WELDING SHOP

PRODUCT REALISATION TECHNOLOGY PRACTICUM (IC-141P)

CENTRAL WORKSHOP

INDIAN INSTITUTE OF TECHNOLOGY MANDI

WELDING SHOP

1) INTRODUCTION

Joining two or more elements to make a single part termed as a **Fabrication process.** A fairly large number of industrial components are made by fabrication processes. Common examples are aircraft and ship bodies, building trusses, welded machine frames, sheet metal parts, etc.

The fabrication is often the most economical method and relies on raw material obtained from one of the primary manufacturing processes such as rolling and extrusion. Hence, it may be called a secondary manufacturing process.

Classification Fabrication process

The Various fabrication processes can be classified according to Method of Joining as follows.

1) Mechanical Joining by means of bolts and nuts, screws, rivets.
2) Adhesive joining by employing synthetic glues such as epoxy resins.
3) Metallurgical fusion process like Welding, Soldering and Brazing

Various fabrication processes can be classified according to Type of assembly.

1) Temporary joining process

2) Permanent. Joining process

Temporary joining process: - The joints obtained by these processes will be such that the connected parts can be separated easily without any damage. Example: - Joints obtained by brazing, soldering, bolts, and nuts. Studs and nuts, screws, etc.

Permanent Joining process: - . The joints obtained by these processes will be such that the connected parts have to be broken in order to separate them. Example: - Joints obtained by riveting, welding, etc;

Welding

Welding is the process of joining similar metals by application of heat, with or without application of pressure or filler material.

Applications of welding

It is used in the manufacture of automobile bodies, aircraft frames, railway wagons, machine frames, structural works, pressure vessels, furnaces, tanks, refrigerators, furniture, boilers, and shipbuilding.

Repair and maintenance work. For example joining broken parts, rebuilding worn-out components, etc.

Classification of welding process.

Plastic welding:

In plastic welding, the metal parts to be joined are heated to the plastic state (or above) and then fused together by applying external pressure. No filler metal is used in this process plastic welding is also called 'pressure welding processes.

Example: -Forge welding, resistance spot welding.

Fusion welding

In fusion welding process, the parts to be joined are heated above their melting temperature and then allowed to solidify without application of pressure. A filler material is used during welding process.

Example: - arc welding and gas welding.

2) BASIC THEORY

2.1 Arc Welding

Electric Arc Welding (Metal Arc Welding):-

Arc welding is a fusion method of welding that utilizes the high intensity of the arc (generated by current flow) to melt the workpieces. A solid continuous joint is formed upon cooling.

In arc welding process makes use of '**filler material'** to supply additional material to fill the gap between the workspaces. The filler material used in welding process is called '**Electrode**'. It is made of a metallic wire called 'core wire', which is of the same material or nearly the same chemical composition as that of the workpiece metal or base metal. The core wire is uniformly coated with flux.

Principle of Arc Welding:

The source of heat for arc welding process is an 'electric arc '.The arc is produced by striking the electrode on the workpiece. The electrode is momentarily separated from the workpiece by a small gap such that the arc is still maintained between the workpiece and the electrode. The electrical energy is thus converted into heat energy. The high heat at the tip of the electrode is sufficient to melt the workpiece. The tip of the electrode melts and combines with the molten metal of the workpiece thereby forming a homogeneous joint.

Types of Arc welding process

1) Carbon arc welding 2) Metal arc welding 3) Metal inert gas welding4) Tungsten inert gas welding 5) Plasma arc welding6) Submerged arc welding.

Operation

In the arc welding process the electrode holder holding the electrode forms one pole of the circuit and the parts to be welded forms the other pole. The electrode serves both to carry the arc and also acts as a filler rod to deposit the molten metal into the joint. An arc is struck by touching the tip of the electrode with the workpiece and instantaneously the electrode is separated from the workpiece by a small distance of 2-4 mm such that the arc is still maintained between the electrode and the workpiece. The temperature of the arc ranges from 5000-6000 ^{0}C. The high heat of the arc melts the workpiece metal forming a small molten metal pool. At the same time, the tip of the electrode also melts and the molten metal of the electrode is transferred into the molten metal of the workpiece in the form of globules of molten metal. The deposited metal fills the joint and bonds the joint to form a single piece of metal.

Applications: The arc welding process is used for fabrication work, repair, and maintenance work. The process finds applications in boiler and pressure vessel fabrication. Shipbuilding. Joining large pipes and penstock, building and bridge construction, automotive and aircraft industries, etc.

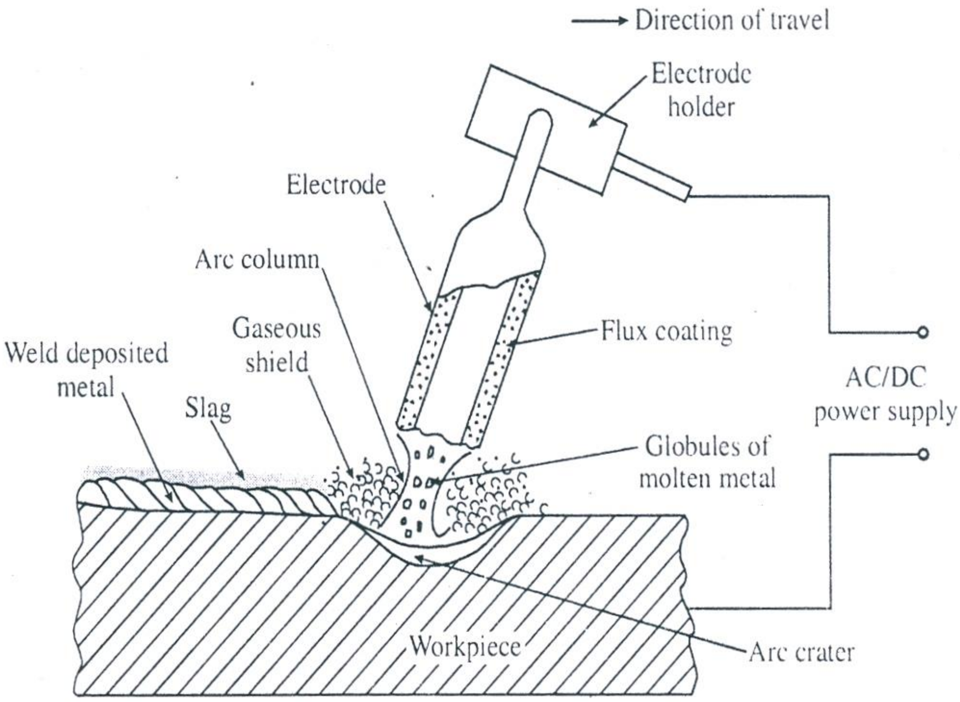


Fig. 1: Typical arc welding process

Arc Welding Machine

The source of heat for arc welding process is an ‘electric arc ‘. To supply the current for welding, two types of power sources are available, viz; alternating current (A.C) and direct current (D.C).

Current requirements:-

20-200 amperes for thin materials

20-300 amperes for general work

300- 600amperes for heavy work.

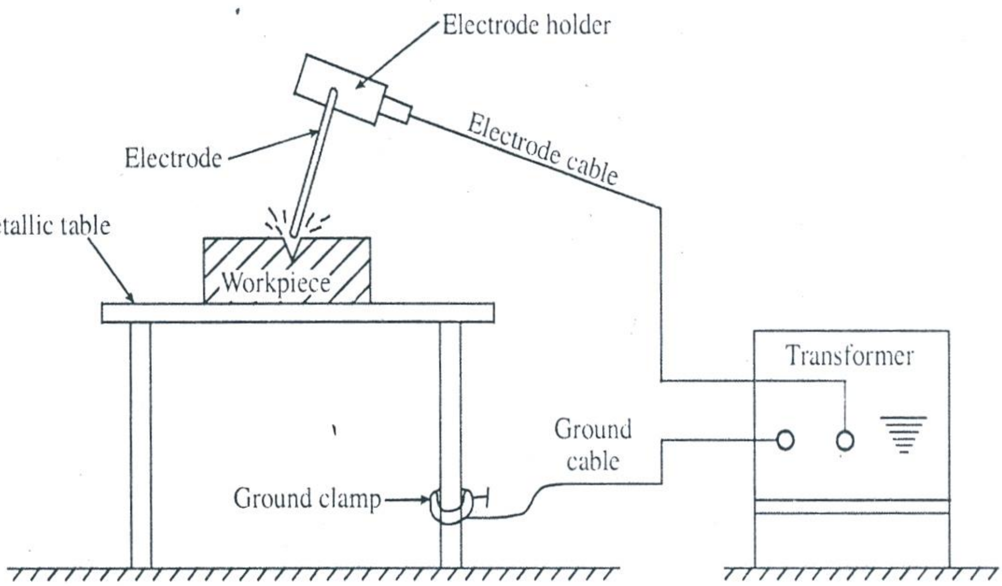


Fig. 2: AC circuit for arc welding

Welding using A.C current: Fig shows the schematic representation of an A.C welding circuit.

The welding circuit consists of

- Step–down transformer-to reduce the usual supply voltage (220-440 V) to that required for welding (15-90V)
- Two cables – one cable, to the electrode holder holding the electrode and other, the ground cable
- Ground clamp – used to connect one end of the ground cable to the workpiece or to the table carrying the workpiece
- Electrode holder and
- Electrode

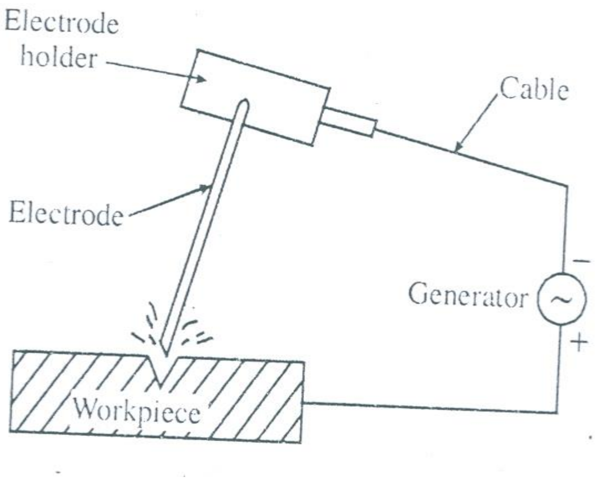


Fig. 3: DC circuit for arc welding

Welding using D.C current:

The schematic representation of a D.C welding circuit is shown in fig

In D.C welding, the electrode acts as one terminal and the workpiece as the other terminal (either +ve or -ve) with D.C generator, greater heat is generated at the positive pole. Hence. The workpiece should be connected to the positive pole of the D.C generator and the electrode to the negative pole in order to melt a greater mass of metal in the workpiece material.

- In A.C, the melting rate cannot be controlled, because equal heat is generated at the electrode and the workpiece.

Comparison between A.C and D.C in Welding

Alternating Current (from Transformer)

- More efficiency
- Power consumption less
- Cost of equipment is less
- Higher voltage – hence not safe
- Not suitable for welding non-ferrous metals
- Not preferred for welding thin sections
- Any terminal can be connected to the work or electrode

Direct Current (from Generator)

- Less efficiency
- Power consumption more
- Cost of equipment is more
- Low voltage – safer operation
- suitable for both ferrous and Non-ferrous metals
- preferred for welding thin sections
- Positive terminal connected to the work
- Negative terminal connected to the electrode

Electrodes used in Arc welding:

Welding electrodes used in arc welding are of two types.

1) Consumable electrodes

2) Non-consumable electrodes.

Consumable electrodes:

These are made of metallic wire and are consumed during the welding process. The selection of a particular metal for the electrode depends upon its purpose and the chemical composition of the workpiece metal to be welded. Consumable electrodes are further classified as coated electrodes and plain/bare electrodes.

Coated electrodes:-In these electrodes, the metallic wire is coated with ‘flux ‘.During welding, the workpiece melts and at the same time, the tip of the electrode also melts. As the globules of molten metal pass from the electrode to the workpiece, they absorb oxygen and nitrogen from the atmospheric air. This causes the formation of some non- metallic constituents that are trapped in the solidifying weld metal and thereby decrease the strength of the joint. In order to avoid this, a ‘flux’ is coated on the metallic wire.

Flux: A flux is a “material used to prevent, dissolve, or facilitate removal of oxides and other undesirable surface substances”.

Various constituents like titanium oxide, cellulose, manganese oxide, calcium carbonates, mica, iron oxide, etc. are used as flux materials for coating.

The flux coated on the electrode performs the following functions.

- prevents oxidation of molten metal
- helps in the removal of oxides and other undesirable substances present on the surface of the workpiece
- Chemically reacts with the oxides and forms a slag. The slag floats and covers the top portion of the molten metal thereby preventing it from rapid cooling.
- To remove any oxide formed.
- To stabilize the arc
- To make welding easy.
- To avoid difficulties in welding.

Plain / Bare electrode: The metallic wire (core wire) is left plain or uncoated with flux. These electrodes do not prevent oxidation of the weld and hence the joint obtained is weak.

Non –consumable electrode: -

Non-consumable Electrodes are made of carbon, graphite or tungsten that does not get consumed during welding.

Oxidation

Metals in molten condition absorb oxygen from atmosphere and form metallic oxides. This process is known as oxidation. The formation of metallic oxides must be prevented. To prevent oxidation, we use coated electrodes.

Advantages of Arc welding:

- Most efficient way to join metals
- Lowest-cost joining method
- Affords lighter weight through better utilization of materials
- Joins all commercial metals
- Provides design flexibility

Limitations of Arc welding:

- Manually applied, therefore high labor cost.
- Need high energy causing danger
- Not convenient for disassembly.
- Defects are hard to detect at joints.

2.2 Gas Welding

Gas Welding Process:

Principle: Gas welding is a fusion type of welding that utilizes a strong flame, generated by the combustion of gases to melt the workpiece. The gases are mixed in proper proportions in a welding blowpipe called ‘welding torch’. A solid continuous joint is formed upon cooling.
The combination of gases used in this process is

- Mixture of oxygen and acetylene
- Mixture of oxygen and hydrogen.

Oxy-Acetylene welding

Oxygen and acetylene mixture are most commonly used in gas welding and the process is widely called oxy-acetylene process. It consists of supply of oxygen and acetylene under pressure in cylinders, pressure regulators, a torch, hoses, and accessories like goggles and lighter. The oxygen and acetylene cylinders are connected to the torch through pressure regulators and hoses. The regulator consists of two pressure gauges. One for indicating the pressure within the cylinder and the other shows the pressure of the gas fed into torch, which may be regulated. The torch mixes the two gases and the flame may be controlled by adjusting the oxygen and acetylene supply.

Gas Welding Equipment.

1. Gas Cylinders

    Pressure

        Oxygen – 125 kg/cm2

        Acetylene – 16 kg/cm2

2. Regulators

    Working pressure of oxygen 1 kg/cm2

    Working pressure of acetylene 0.15 kg/cm2

    Working pressure varies depends upon the thickness of the workpieces welded.

3. Pressure Gauges
4. Hoses
5. Welding torch
6. Check valve
7. Non return valve

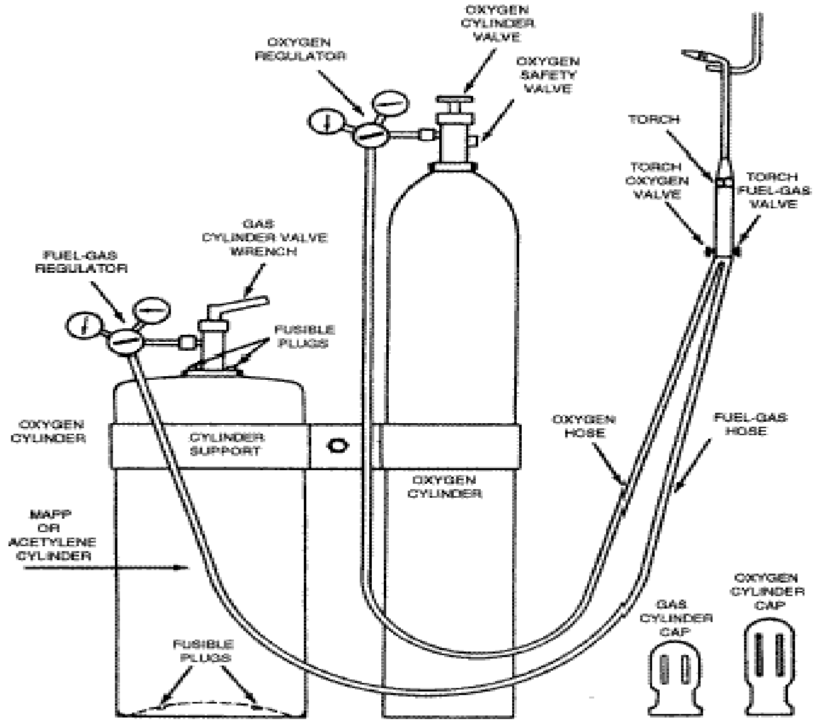


Fig. 4: Gas welding setup

Some of the Important points related to Gas Welding.

- Sound weld is obtained by selecting proper size of flame, filler material and method of moving torch
- The temperature generated during the process is 3300^0C
- When the metal is fused, oxygen from the atmosphere and the torch combines with molten metal and forms oxides, results in defective weld
- Fluxes are added to the welded metal to remove oxides
- Common fluxes used are made of sodium, potassium. Lithium and borax.
- Flux can be applied as paste, powder, liquid. Solid coating or gas.

Types of flames produced in gas welding

Three types of flames can be produced at the torch tip by regulating the ratio of oxygen to acetylene**.** : (a) Neutral flame; (b) oxidizing flame; (c) carburizing, or reducing flame.

Neutral flame (Oxygen and Acetylene are mixed in equal proportions)

A neutral flame is produced when approximately equal volumes of oxygen and acetylene are burnt at the torch tip (I have a balance of fuel gas and oxygen). The flame has a nicely defined inner whitish cone surrounded by sharp blue flame. The temperature of the neutral flame is around 3200^{0}C. . Used for welding steels, aluminium, copper and cast iron, etc and can also be used for metal cutting.

Oxidizing flame (Excess of Oxygen)

If more oxygen is added to the Neutral flame, the cone becomes darker and more pointed, while the envelope becomes shorter and fiercer is called Oxidizing flame. It has the highest temperature of about 3400^{0}C. Used for welding brass and brazing operation

Carburizing flame (Excess of Acetylene):-

If the volume of oxygen supplied to the Neutral flame is reduced, the resulting flame will be a Carburizing or reducing flame i.e., rich in acetylene. A reducing flame can be recognized acetylene feather that exists between the inner cone and the outer envelope. Has the highest temperature about 3000^{0}C .The outer flame envelope is longer than that of the neutral flame and is usually much brighter in colour . This type of flame is used for welding non- ferrous metals.

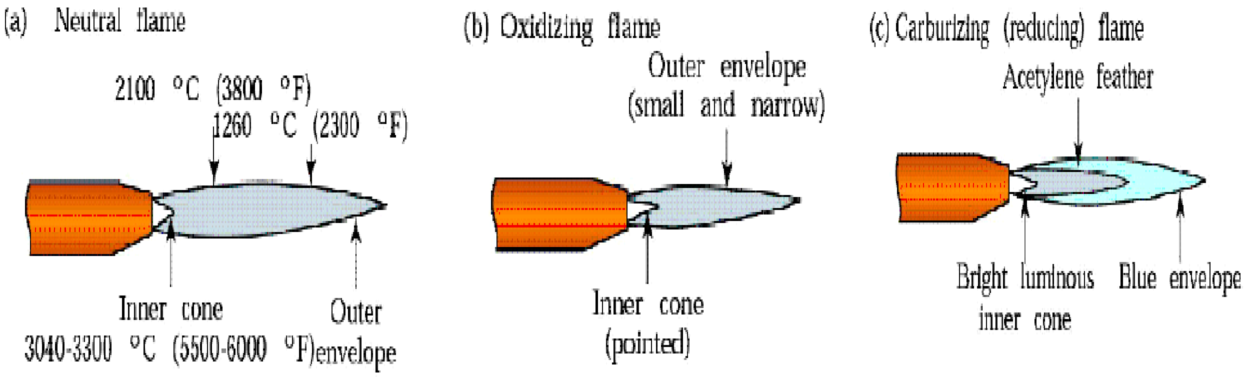


Fig. 5: Types of flame

Soldering

Soldering is a method of joining similar or dissimilar metals by means of filler metal whose melting temperature is below 450 ^{0}C. The filler metal usually called 'solder' is an alloy of tin and lead in various proportions.

Soldering is commonly used for joining circuits in electronic components. In sheet metal work and in sealing of metal containers

Brazing

Brazing is a method of joining similar or dissimilar metals by means of a filler metal whose melting temperature is above 450 ^{0}C, but below the melting point of the base metal.

The filler metal called 'spelter' is a non –ferrous metal or alloy. Copper and copper alloys Silver and silver alloys and aluminum alloys are the most commonly used filler metals for brazing.

Welding Tools and Safety Equipments

Electrode holder:- It is used to hold the electrode during welding refer fig it consists of a handle and a pair of jaws operated by means of spring. The electrode holder forms one element of the welding circuit. One cable (wire) from the transformer is connected to the electrode. Due to this reason, the electrode holder should be well insulated.

C**hipping Hammer**:-During welding, the flux coated on the electrode reacts with the oxides and other impurities and forms a slag. The slag being lighter floats over the surface of the molten metal and on solidification forms a thin layer over the weld bead.

A chipping hammer is used for removing the slag formed on the weld bead. One end of the chipping hammer is sharpened like a cold chisel and the other end to a blunt, round point.

Material- Tool steel

Wire brush: - The wire brush usually made up of steel wire is used for cleaning the workpiece before and after welding.

Tong:-A tong is used for holding the workpiece during/after welding.

Ground clamp: - Ground clamp is connected to the end of the 'ground cable'. Ground cable forms one pole of A.C.

Goggles and Hand shields:-The sparks produced during welding are harmful and should not be seen with naked eyes. Goggles are used to protect the eyes of the welder form the 'rays of the arc' and 'flying particles of hot metal'. Hand shields and helmet type shields are used to protect the eyes and also the face of the welder.

Hand gloves:-Hand gloves are used to protect the hands from the sparks produced during welding and also from the heat of the electrode holder.

C- Clamp

The C-Clamp shown in fig is used for holding the job firmly on the work table during welding.

Common welding terms

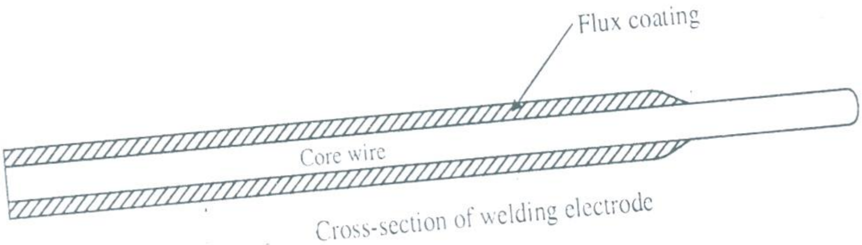
Base metal: - The metal to be joined or cut is termed as the base metal.

Bead or weld bead:-Bead is the metal added during single pass of welding. The bead appears as a separate material from the base metal.

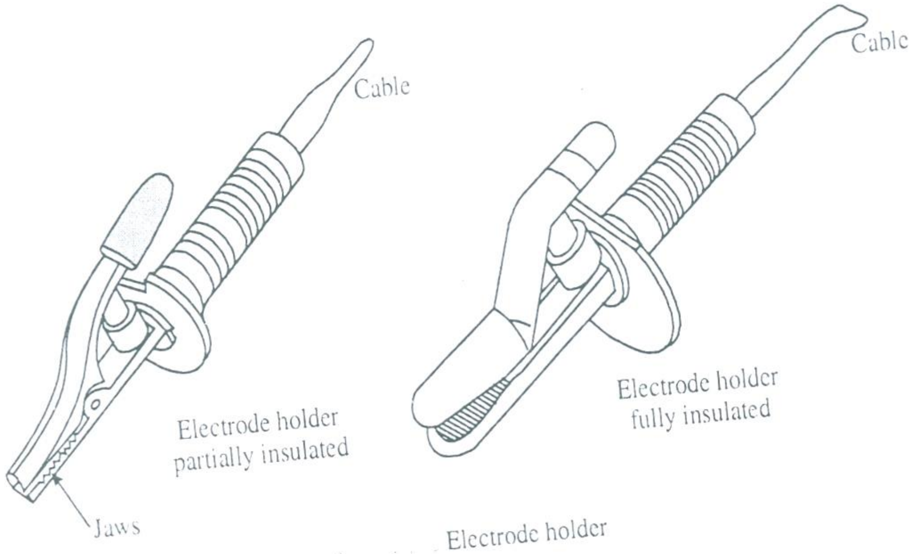
Striking voltage: - The minimum voltage at which the arc may be struck.

Fillet weld:- The metal fused into the corner of a joint made of two pieces placed at approximately 90 degrees to each other.

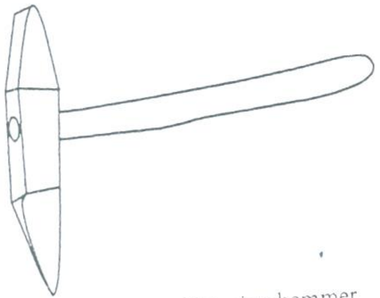
Tack weld- A small weld, generally used to temporarily hold the two work pieces together during actual welding, is the tack weld**.**

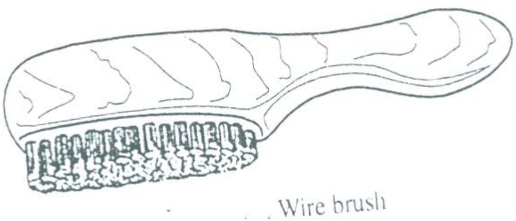


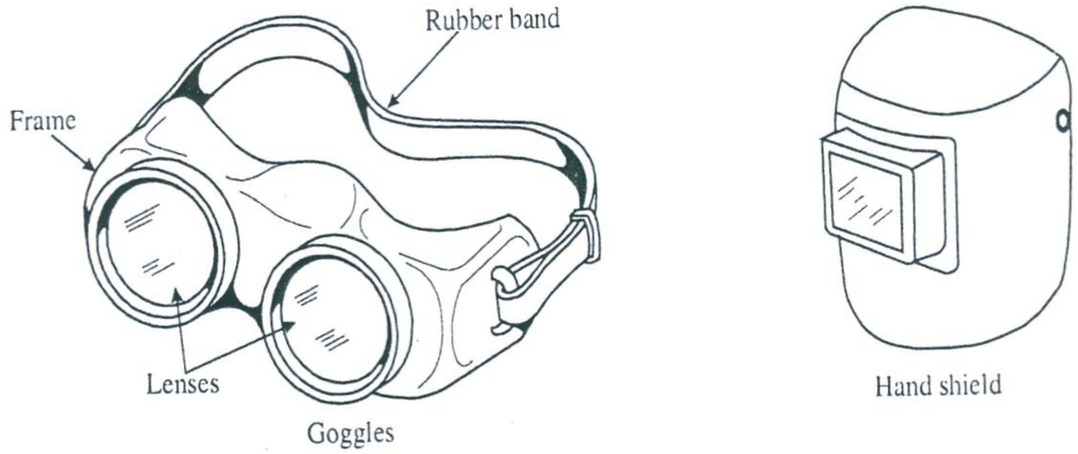
Cross-section of welding electrode



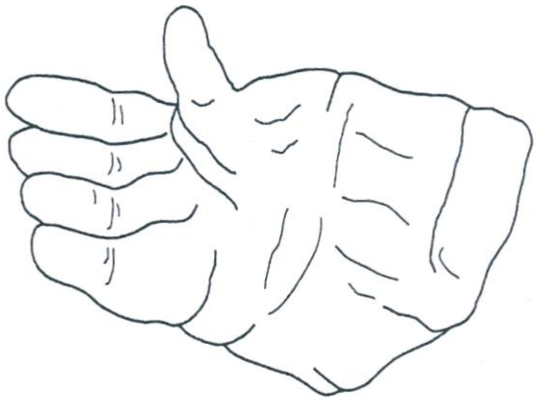
Electrode holder


Chipping hammer

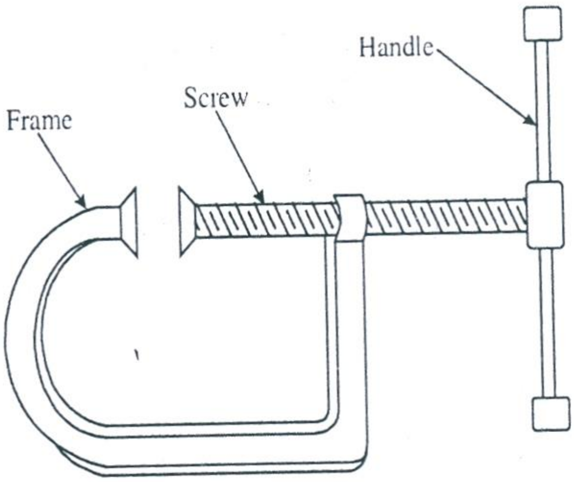

Wire brush



Goggles/Hand shield



Hand gloves



C-clamp

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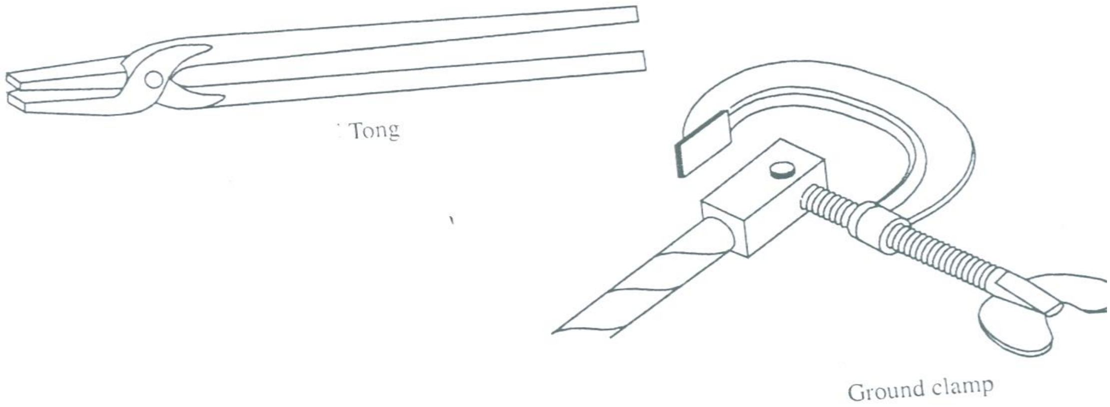


Fig. 6: Tools required during welding

Weld Joints: Different joints are adopted in welding process.

a) **Butt joint:** A joint between two pieces lying in the same plane is called butt joint.
b) **Lap joint:** A joint between pieces, over lapping each other. They may be of single fillet or double fillet joint. This does not require edge preparation.
c) **Corner joint:** A Joint forming a corner between pieces located at approximately right angles to each other is known as corner joint. They are of flush corner joint , half open corner joints, full open corner joint.
d) **T-joint:** A Joint between pieces located at a right angle, forming a 'T' is known as a t-joint. They are of square –T or plain T-joint, single bevel T- Joint, double bevel T-joint. This joint requires edge preparation except for plain T-joint.

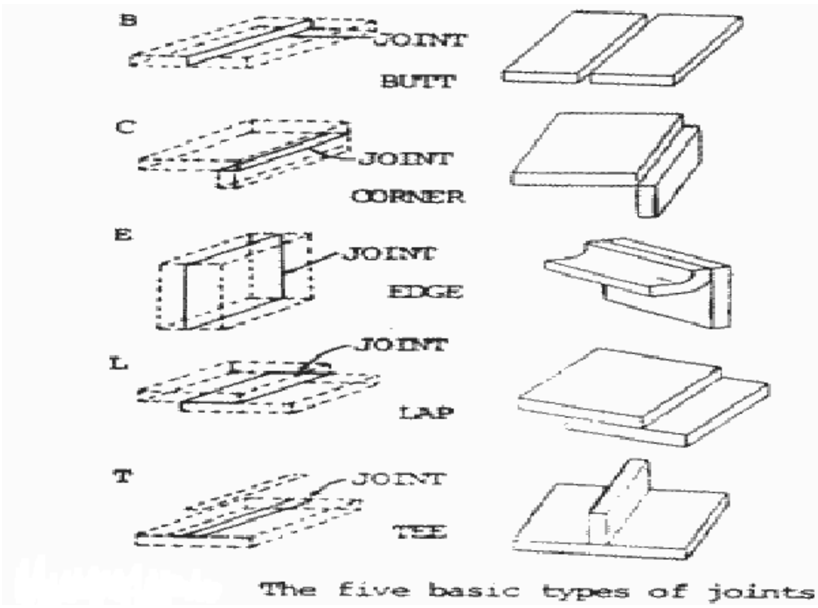


Fig. 7: Types of weld joint

Safe and correct practices.

1) Welding should be carried out in a well-ventilated place and the place should be free of inflammable materials.
2) All the safety gadgets are to be used strictly.
3) Care should be taken to avoid dragging the welding cable and checked periodically for any open insulation.
4) The cables should be prevented from coming into contact with hot metal, water, oil, etc.
5) Always keeps fire-fighting equipment like water, sand, gas fire extinguisher, for any fire hazard emergency.
6) Before welding, the parts to be welded are thoroughly cleaned from dust, foreign matter, oil grease, rust, etc.
7) The instructions given in the manufacture's catalogue are to be strictly followed.

2.3 Spot Welding

Spot welding (RSW) is a process in which contacting metal surfaces are joined by the heat obtained from resistance to electric current flow. Work-pieces are held together under pressure exerted by electrodes. Typically the sheets are in the 0.5 to 3 mm (0.020 to 0.12 in) thickness range. The process uses two shaped copper alloy electrodes to concentrate welding current into a small "spot" and to simultaneously clamp the sheets together. Forcing a large current through the spot will melt the metal and form the weld. The attractive feature of spot welding is a lot of energy can be delivered to the spot in a very short time (approximately ten milliseconds). That permits the welding to occur without excessive heating to the rest of the sheet.

The amount of heat (energy) delivered to the spot is determined by the resistance between the electrodes and the amperage and duration of the current. The amount of energy is chosen to match the sheet's material properties, its thickness, and type of electrodes. Applying too little energy won't melt the metal or will make a poor weld. Applying too much energy will melt too much metal, eject molten material, and make a hole rather than a weld. Another attractive feature of spot welding is the energy delivered to the spot can be controlled to produce reliable welds.

Applications:

Spot welding is typically used when welding particular types of sheet metal. Thicker stock is more difficult to spot weld because the heat flows into the surrounding metal more easily. Spot welding can be easily identified on many sheet metal goods, such as metal buckets. Aluminium alloys can be spot welded, but their much higher thermal conductivity and electrical conductivity requires higher welding currents. This requires larger, more powerful, and more expensive welding transformers.

The most common application of spot welding is in the automobile manufacturing industry, where it is used almost universally to weld the sheet metal to form a car. Spot welders can also be completely automated, and many of the industrial robots found on assembly lines are spot welders.

Spot welding is also used is in the orthodontist's clinic, where small scale spot welding equipment is used when resizing metal "molar bands" used in orthodontics.

Another application is spot welding straps to nickel-cadmium or nickel-metal-hydride cells in order to make batteries. The cells are joined by spot welding thin nickel straps to the battery terminals. Spot welding can keep the battery from getting too hot, as might happen if conventional soldering were done.

Good design practice must always allow for adequate accessibility. Connecting surfaces should be free of contaminants, such as scale, oil, and dirt, for quality welds. Metal thickness is generally not a factor in determining good welds.

Processing and Equipment:

Spot welding involves three stages; the first of which involves the electrodes being brought to the surface of the metal and applying a slight amount of pressure. The current from the electrodes is then applied briefly after which the current is removed but the electrodes remain in place in order for the material to cool. Weld times range from 0.01 sec to 0.63 sec depending on the thickness of the metal, the electrode force and the diameter of the electrodes themselves.

The equipment used in the spot welding process consists of tool holders and electrodes. The tool holders function as a mechanism to hold the electrodes firmly in place and also support optional water hoses which cool the electrodes during welding. Tool holding methods include a paddle-type, light duty, universal, and regular offset. The electrodes generally are made of a low resistance alloy, usually copper, and are designed in many different shapes and sizes depending on the application needed.

The two materials being welded together are known as the workpieces and must conduct electricity. The width of the workpieces is limited by the throat length of the welding apparatus and ranges typically from 5 to 50 inches. Workpiece thickness can range from 0.008in. to 1.25in.

After the current is removed from the workpiece, it is cooled via the coolant holes in the center of the electrodes. Both water and a brine solution may be used as coolants in spot welding mechanisms.

Tool Styles:

Electrodes used in spot welding can vary greatly with different applications. Each tool style has a different purpose. Radius style electrodes are used for high heat applications, electrodes with a truncated tip for high pressure, eccentric electrodes for welding corners, offset eccentric tips for reaching into corners and small spaces, and finally offset truncated for reaching into the workpiece itself.

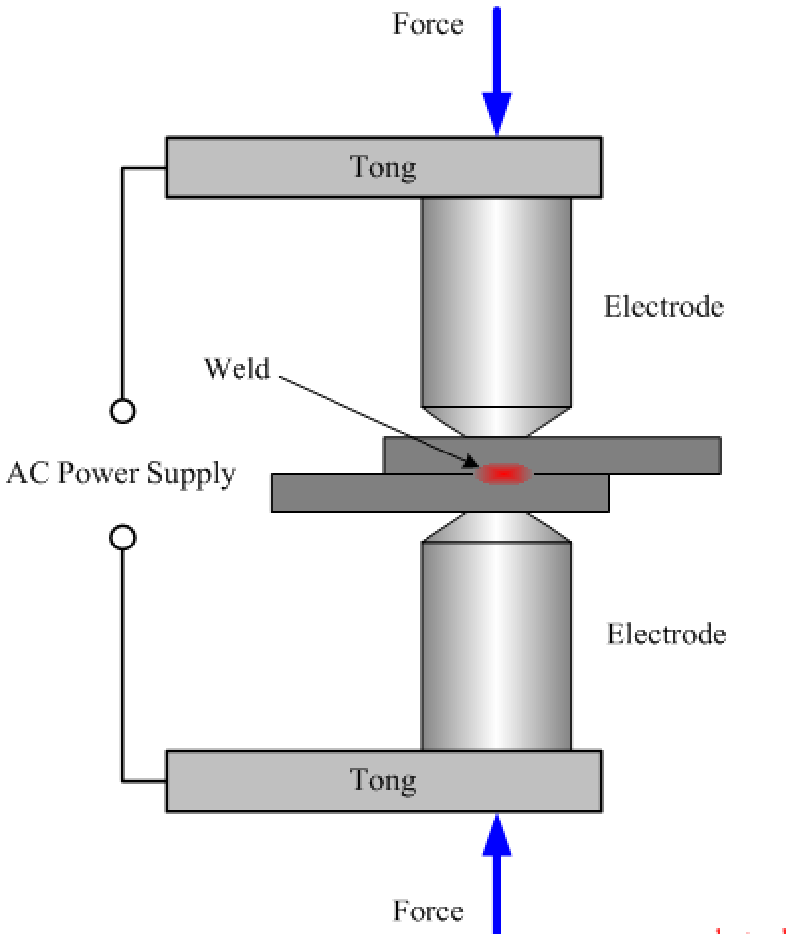


Fig. 8: Setup of spot resistance welding

2.4 Brazing

Introduction:

Brazing is a metal-joining process whereby a filler metal is heated above melting point and distributed between two or more close-fitting parts by capillary action. The filler metal is brought slightly above its melting (liquidus) temperature while protected by a suitable atmosphere, usually a flux. It then flows over the base metal (known as wetting) and is then cooled to join the work-pieces together. It is similar to soldering, except the temperatures used to melt the filler metal are higher.

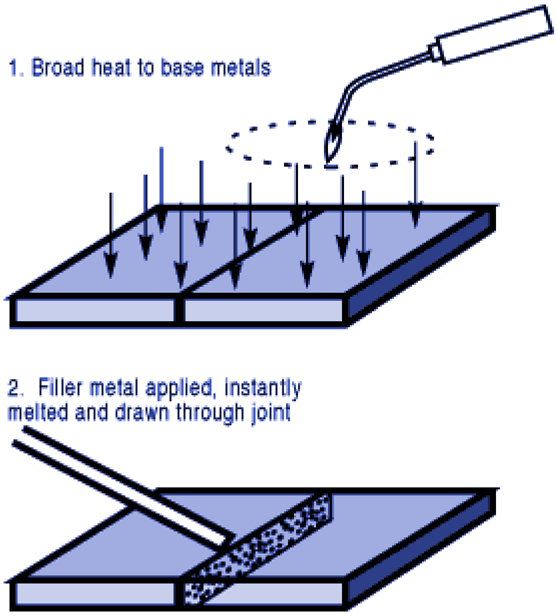


Fig. 9: Schematic of brazing

Fundamentals:

In order to obtain high-quality brazed joints, parts must be closely fitted, and the base metals must be exceptionally clean and free of oxides. Joint clearances of 0.03 to 0.08 mm (0.0012 to 0.0031 in) are recommended for the best capillary action and joint strength. However, some brazing operations can have joint clearances around 0.6 mm (0.024 in). Cleanliness of the brazing surfaces is important, as any contamination can cause poor wetting (flow). The two main methods for cleaning parts, prior to brazing are chemical cleaning and abrasive or mechanical cleaning. In the case of mechanical cleaning, it is important to maintain the proper surface roughness as wetting on a rough surface occurs much more readily than on a smooth surface of the same geometry.

Another important consideration is the effect of temperature and time on the quality of brazed joints. As the temperature of the braze alloy is increased, the alloying and wetting action of the filler metal increases. In general, the brazing temperature selected must be above the melting point of the filler metal. However, there are several factors that influence the joint designer's temperature selection. The best temperature is usually selected so as to:

(1) Be the lowest possible braze temperature, (2) minimize any heat effects on the assembly, (3) keep filler metal/base metal interactions to a minimum, and (4) maximize the life of any fixtures or jigs used. In some cases, a higher temperature may be selected to allow for other factors in the design (e.g. to allow the use of different filler metal, or to control metallurgical effects, or to sufficiently remove surface contamination). The effect of time on the brazed joint primarily affects the extent to which the aforementioned effects are present; however, in general, most production processes are selected to minimize brazing time and the associated costs. This is not always the case, however, since in some non-production settings, time and cost are secondary to other joint attributes (e.g. strength, appearance).

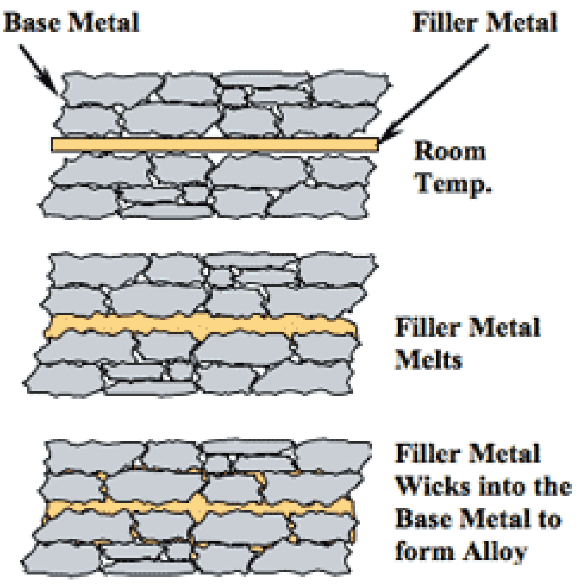


Fig. 10: Mechanism of brazing

Flux:

In the case of brazing operations not contained within an inert or reducing atmosphere environment (i.e. a furnace), flux is required to prevent oxides from forming while the metal is heated. The flux also serves the purpose of cleaning any contamination left on the brazing surfaces. Flux can be applied in any number of forms including flux paste, liquid, powder or pre-made brazing pastes that combine flux with filler metal powder. Flux can also be applied using brazing rods with a coating of flux, or a flux core. In either case, the flux flows into the joint when applied to the heated joint and is displaced by the molten filler metal entering the joint. Excess flux should be removed when the cycle is completed because flux left in the joint can lead to corrosion, impede joint inspection, and prevent further surface finishing operations. Phosphorus-containing brazing alloys can be self-fluxing when joining copper to copper. Fluxes are generally selected based on their performance on particular base metals. To be effective, the flux must be chemically compatible with both the base metal and the filler metal being used. Self-fluxing phosphorus filler alloys produce brittle phosphides if used on iron or nickel. As a general rule, longer brazing cycles should use less active fluxes than short brazing operations.

ASTM Spec #B-73-29	Percent				Melts°F	Flows°F	Color
	Silver	Copper	Zinc	Cadmium			
	9	53	38		1450	1565	
1	10	52		.05	1510	1600	Yellow
	*15	80		(5% Phos)	1185	1300	Gray
2	20	45	35	.05	1430	1500	Yellow
3	20	45	30	.05	1430	1500	Yellow
	30	38	32		1370	1410	
	**35	26	21	18	1125	1295	Almost white
	40				1135	1205	Almost white
4	45	30	25		1250	1370	Almost white
	**45	15	16	24	1125	1145	Almost white
5	50	34	16		1280	1425	Almost white
	**50	15.5	16.5	18	1160	1175	Almost white
	**50	15.5	15.5	16 (3% Ni)	1195	1270	White
6	65	20	15		1280	1325	White
7	70	20	10		1335	1390	White
8	80	16	4		1360	1490	White

*–A special alloy containing phosphorus and used only on nonferrous metals
**–Some special alloys of silver using a fairly high cadmium content

Filler materials:

A variety of alloys are used as filler metals for brazing depending on the intended use or application method. In general, braze alloys are made up of 3 or more metals to form an alloy with the desired properties. The filler metal for a particular application is chosen based on its ability to: wet the base metals, withstand the service conditions required, and melt at a lower temperature than the base metals or at a very specific temperature.

Braze alloy is generally available as rod, ribbon, powder, paste, cream, wire and preforms (such as stamped washers). Depending on the application, the filler material can be pre-placed at the desired location or applied during the heating cycle. For manual brazing, wire and rod forms are generally used as they are the easiest to apply while heating. In the case of furnace brazing, alloy is usually placed beforehand since the process is usually highly automated. Some of the more common types of filler metals used are:

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

Types of Brazing:

Torch brazing

Torch brazing is by far the most common method of mechanized brazing in use. It is best used in small production volumes or in specialized operations. There are three main categories of torch brazing in use: manual, machine, and automatic torch brazing.

Manual torch brazing is a procedure where the heat is applied using a gas flame placed on or near the joint being brazed. The torch can either be hand held or held in a fixed position depending on if the operation is completely manual or has some level of automation. Manual brazing is most commonly used on small production volumes or in applications where the part size or configuration makes other brazing methods impossible. The main drawback is the high labour cost associated with the method as well as the operator skill required to obtain quality brazed joints. The use of flux or self-fluxing material is required to prevent oxidation. Torch brazing of copper can be done without the use of flux if it is brazed with an oxygen & hydrogen gas torch set up vs. oxygen and other flammable gasses.

Machine torch brazing is commonly used where a repetitive braze operation is being carried out. This method is a mix of both automated and manual operations with an operator often placing brazes material, flux and jigging parts while the machine mechanism carries out the actual braze. The advantage of this method is that it reduces the high labour and skill requirement of manual brazing. The use of flux is also required for this method as there is no protective atmosphere, and it is best suited to small to medium production volumes.

Automatic torch brazing is a method that almost eliminates the need for manual labour in the brazing operation, except for loading and unloading of the machine. The main advantages of this method are: high production rate, uniform braze quality, and reduced operating cost. The equipment used is essentially the same as that used for Machine torch brazing, with the main difference being that the machinery replaces the operator in the part preparation.

Furnace brazing:

Furnace brazing is a semi-automatic process used widely in industrial brazing operations due to its adaptability to mass production and use of unskilled labour. There are many advantages of furnace brazing over other heating methods that make it ideal for mass production. One main advantage is the ease with which it can produce large numbers of small parts that are easily jigged or self-locating. The process also offers the benefits of a controlled heat cycle (allowing use of parts that might distort under localized heating) and no need for post braze cleaning. Common atmospheres used include: inert, reducing or vacuum atmospheres all of which protect the part from oxidation. Some other advantages include: low unit cost when used in mass production, close temperature control, and the ability to braze multiple joints at once. Furnaces are typically heated using either electric, gas or oil depending on the type of furnace and application. However, some of the disadvantages of this method include: high capital equipment cost, more difficult design considerations and high power consumption.
There are four main types of furnaces used in brazing operations: batch type; continuous; retort with controlled atmosphere; and vacuum.

Batch type furnaces have relatively low initial equipment costs and heat each part load separately. It is capable of being turned on and off at will which reduces operating expenses when not in use. These furnaces are well suited to medium to large volume production and offer a large degree of flexibility in type of parts that can be brazed. Either controlled atmospheres or flux can be used to control oxidation and cleanliness of parts.

Continuous type furnaces are best suited to a steady flow of similar-sized parts through the furnace. These furnaces are often conveyor fed, allowing parts to be moved through the hot zone at a controlled speed. It is common to use either controlled atmosphere or pre-applied flux in continuous furnaces. In particular, these furnaces offer the benefit of very low manual labour requirements and so are best suited to large scale production operations.

Retort-type furnaces differ from other batch-type furnaces in that they make use of a sealed lining called a "retort". The retort is generally sealed with either a gasket or is welded shut and filled completely with the desired atmosphere and then heated externally by conventional heating elements. Due to the high temperatures involved, the retort is usually made of heat resistant alloys that resist oxidation. Retort furnaces are often either used in a batch or semi-continuous versions.

A vacuum furnace is a relatively economical method of oxide prevention and is most often used to braze materials with very stable oxides (aluminium, titanium, and zirconium) that cannot be brazed in atmosphere furnaces. Vacuum brazing is also used heavily with refractory materials and other exotic alloy combinations unsuited to atmosphere furnaces. Due to the absence of flux or a reducing atmosphere, the part cleanliness is critical when brazing in a vacuum. The three main types of vacuum furnace are single-wall hot retort, double-walled hot retort, and cold-wall retort. Typical vacuum levels for brazing range from pressures of 1.3 to 0.13 pascals (10^{-2} to 10^{-3} Torr) to 0.00013 Pa (10^{-6} Torr) or lower. Vacuum furnaces are most commonly batch-type, and they are suited to medium and high production volumes.

Silver brazing:

Silver brazing, sometimes known as a silver soldering or hard soldering, is brazing using silver alloy based filler. These silver alloys consist of many different percentages of silver and other metals, such as copper, zinc, and cadmium.

Brazing is widely used in the tool industry to fasten hard-metal (carbide, ceramics, cermet, and similar) tips to tools such as saw blades. "Pretinning" is often done: the braze alloy is melted onto the hard-metal tip, which is placed next to the steel and re-melted. Pretinning gets around the problem that hard-metals are hard to wet.

Brazed hard-metal joints are typically two to seven mils thick. The braze alloy joins the materials and compensates for the difference in their expansion rates. In addition, it provides a cushion between the hard carbide tip and the hard steel which softens impact and prevents tip loss and damage, much as the suspension on a vehicle helps prevent damage to both the tires and the vehicle. Finally, the braze alloy joins the other two materials to create a composite structure, much as layers of wood and glue create plywood.

The standard for braze joint strength in many industries is a joint that is stronger than either base material, so that when under stress, one or other of the base materials fails before the joint.

One special silver brazing method is called pinbrazing or pin brazing. It has been developed especially for connecting cables to railway track or for cathodic protection installations. The method uses a silver-and flux-containing brazing pin which is melted down in the eye of a cable lug. The equipment is normally powered from batteries.

Braze welding:

Braze welding is the use of a bronze or brass filler rod coated with flux to join steel work-pieces. The equipment needed for braze welding is basically identical to the equipment used in brazing. Since braze welding usually requires more heat than brazing, acetylene or methylacetylene-propadiene (MPS) gas fuel is commonly used. The name comes from the fact that no capillary action is used.

Braze welding has many advantages over fusion welding. It allows the joining of dissimilar metals, minimization of heat distortion, and can reduce the need for extensive pre-heating. Additionally, since the metals joined are not melted in the process, the components retain their original shape; edges and contours are not eroded or changed by the formation of a fillet. Another side effect of braze welding is the elimination of stored-up stresses that are often present in fusion welding. This is extremely important in the repair of large castings. The disadvantages are the loss of strength when subjected to high temperatures and the inability to withstand high stresses.

Carbide, cermet and ceramic tips are plated and then joined to steel to make tipped band saws. The plating acts as a braze alloy.

Cast iron "welding":

The "welding" of cast iron is usually a brazing operation; with a filler rod made chiefly of nickel being used although true welding with cast iron rods is also available. Ductile cast iron pipe may be also "cadwelded," a process that connects joints by means of a small copper wire fused into the iron when previously ground down to the bare metal, parallel to the iron joints being formed as per hub pipe with neoprene gasket seals. The purpose behind this operation is to use electricity along with the copper for keeping underground pipes warm in cold climates.

Vacuum brazing:

Vacuum brazing is a materials joining technique that offers significant advantages: extremely clean, superior, flux-free braze joints of high integrity and strength. The process can be expensive because it must be performed inside a vacuum chamber vessel. Temperature uniformity is maintained on the workpiece when heating in a vacuum, greatly reducing residual stresses due to slow heating and cooling cycles. This, in turn, can significantly improve the thermal and mechanical properties of the material, thus providing unique heat treatment capabilities. One such capability is heat-treating or age-hardening the workpiece while performing a metal-joining process, all in a single furnace thermal cycle.

Vacuum brazing is often conducted in a furnace; this means that several joints can be made at once because the whole workpiece reaches the brazing temperature. The heat is transferred using radiation, as many other methods cannot be used in a vacuum.

Dip brazing:

Dip brazing is especially suited for brazing aluminium because air is excluded, thus preventing the formation of oxides. The parts to be joined are fixtured and the brazing compound applied to the mating surfaces, typically in slurry form. Then the assemblies are dipped into a bath of molten salt (typically NaCl, KCl and other compounds) which functions both as heat transfer medium and flux.

Advantages and disadvantages:

Brazing has many advantages over other metal-joining techniques, such as welding. Since brazing does not melt the base metal of the joint, it allows much tighter control over tolerances and produces a clean joint without the need for secondary finishing. Additionally, dissimilar metals and non-metals (i.e. metalized ceramics) can be brazed. In general, brazing also produces less thermal distortion than welding due to the uniform heating of a brazed piece. Complex and multi-part assemblies can be brazed cost-effectively. Welded joints must sometimes be ground flush, a costly secondary operation that brazing does not require because it produces a clean joint. Another advantage is that the brazing can be coated or clad for protective purposes. Finally, brazing is easily adapted to mass production and it is easy to automate because the individual process parameters are less sensitive to variation.

One of the main disadvantages is the lack of joint strength as compared to a welded joint due to the softer filler metals used. The strength of the brazed joint is likely to be less than that of the base metal(s) but greater than the filler metal. Another disadvantage is that brazed joints can be damaged under high service temperatures. Brazed joints require a high degree of base-metal cleanliness when done in an industrial setting. Some brazing applications require the use of adequate fluxing agents to control cleanliness. The joint colour is often different from that of the base metal, creating an aesthetic disadvantage.

2.5 Soldering

Introduction:

Soldering is a process in which two or more metal items are joined together by melting and flowing a filler metal (solder) into the joint, the filler metal having a lower melting point than the workpiece. Soldering differs from welding in that soldering does not involve melting the workpieces. In brazing, the filler metal melts at a higher temperature, but the workpiece metal does not melt. Formerly nearly all solders contained lead, but environmental concerns have increasingly dictated use of lead-free alloys for electronics and plumbing purposes.

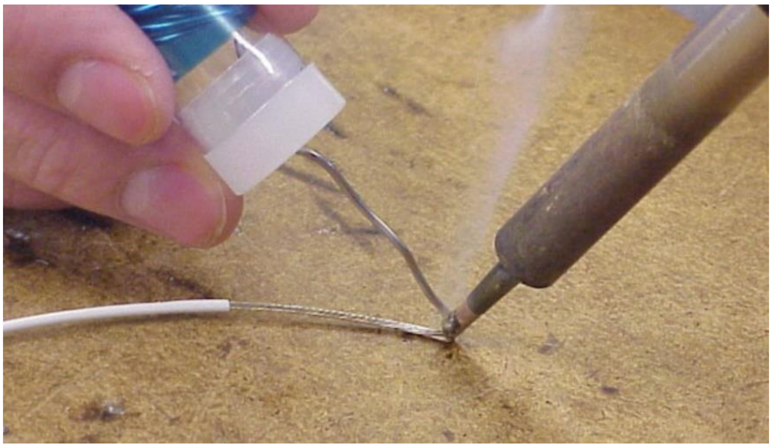


Fig. 11: Soldering

Solders:

Soldering filler materials are available in many different alloys for differing applications. In electronics assembly, the eutectic alloy of 63% tin and 37% lead (or 60/40, which is almost identical in melting point) has been the alloy of choice. Other alloys are used for plumbing, mechanical assembly, and other applications. Some examples of soft-solder are tin-lead for general purposes, tin-zinc for joining aluminium, lead-silver for strength at higher than room temperature, cadmium-silver for strength at high temperatures, zinc-aluminum for aluminium and corrosion resistance, and tin-silver and tin-bismuth for electronics.

A eutectic formulation has advantages when applied to soldering: the liquidus and solidus temperatures are the same, so there is no plastic phase, and it has the lowest possible melting point. Having the lowest possible melting point minimizes heat stress on electronic components during soldering. And, having no plastic phase allows for quicker wetting as the solder heats up, and quicker setup as the solder cools. A non-eutectic formulation must remain still as the temperature drops through the liquidus and solidus temperatures. Any movement during the plastic phase may result in cracks, resulting in an unreliable joint.

Common solder formulations based on tin and lead are listed below. The fraction represents percentage of tin first, then lead, totaling 100%:

63/37: melts at 183 °C (361 °F) (eutectic: the only mixture that melts at a point, instead of over a range)
60/40: melts between 183–190 °C (361–374 °F)
50/50: melts between 185–215 °C (365–419 °F)
For environmental reasons (and the introduction of regulations such as the European RoHS (Restriction of Hazardous Substances Directive)) lead-free solders are becoming more widely used. They are also suggested anywhere young children may come into contact with (since young children are likely to place things into their mouths), or for outdoor use where rain and other precipitation may wash the lead into the groundwater. Unfortunately, most lead-free solders are not eutectic formulations, melting at around 250 °C (482 °F), making it more difficult to create reliable joints with them.

Other common solders include low-temperature formulations (often containing bismuth), which are often used to join previously-soldered assemblies without un-soldering earlier connections, and high-temperature formulations (usually containing silver) which are used for high-temperature operation or for first assembly of items which must not become unsoldered during subsequent operations. Alloying silver with other metals changes the melting point, adhesion and wetting characteristics, and tensile strength. Of all the brazing alloys, silver solders have the greatest strength and the broadest applications. Specialty alloys are available with properties such as higher strength, better electrical conductivity, and higher corrosion resistance.

Flux

The purpose of flux is to facilitate the soldering process. The obstacle to a successful solder joint is an impurity at the site of the union, e.g. dirt, oils or oxidation. The impurities can be removed by mechanical cleaning or by chemical means, but the elevated temperatures required to melt the filler metal (the solder) encourages the workpiece (and the solder) to re-oxidize. This effect is accelerated as the soldering temperatures increase and can completely prevent the solder from joining to the workpiece. One of the earliest forms of flux was charcoal, which acts as a reducing agent and helps prevent oxidation during the soldering process. Some fluxes go beyond the simple prevention of oxidation and also provide some form of chemical cleaning (corrosion).

For many years, the most common type of flux used in electronics (soft soldering) was rosin-based, using the rosin from selected pine trees. It was ideal in that it was non-corrosive and non-conductive at normal temperatures but became mildly reactive (corrosive) at the elevated soldering temperatures. Plumbing and automotive applications, among others, typically use an acid-based (muriatic acid) flux which provides cleaning of the joint. These fluxes cannot be used in electronics because they are conductive and because they will eventually dissolve the small diameter wires. Many fluxes also act as a wetting agent in the soldering process, reducing the surface tension of the molten solder and causing it to flow and wet the workpieces more easily.

Fluxes for soft solder are currently available in three basic formulations:
Water-soluble fluxes - higher activity fluxes designed to be removed with water after soldering (no VOCs required for removal).
No-clean fluxes - mild enough to not "require" removal due to their non-conductive and non-corrosive residue. These fluxes are called "no-clean" because the residue left after the solder operation is non-conductive and won't cause electrical shorts; nevertheless, they leave a plainly visible white residue that resembles diluted bird-droppings. Because discernible flux residue on circuit boards is a defect for all three classes of electronic circuit boards (ranging from cheap consumer electronics to high-reliability, mission-critical applications), this application requires cleaning of these fluxes as well. (Typically brushing with 99% isopropyl alcohol as the solvent and wiping with lint-free non-synthetic (e.g., cotton) wipes.)

Traditional rosin fluxes - available in non-activated (R), mildly activated (RMA) and activated (RA) formulations. RA and RMA fluxes contain rosin combined with an activating agent, typically an acid, which increases the wettability of metals to which it is applied by removing existing oxides. The residue resulting from the use of RA flux is corrosive and must be cleaned. RMA flux is formulated to result in a residue that is not significantly corrosive, with cleaning being preferred but optional.

Flux performance needs to be carefully evaluated; a very mild 'no-clean' flux might be perfectly acceptable for production equipment, but not give adequate performance for a poorly controlled hand-soldering operation.

Types of soldering:

Silver soldering

"Hard soldering" or "silver soldering" is used to join precious and semi-precious metals such as gold, silver, brass, and copper. The solder is usually referred to as easy, medium, or hard. This refers to its melting temperature, not the strength of the joint. Extra-easy solder contains 56% silver and has a melting point of 1,145 °F (618 °C). Extra-hard solder has 80% silver and melts at 1,370 °F (740 °C).

If multiple joints are needed, then the jeweler will start with hard or extra-hard solder and switch to lower temperature solders for later joints.

Silver solder is absorbed by the surrounding metal, resulting in a joint that is actually stronger than the metal being joined. The metal being joined must be perfectly flush, as silver solder cannot normally be used as a filler and any gaps will remain.

Another difference between brazing and soldering is how the solder is applied. In brazing, one generally uses rods that are touched to the joint while being heated. With silver soldering, small pieces of solder wire are placed onto the metal prior to heating. A flux, often made of borax and water, is used to keep the metal and solder clean and to prevent the solder from moving before it melts.

When silver solder melts, it tends to flow towards the area of greatest heat. Jewelers can somewhat control the direction the solder moves by leading it with a torch; it will even run straight up along a seam.

Induction soldering:

Induction soldering uses induction heating by high-frequency AC current in a surrounding copper coil. This induces currents in the part being soldered, which generates heat because of the higher resistance of a joint versus its surrounding metal (resistive heating). These copper coils can be shaped to fit the joint more precisely. A filler metal (solder) is placed between the facing surfaces, and this solder melts at a fairly low temperature. Fluxes are commonly used in induction soldering. This technique is particularly suited to continuously soldering, in which case these coils wrap around a cylinder or a pipe that needs to be soldered.
Some metals are easier to solder than others. Copper, silver, and gold are easy. Iron, mild steel and nickel are next in difficulty. Because of their thin, strong oxide films, stainless steel and aluminium are even more difficult to solder. Titanium, magnesium, cast irons, some high-carbon steels, ceramics, and graphite can be soldered but it involves a process similar to joining carbides: they are first plated with a suitable metallic element that induces interfacial bonding.

Hot-bar reflow:

Hot-bar reflow is a selective soldering process where two pre-fluxed, solder coated parts are heated with heating element (called a thermode) to a sufficient temperature to melt the solder.
Pressure is applied through the whole process (usually 15 s) to ensure that components stay in place during cooling. The heating element is heated and cooled for each connection. Up to 4000 W can be used in the heating element allowing fast soldering, good results with connections requiring high energy.
Laser:

Laser soldering is a technique where a ~30-50 W laser is used to melt and solder an electrical connection joint. Diode laser systems based on semiconductor junctions are used for this purpose.

Wavelengths are typically 808 nm through 980 nm. The beam is delivered via an optical fiber to the workpiece, with fiber diameters 800 um and smaller. Since the beam out of the end of the fiber diverges rapidly, lenses are used to create a suitable spot size on the workpiece at a suitable working distance. A wire feeder is used to supply solder.

Both lead-tin and silver-tin material can be soldered. Process recipes will differ depending on the alloy composition. For soldering 44-pin chip carriers to a board using soldering preforms, power levels were on the order of 10 Watts and solder times approximately 1 second. Low power levels can lead to incomplete wetting and the formation of voids, both of which can weaken the joint.

Resistance soldering:

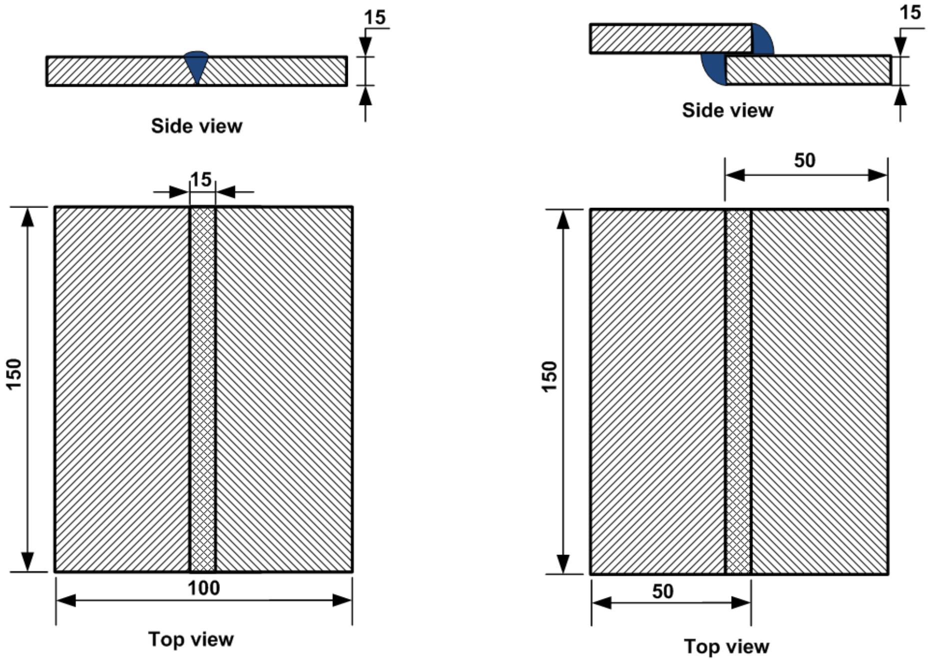
Resistance soldering is unlike using a conduction iron, where heat is produced within an element and then passed through a thermally conductive tip into the joint area. A cold soldering iron requires time to reach working temperature and must be kept hot between solder joints. Thermal transfer may be inhibited if the tip is not kept properly wetted during use. With resistance soldering an intense heat can be rapidly developed directly within the joint area and in a tightly controlled manner. This allows a faster ramp up to the required solder melt temperature and minimizes thermal travel away from the solder joint, which helps to minimize the potential for thermal damage to materials or components in the surrounding area. Heat is only produced while each joint is being made, making resistance soldering more energy efficient. Resistance soldering equipment, unlike conduction irons, can be used for difficult soldering and brazing applications where significantly higher temperatures may be required. This makes resistance comparable to flame soldering in some situations. When the required temperature can be achieved by either flame or resistance methods the resistance heat is more localized because of direct contact, whereas the flame will spread thus heating a potentially larger area.

Fig. 12: Equipment required during resistance soldering

2.6 Comparison:

S. No.	Aspects	Soldering	Brazing	Gas Welding	Arc Welding
1.	Temperature	Below 400 C	Above 400 C, up to 850	Up to 1500 C	Up to 3500 C
2.	Joint Strength	Poor	Fair	Good	High
3.	Filler material	Soldering iron	Copper and aluminium alloys	Same as base material	Same as base material
4.	Flux Required	Yes	Yes	No	Yes
5.	Major Application	Electrical connections	Low strength heterogeneous joint	Sheet metal welding	Thick section welding
6.	Types of joints possible	Heterogeneous	Heterogeneous	Homogeneous only	Homogeneous only
7.	Cost of equipment	Low	Moderate	High	High

Welding

Aim	To perform arc welding and gas welding
Drawing	 **V-Butt Joint** **Lap Joint** **All dimensions are in mm**
Material required	• Mild steel (MS) plate [size: 150 × 100× 15 mm]; 4 nos.
Equipment and tools required *(Please illustrate equipment and tools using appropriate drawings)*	• Arc welding equipment • Gas welding equipment • Spot welding equipment • MS electrodes • Ground clamp • Flat nose tong • Face shield • Apron • Hand gloves • Metallic work table • Wire brush • Ball peen hammer • Chipping hammer
Sequence of operations	• Cleaning the workpieces • Tack welding • Full welding • Cooling • Chipping • Finishing
Procedure	• Take the workpiece (MS plates) of the given dimension and clean the surface to be welded thoroughly to remove rust, dust particles, oil and grease. • Remove sharp corners and burrs by filling the workpieces **ARC WELDING** • The workpieces are positioned on the welding table to form a lap joint

	• The electrode is fitted into the electrode holder and the welding current is set to proper value. • The ground clamp is fastened to the welding table • Wearing the apron, hand gloves using a face shield and holding the overlapped pieces, the arc is struck and workpieces are tack welded at ends of both sides. • The alignment of lap joint is checked and the tack welded pieces are rest. • Welding is carried out throughout the length of the lap joint on both the sides. • Remove the slag spatters and clean the joint. **GAS WELDING** • To light the flame, acetylene valve on the torch is slightly opened first and lighted and adjust the needed flow rate. • Flame draws the oxygen from the atmospheric air and thus results in a reducing flame. • Then adjust the oxygen valve opening to get desired flame. • Choice of the torch size depends on the thickness of the material to be joined. • Larger torch tip sizes for thicker materials, larger tip radii are used. • Welding is carried out throughout the length of the lap joint on both sides. • Remove the slag spatters and clean the joint.
Precautions	• Use googles, gloves to protect the human body • Maintain the constant arc length • Always use the recommended settings of voltage and current according to the electrode and work-piece requirements. • Never watch the arc with naked eyes. • Avoid contact with hot metal surfaces • Do not short circuit the apparatus by connecting the electrode to the earth directly.