods are used
(*a*) Arc welding (*b*) Induction welding
(*c*) Oxy-Acetylene welding

Q.4. Gas welding process employs the following electrodes:
(*a*) Carbon electrodes (*b*) Metal electrodes
(*c*) None of the above.

Q.5. Can soldering or brazing be used to join steel alloys parts together
(*a*) Yes (*b*) No.

Q.6. Can cast iron or non-ferrous metals are welded.
(*a*) Yes (*b*) No.

Q.7. Is pressure applied in thermit welding
(*a*) Yes (*b*) No.

Answers

1. (*c*)	2. (*c*)	3. (*a*+*b*)	4. (*c*)
5. (*b*)	6. (*a*)	7. (*b*)	