Chapter 3: Basic Fabrication Processes

Welding, brazing and soldering

Welding

- Welding is a process of **metallurgically joining two pieces** of similar metals by the application of **heat with or without the application of pressure** and addition of filler metal. The joint formed is a permanent joint.

Welding is a material **joining process** used in making welds.

A weld is a localized **coalescence** of metals or non-metals produced either by heating the materials to a suitable **temperate with or without** the **application of pressure** and **with or without** the use of **filler metal**

Applications of welding

1. Used to construct **tankers** for transporting water, oil, milk etc.
2. Fabrication of welded **tubes, pipes, chains, LPG cylinders**
3. Fabrication of steel **furniture, gates, doors frames**
4. Fabrication of **automobile body**, washing machines, microwave Owens
5. Used in manufacture of **hoists and cranes**
6. Used in construction of **ships**
7. Used in construction of **buildings** and **bridges**

Advantages of welding

1. A good weld is **stronger than parent** or base metal
2. **Faster process** compared to riveting and casting
3. Applicable to **all metals** and alloys
4. **Difficult shapes** can be produced
5. Process can be **automated** for faster production
6. Can be carried out in **all places**
Limitations of welding

1. Gives out harmful radiations and fumes or sparks
2. Parent material may be distorted due to high temperature
3. Sometimes, jigs and fixtures may be required to hold the job
4. Skilled labour is necessary
5. Residual stresses in weld area
6. Poor fatigue resistance due to stress concentration
7. Undesirable changes may be induced in the property of the metals due to change in microstructure due to high heat

Classification of welding

1. Plastic Welding
2. Fusion Welding

Plastic welding

- Plastic Welding: In this process the metal to be joined are heated to a plastic state and then forced together by external pressure.
- E.g.: This process is used in forge welding, resistance welding etc.

Fusion welding

- Fusion Welding: In this process, materials to be joined are heated to a molten state and allowed to solidify.

E.g.: This includes arc welding and gas welding
Arc Welding

1. Carbon arc welding
2. Metal arc welding
3. Plasma arc welding
4. Submerged arc welding
5. Electro Slag arc welding
6. Flux cored arc welding
7. Metal Inert Gas Arc Welding (MIG)
8. Tungsten Inert Gas Arc Welding (TIG)
9. Atomic Hydrogen welding

Gas Welding

1. Oxy – Acetylene Welding
2. Air – Acetylene Welding
3. Oxy – Hydrogen Welding
4. Pressure Gas Welding

Resistance welding

1. Butt welding
2. Sport Welding
3. Seam Welding
4. Projection Welding
5. Percussion Welding

Solid state welding

1. Friction Welding
2. Forge Welding
3. Ultra sonic Welding
4. Cold Welding
5. Thermit Welding
6. Laster Welding
7. Electron beam welding
Arc Welding

- Arc welding is a method of joining metals with heat produced by an electrical arc.
- In this process the heat necessary to melt the edges of the metal to be joined is obtained from an electric arc struck between the electrode and the work, producing a temperature of 4000°C, in the welding zone.
- The heat of the arc melts the base metal or edges of the parts fusing them together. Filler metal, usually added melts and mixes with molten base metal to form the weld metal. The weld metal cools and solidifies to form the weld.
- In most cases, the composition of the filler material, known as welding rod, needed to provide extra metal to the weld, is same as that of the material being welded.

Arc welding equipment

- An arc welding circuit consists of a power supply to furnish electric power.
- An electrode to conduct the electricity to the arc (-ve side).
- Cables which connect the power supply to the electrode and work-piece to complete the welding circuit.
- The arc itself provides the heat for welding.
- The work-piece to be welded is kept on a metallic table (+ve side)
Arc welding process

- The **ARC must be shielded** because, as it hardens the molten metal combines with **oxygen** and **nitrogen** to form impurities that weaken the weld.

- Shielding can be obtained by adding a **paste**, powder or **fibrous flux** to the arc. The electrodes are usually coated with a flux. This coating forms a gaseous cloud that shields the molten metal from the atmosphere.

- The coating also forms a **protective slag**. The **Slag floats** on the molten pool and hardens as the weld cools. This keeps **impurities out of the weld**.

**Fluxes**

- **Fluxes**: Surfaces to be joined by welding must be **clean** to permit metallic surfaces to come in contact.

- In some operations, materials known as fluxes are applied to the parts being welded to **dissolve the oxides** or to **prevent the formation of oxides**.

- Fluxes are **different for different metals**. For ferrous metals **borax**, sodium carbonate are used. Welding rods are provided with a coating of flux material.
Precautions in welding

- All parts and equipment's must be properly installed and in good condition
- Only skilled operators must be allowed to do the work
- The protective equipment like Eye shield, helmet, protective clothing, boots and gloves must be used. One should never look at arc with bare eye.
- Floor should be dry
- All flammable materials like kerosene, petrol must be kept at a distance
- There should be proper ventilation to the welding area
- First Aid Appliances must be available near the welding area
- The welding equipment must be disconnected from mains when not in use

Advantages of arc welding

1. A good weld is stronger than parent or base metal
2. Faster and simple process
3. Wide range of metals and alloys can be welded
4. Difficult shapes can be produced. Weld can be carried out in any position
5. Process can be automated for faster production
6. Portable equipment are used.
7. Can be carried out in all places

Limitations of arc welding

1. Gives out harmful radiations and fumes or sparks
2. Parent material may be distorted due to high temperature
3. Not suitable for thin sheets
4. Chances of slag being entrapped in joint is high
5. Skilled labour is necessary
6. Edge preparation is necessary before welding

Uses or arc welding

- Used in fabrication work
- Used in production of chassis of trucks, cars etc.
- Used in constructions works of buildings and factories
- Used in structural works
- Used for pressure vessels
Gas welding

- Gas welding is a fusion welding process, in which a flame produced by the combustion of, gases is employed to melt the metal.

- The molten metal is allowed to flow together thus forming a solid continuous joint upon cooling. By burning pure oxygen in combination with other gases, in special torches, a flame upto 3300°C can be attained.

- The gas is purchased in cylinder and connected through resulting valves and pressure gauges into flexible hoses attached to the nozzle. A typical arrangement is shown in figure.

Gas welding equipment

- The oxy-acetylene flame is used to pre heat the parts to be welded around the joint and also to melt the filler metal.

- A jet of oxy acetylene flame issuing from the nozzle of a burner is played on the junction of the two pieces to be welded. At the same time a filler rod is held in the zone of jet and its melt is deposited on the fused junction.

A weld is obtained after the molten metal solidifies. The coating on the filler rod acts as a flux to keep the joint clean. The filler metal or filler rod used must combine with the parts being joined. The melting point of the filler metal must be the same, or lower than the melting point of the metal being joined.
Flames in oxy-acetylene welding

- Neutral Flame
- Carbonising or reducing flame
- Oxydising Flame

Neutral flame

- The correct adjustment of the flame is very important for reliable works.
- When oxygen and acetylene are supplied to the torch in nearly equal volumes, a neutral flame is produced having a maximum temperature of 3200 C.
- This neutral flame is desired for most welding operations.
- Neutral flame has little effect on the base metal and sound welds are produced

Carbonising flame

- In a carbonizing flame or reducing flame excess of acetylene is present
- The temperature of this flame is low.
- The excess unburnt carbon is absorbed in ferrous metals, making the weld hard and brittle.
- In between the outer blue flame and inner white cone, an intermediate flame feather exists, which is reddish in colour.
- The length of the flame feather is an indication of the excess acetylene present
- Carbonizing flame is used for welding high carbon steels and cast iron, alloy steel.
Oxidising flame

- In an oxidizing flame excess of oxygen is present
- The flame is similar to the neutral flame with the exception that the inner white cone is some what small, giving rise to higher tip temperatures.
- Excess of oxygen in the oxidizing flame causes the metal to burn or oxidize quickly.
- Oxidizing flame is useful for welding some nonferrous alloys such as copper and zinc base alloys.

Advantages of gas welding

- The equipment is inexpensive, not complicated and it is easily portable.
- Useful for welding light metals such as automobile bodies and repair works.
- A large variety of material can be welded.
- Welds can be produced at reasonable cost.
- Compared to electric arc welding this provides greater flexibility with respect to heat impact and cooling rates.

Limitations of gas welding

- Gas welding equipment must always be handled carefully as in certain circumstances acetylene is explosive.
- A high temperature flame from a hand torch is dangerous, when handled carelessly.
- It is much slower than electric arc welding and does not concentrate the heat close to the weld. Thus, the heat treated area is larger, which causes more distortion.
- Highly skilled operators are required to produce a good weld.
- If electric arc welding is available, gas welding is seldom used for work over 3.2mm thick.
- The process is not satisfactory for heavy section.
Gas welding applications

1. Used for gas cylinder welding
2. Used for welding Tankers
3. Used for automobile bodies
4. Used in fabrication works
5. Used in Ship building
6. Used in Power Plants
7. Used in pipeline work

<table>
<thead>
<tr>
<th>Arc Welding</th>
<th>Gas Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Electric arc is the source of heat</td>
<td>Burning of gas is the source of heat</td>
</tr>
<tr>
<td>2. High concentration of heat due to localized spark</td>
<td>Heat is spread over a large area</td>
</tr>
<tr>
<td>3. Stronger joints</td>
<td>Weaker joints</td>
</tr>
<tr>
<td>4. Reduced buckling and warping</td>
<td>More buckling and warping</td>
</tr>
<tr>
<td>5. More Economical</td>
<td>Less economical</td>
</tr>
<tr>
<td>6. Less suitable for mobile applications due to heavy transformers</td>
<td>More useful due to mobile applications</td>
</tr>
</tbody>
</table>

Types of arc welding

1. MIG Welding
2. TIG Welding
3. Submerged Arc Welding
MIG welding

- This method uses a **consumable electrode** which is fed into the arc in the form of a wire. **Helium or argon gases** are used as inert gas. The working principle of MIG welding is shown in figure.

- An **electric arc** is produced between **workpieces** and consumable **electrode**, which melts the electrode and is deposited in the joint. The inert or **shielding gas** surrounds the arc and **protects the weld** from atmospheric effects which may cause defects in the weld.

- The **electrode wire is automatically fed** from the reel by a variable speed roller depending upon the arc voltage.

- MIG welding may be **semiautomatic** in which the welder guides the gun and adjusts process parameters or **Automatic** Welding where all functions are taken care by the welding machine or robot.

MIG welding may be used for **stainless-steel, magnesium, aluminum** etc.
Advantages and limitations of MIG welding

Advantages

1. Much greater penetration and higher welding speed.
2. No possibility of cracks.
3. There is no slag to clean off after the welding.
4. It can be readily automated.
5. Produce very high quality of weld.
6. It is fast and economical.

Limitations

1. Difficult to weld in small corners.
2. Welding equipment is costly and more complex

TIG welding

- The arc is maintained between the workpiece and a tungsten electrode protected by an inert gas such as helium or argon or the mixture of the two.
- The electrode is non-consumable since its melting point is about 3400 °C which is higher than the arc temperature.
- TIG welding equipment consists of welding gun with handle.
- The stationary tungsten electrode is firmly held in a welding gun with shielding gas flow along the electrode through a nozzle at the end of the gun into the arc zone.
- An electric arc is produced between the workpiece and the non consumable electrode, which melts the metals to be joined in that area and forms the molten pool.
- An inert or shielding gas surrounds the arc and protects the weld from atmospheric effects and welds are made without defects.
- A filler metal may or may not be used. Water is used to cool the welding gun.
Advantages and limitations of TIG welding

Advantages

1. It is faster process.
2. Produces a clean weld.
3. Flux is not required.
4. Unlike metals can be welded like brass to copper.
5. Heat affected zone is very small.
6. Requires no clean up due to absence of slag or spatter.
7. No possibility of cracks.
8. Weld zone is visible.

Limitations

1. Initial cost of equipment is high.
2. Can produce non uniform weld as the process is manual

<table>
<thead>
<tr>
<th>MIG Welding</th>
<th>TIG Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Uses consumable metal</td>
<td>Uses non consumable</td>
</tr>
<tr>
<td>electrode</td>
<td>tungsten electrode</td>
</tr>
<tr>
<td>2 Metal electrode also acts</td>
<td>Tungsten electrode does not</td>
</tr>
<tr>
<td>as filler metal</td>
<td>act as filler metal</td>
</tr>
<tr>
<td>3 Arc is less stable</td>
<td>Arc is more stable</td>
</tr>
<tr>
<td>4 Low quality weld having</td>
<td>High quality precise welds</td>
</tr>
<tr>
<td>less precision</td>
<td></td>
</tr>
<tr>
<td>5 More contamination present</td>
<td>Less contamination</td>
</tr>
<tr>
<td>in weld</td>
<td></td>
</tr>
<tr>
<td>6 More sparks, fumes and</td>
<td>Less spark, fumes and smoke</td>
</tr>
<tr>
<td>smoke</td>
<td></td>
</tr>
</tbody>
</table>
Submerged arc welding

- This process is also known as hidden arc or sub-arc welding.
- It is an automatic process developed primarily for the production of high quality butt welds in thick steel plates.
- In this arc welding, coalescence is produced by heating with an arc between a bare Wire electrode and the work.
- The weld zone is shielded or covered by a blanket of fusible granular flux material supplied continuously on the weld seam ahead of the electrode to cover the arc.
- The working principle of submerged arc welding is shown in figure. It consists of wire electrode supplied by wire reel and flux feed hopper to supply the flux on a weld seam.
- An arc is struck below the granular flux over the metals to be joined, a bare feed wire is fed through the welding heat into the granular material.
- The intense heat of the arc produces a pool of molten metal in the joint. Since arc is fully covered by flux, its is not visible.
- During welding, the flux floats over molten metal and forms a protective cover. On solidifies on cooling and can be easily removed.
Advantages and limitations of submerged arc welding

Advantages

1. Welder need not to wear protective glass.
2. Wire electrodes are inexpensive.
3. Weld is free from spatter.
4. Nearly 100% deposition efficiency is achieved.
5. Provide excellent protection from oxidation.
6. Very high quality of welding can be achieved.
7. Welding process is faster.
8. Very thick plates can be welded easily

Limitations

• Can not be used for thing plates (less than 5 mm).
• Difficult to guide path as arc is not visible
• Process is limited to straight weld in flat position

Resistance welding

• Resistance welding is a metal joining process in which a heavy electric current is passed through the metals to be joined over a limited area, causing them to be locally heated to a plastic state
• Weld is completed by the application of pressure. No filler material is used
• The amount of heat generated at the contact area of the elements to be welded is determined from Joule's law, \( H = \frac{I^2Rt}{12} \) where

\[
\begin{align*}
I &= \text{Current in amperes} \\
R &= \text{Resistance of the circuit at the contact area of the element in ohms} \\
t &= \text{Time during which the current flow in seconds.}
\end{align*}
\]
• The **voltage** can be **low** as 0.5 to 10 V, but **currents** are very high as **thousands of amperes**.

• The machine consists of **transformer**, a **clamping** device for holding the workpieces and a **peddle** to **force the workpieces** to be weld together to complete the weld.

• This machine is operated continuously by **heating** the **metals** to be joined to a **plastic state** using **electric resistance** and **pressing together** by means of two **copper electrodes** in a circuit to make the welding.

• The metals such as **steel, stainless steel, Monel metal and silicon bronze** are welded in this process.

**Advantages and limitations of resistance welding**

**Advantages**

1. The **heat** is **localized**.

2. Welding is **rapid**.

3. **No filler** metal is required.

4. It requires **less skill**.

5. Common and **dissimilar metals** can be welded.

6. Easily mechanized and **automated**.

7. Suitable for **mass production**.

8. High degree of **reliability**.

9. Excellent **reproducibility**.

**Limitations**

• **High initial cost** of equipment

• Sheet **thickness limited** to 6 mm

• Weld has **lower strength**
Butt welding

- Butt welding process is in which the metal of same cross section are gripped together in a clamps and pressed.
- Heat is generated in the contact surface by electrical resistance when the current as the current is made to pass through the joint.
- As the pressure keeps on acting continuously, the joint is upset slightly to be rounded up by machining or grinding.
- Here there is no arcing at the joint.

Spot welding

- It is a resistance welding process used to join overlapping sheets or strips of metal.
- The pieces are assembled and placed between two electrodes and high electrical and thermal conductivity.
- When the current is passed, the place where the sheet is held between the two electrodes gets heated and forms the weld by the application of pressure.
• The welds are formed at evenly spaced spots.
• A foot pedal may be used to apply pressure.
• Metal strips upto 12 mm can be welded by this method.

**Seam welding**

- It is a welding process used for making a **continuous joint** between two overlapping pieces of sheet metal.
- It consists of **two rotating wheel electrodes**, the work pieces to be welded are joined are placed between these wheels.
- These **wheels serve as conductors** for producing continuous welds.
- First **pressure is applied** then the **drive is started** and the welding **current is switched on**.
- **Heat is generated** by the **current** which heats the metal. Pressure is applied to complete the weld. The sheet is continuously moved through the wheels to produce a continuous weld.
- This is used for **leak proof joints** as in pressure vessels, radiators etc.
Defects in Welds and remedies

<table>
<thead>
<tr>
<th>Defect</th>
<th>Cause</th>
<th>Remedies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor fusion</td>
<td>An incomplete union between the deposited and parent metal due to faulty welding techniques and conditions.</td>
<td>Provide sufficient heat and slow travel of electrode</td>
</tr>
<tr>
<td>Undercut</td>
<td>A groove melted into the base metal adjacent to the toe of the weld due to non-uniform feeding of the welding rod or excessive heat.</td>
<td>Establish the uniform feeding of the electrode and required amount of heat.</td>
</tr>
<tr>
<td>Porosity</td>
<td>The formation of blow holes or gas pockets, on the surface of the weld due to the presence of gases in the metal or moisture in the flux.</td>
<td>Using proper weld technique to avoid absorption of gases by weld pool</td>
</tr>
<tr>
<td>Slag inclusion</td>
<td>The presence of nonmetallic substances in the metal or contamination of weld metal by atmosphere.</td>
<td>Avoid contamination of the weld metal by atmosphere. Proper removal of slag between layers of metal.</td>
</tr>
<tr>
<td>Cracks in Weld</td>
<td>Cracks may arise from locked up stresses setup due to non-uniform heating and cooling, excessive sulphur or phosphorus in the weld metal.</td>
<td>Providing uniform heating and cooling to avoid locking of stresses. Steady welding speed</td>
</tr>
<tr>
<td>Spatter</td>
<td>Spatter refers to small particles or globules of metal scattered around the vicinity of the weld along its length.</td>
<td>Use appropriate current. Avoid trapping of gases in weld along its length.</td>
</tr>
</tbody>
</table>

Brazing

- Brazing is a joining process in which a filler rod with a melting point lower than that of the base metal, but above 427°C is used.
- A groove, fillet, plug, or slot weld is made and the filler metal is distributed by capillary attraction.
- In brazing, a nonferrous filler rod, strip, or wire is used for repairing or joining cast iron, malleable iron, wrought iron, steel, copper, nickel, brasses and bronzes.

Brazing – steps

- Parts to be joined are cleaned and made free from dirt, oxides etc.
- Adjust the gap between metals to be joined so as to make it very small
- Coat all mating surfaces with flux
• Heat the metal above 420 °C
• Allow molten metal to flow into gap by capillary action and then allow to cool and solidify
• Clean the parts by hot water or steam to remove residual fluxes

Advantages of brazing
• Dissimilar metals can be joined
• Assemblies can be brazed in short time
• Complex assemblies can be brazed together
• Material of different thickness can be joined
• Non metals can be joined to metals when non metal is coated
• Brazed joints require little or no finishing
• Metallurgical properties of base metals are not affected much

Soldering
• Soldering is a method of joining similar or dissimilar metals by the application of heat and using fusible alloys (a filler metal commonly known as solder) for joining two metals without heating them to their melting points.
• Soldering is valuable to the sheet metal worker because it is a simple and fast means for joining sheet metal, making electrical connections, and sealing seams against leakage.

Types of soldering
• Soft soldering
• Hard soldering

Soft soldering
• Soft soldering is used extensively in sheet metal work for joining parts that are not exposed to the action of high temperatures and are not subjected to excessive loads and forces or vibrations.
• Soft soldering is also employed for joining wires and small parts.
• The solder is mostly composed of lead and tin. In soft soldering, Zinc chloride and ammonium chloride are the most common soldering fluxes used which are quick acting and produce efficient joints. But because of their corrosive nature the joint should thoroughly cleaned of all the flux residue from the joint.
Hard soldering

- Hard soldering employs **solder which melts at higher temperature** (600°C to 900°C) is **stronger** than used in soft soldering.

- Hard solder is an **alloy of copper and zinc** to which **silver is added some times**. German silver, used as a hard solder for steel is an alloy of **copper, zinc and nickel**.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Soldering</th>
<th>Brazing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td>Metals are joined with the help of a filler metal with low melting point (below 450 °C and below the melting of metal joined)</td>
<td>Filler material has a high melting point above 450 °C, up to 1000 °C</td>
</tr>
<tr>
<td><strong>Strength of joints</strong></td>
<td>Weaker joints compared to brazing</td>
<td>Stronger joints compared to soldering</td>
</tr>
<tr>
<td><strong>Typical solder metal</strong></td>
<td>Typical solder metals are alloys of tin</td>
<td>Typical filler metals are aluminium, silver, copper, nickel and gold</td>
</tr>
<tr>
<td><strong>Flux material</strong></td>
<td>Usually Rosin</td>
<td>Usually borax</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>More economical</td>
<td>Less economical</td>
</tr>
<tr>
<td><strong>Thickness of metal</strong></td>
<td>Metal of only small thickness joined</td>
<td>Metals of larger thickness can be joined</td>
</tr>
</tbody>
</table>
### Brazing v/s Welding

<table>
<thead>
<tr>
<th>Factor</th>
<th>Brazing</th>
<th>Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting</td>
<td>Metals to be joined are not melted. Joint is produced by solidification and adhesion of a thin layer of filler metal</td>
<td>Surfaces to be joined are melted and allowed to solidify</td>
</tr>
<tr>
<td>Penetration of filler metal</td>
<td>There is no penetration of filler metal into base metal</td>
<td>There is penetration into base metal</td>
</tr>
<tr>
<td>Spreading of filler metal</td>
<td>Molten brazing filler alloy spreads along the joint</td>
<td>Does not spread along joint, but solidify where it melts</td>
</tr>
<tr>
<td>Strength of joint</td>
<td>Relatively weaker joint</td>
<td>Relatively stronger joint</td>
</tr>
<tr>
<td>Skill</td>
<td>Ordinary skill is enough for performing brazing</td>
<td>High skill required</td>
</tr>
<tr>
<td>Cost</td>
<td>Economical</td>
<td>More expensive</td>
</tr>
</tbody>
</table>

### Welding v/s Soldering

<table>
<thead>
<tr>
<th>Factor</th>
<th>Welding</th>
<th>Soldering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Metals to be joined are heated to liquid state</td>
<td>Heated to a temperature below 420 °C</td>
</tr>
<tr>
<td>Heat required</td>
<td>Heat required is up to 4000 °C</td>
<td>Temperature required is below 420 °C</td>
</tr>
<tr>
<td>Strength of joint</td>
<td>High strength</td>
<td>Low strength</td>
</tr>
<tr>
<td>Plate thickness</td>
<td>Suitable for thick plates</td>
<td>Suitable for thin plates</td>
</tr>
<tr>
<td>Flux</td>
<td>Flux coated electrode is melted by arc</td>
<td>Flux is applied and then filler metal is heated and applied</td>
</tr>
<tr>
<td>Use</td>
<td>Used in wide engineering applications.</td>
<td>Used commonly in electronic applications</td>
</tr>
</tbody>
</table>