LECTURE-04: METAL JOINING METHODS

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Metal Joining Processes

- Joining is an important process in a number of industries, such as aerospace, automotive, oil, and gas. Many products cannot be fabricated as a single piece, so components are fabricated first and assembled later. Joining technology can be classified as a liquid-solid-state process and mechanical means. Liquid-solid-state joining includes welding, brazing, soldering, and adhesive bonding. Mechanical joining includes fasteners, bolts, nuts, and screws.
- Metal joining is a process that uses heat to melt or heat metal just below the melting temperature. Joining metal by fusion is known as fusion welding. Without fusion, the process is known as solid-state welding. Fusion welding includes arc welding and laser welding, Whereas solid-state welding such as friction stir welding where process occurred below the melting temperature.

Classification of Metal Joining Processes

METAL JOINING PROCESSES

Arc Welding
- Gas Metal Arc (GMAW)
- Gas Tungsten Arc (GTAW)
- Plasma Arc (PAW)
- Shielded Metal Arc (SMAW)
- Submerged Arc (SAW)

Solid State Welding
- Diffusion Welding (DFW)
- Explosion Welding (EXW)
- Friction Welding (FRW)
- Hot Pressure Welding (HPW)
- Ultrasonic Welding (USW)

Resistance Welding
- Flash Welding (FW)
- Percussion Welding (PEW)
- Projection Welding (RPW)
- Resistance-Seam Welding (RSEW)
- Resistance-Spot Welding (RSW)

Modern Welding Processes
- Electron Beam Welding (EBW)
- Laser Beam Welding (LBW)
- Plasma Arc Welding (PAW)
- Thermit Welding (TW)

Oxyfuel Gas Welding
- Oxyacetylene Welding (OAW)
- Oxyhydrogen Welding (OHW)
- Pressure Gas Welding (PGW)

Brazing
- Diffusion Brazing (DFB)
- Induction Brazing (IB)
- Resistance Brazing (RB)

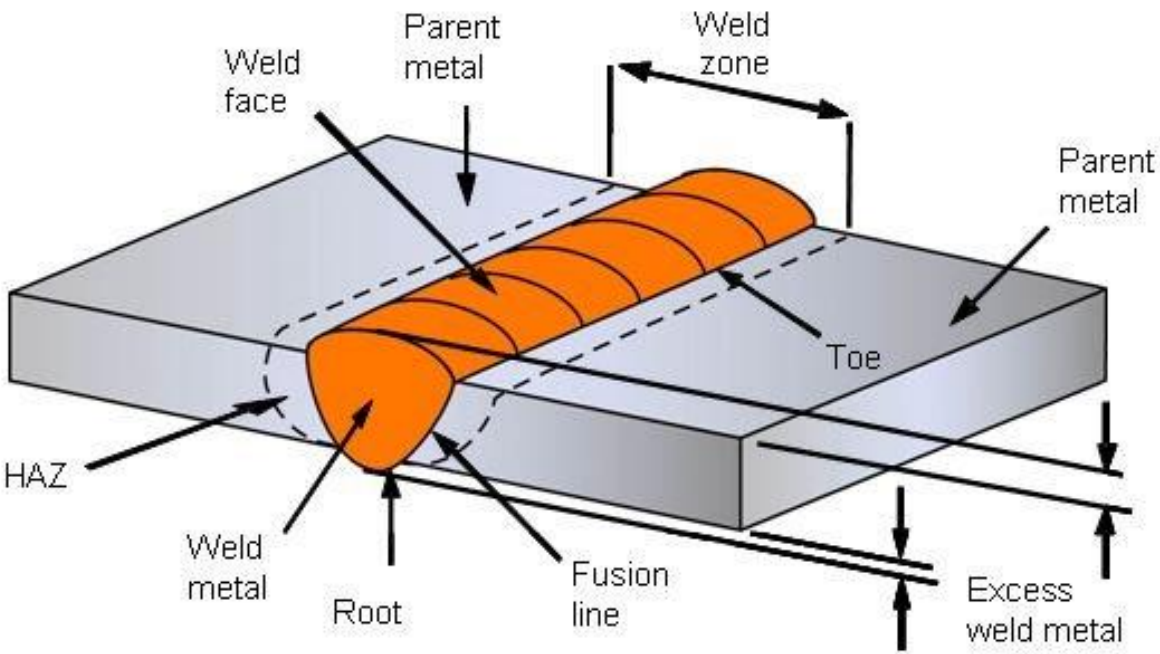
Soldering
- Infrared Soldering (IRS)
- Iron Soldering (INS)
- Resistance Soldering (RS)

Metal Joining Processes-Welding

- Welding process is a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler material. Features of completed welds are as:

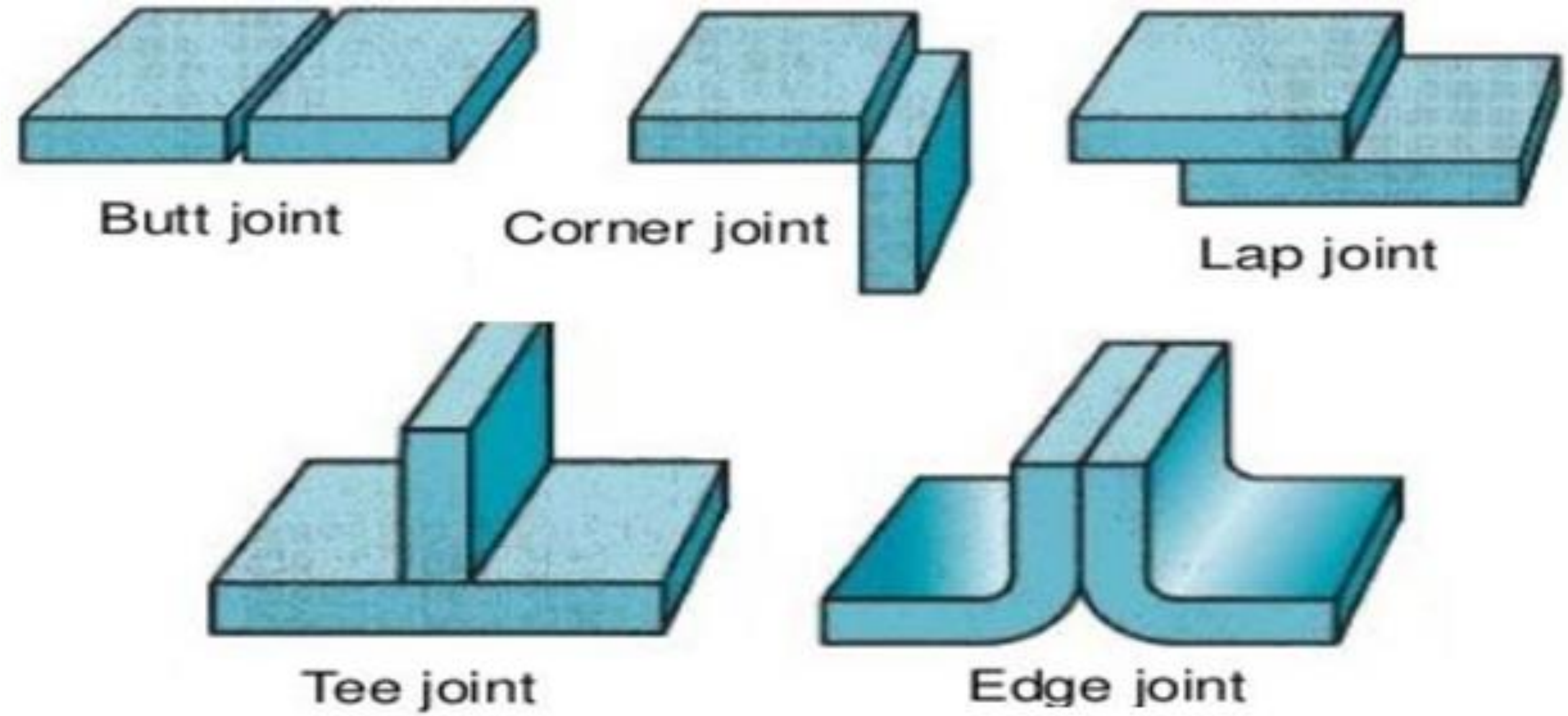
Heat-affected Zone (HAZ):

In welding, the heat-affected zone is the area of base material, either a metal or a thermoplastic, which is not melted but has had its microstructure and properties altered by welding or heat intensive cutting operations.

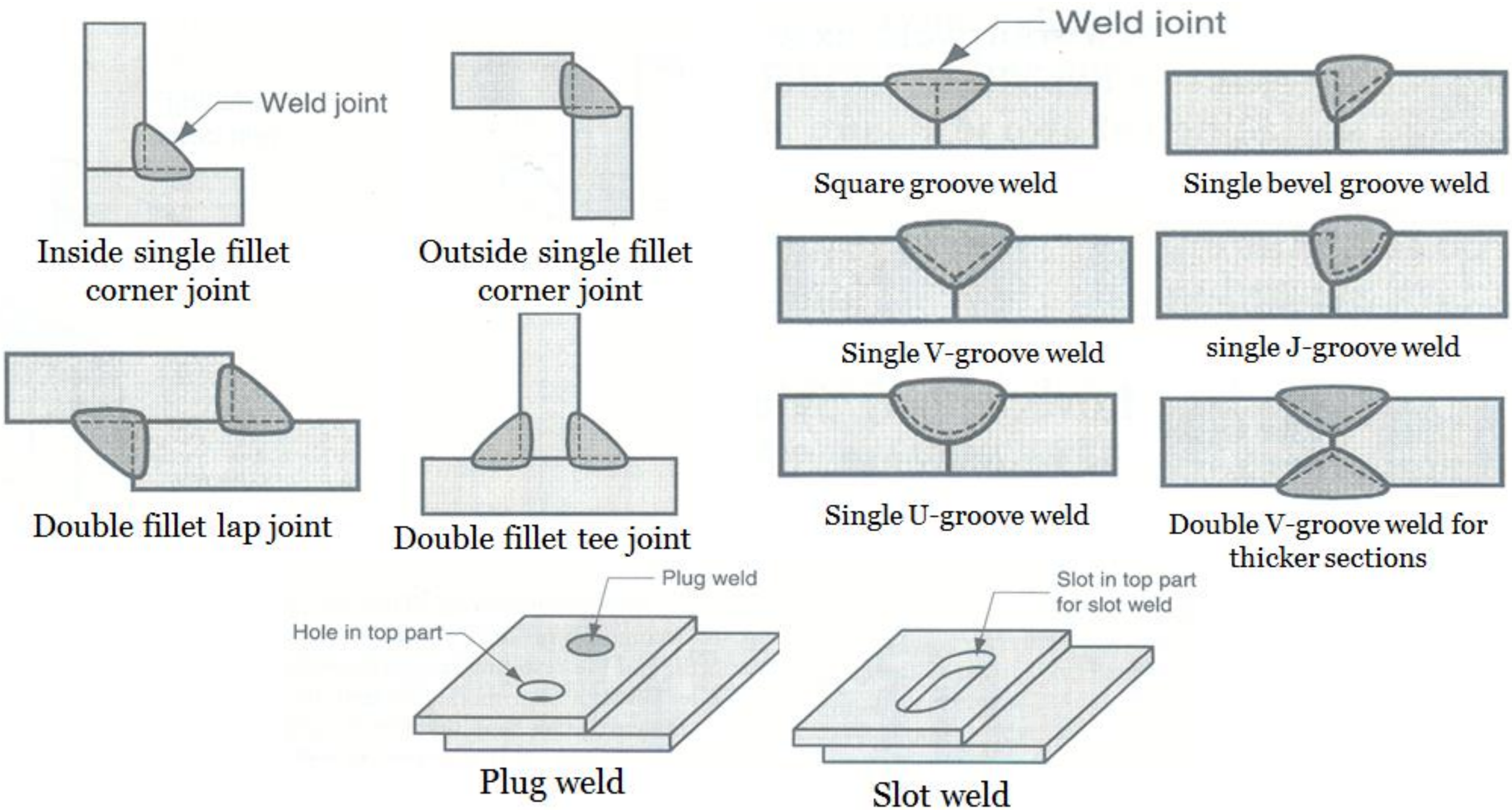


Types of Weld Joint

- Welding produces a solid connection between two pieces called a **weld joint**. A weld joint is the junction of the edges or surfaces of parts that have been joined by welding. There are **five basic types of joints** for bringing two parts together for joining.



Types of Welds

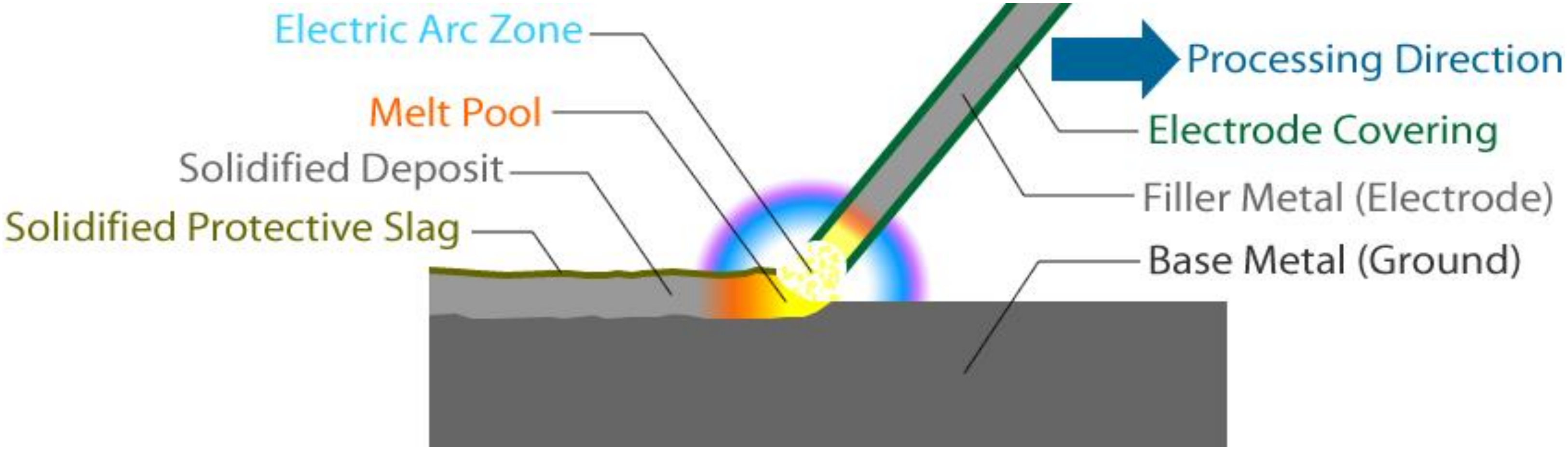


Types of Welding based on Filler Metals

- Autogenous Weld: A weld joint can be developed just by melting of edges of plates or sheets to be welded especially when thickness is less than 5 mm thickness. A weld joint developed by melting the fating surfaces and subsequently solidification only (without filler metal) is called autogenous weld. However, autogenous weld can be crack sensitive when solidification temperature range of the base metal to be welded is significantly high (750^o-100^oC). For example: Laser beam welding, Electron beam welding, Resistance welding, Friction stir welding.
- Homogeneous or Heterogeneous Weld: For welding of thick plates/sheets using any of the following processes. Filler metal can be used as per needs according to thickness of plates. The composition of the filler metal can be similar to that of base metal or different one accordingly weld joints. For example: Metal inert gas welding, Submerged arc welding, Flux cored arc welding.

Shielded Metal Arc Welding (SMAW)

- Shielded Metal Arc Welding, also known as Manual Metal Arc welding or informally as stick welding, is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric current, in the form of either AC or DC from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.



Advantages of SMAW

- Simple, portable and inexpensive equipment.
- Wide variety of metals, welding positions and electrodes are applicable;
- A big range of metals and their alloys can be welded.
- Welding can be carried out in any position with highest weld quality.

Disadvantages of SMAW

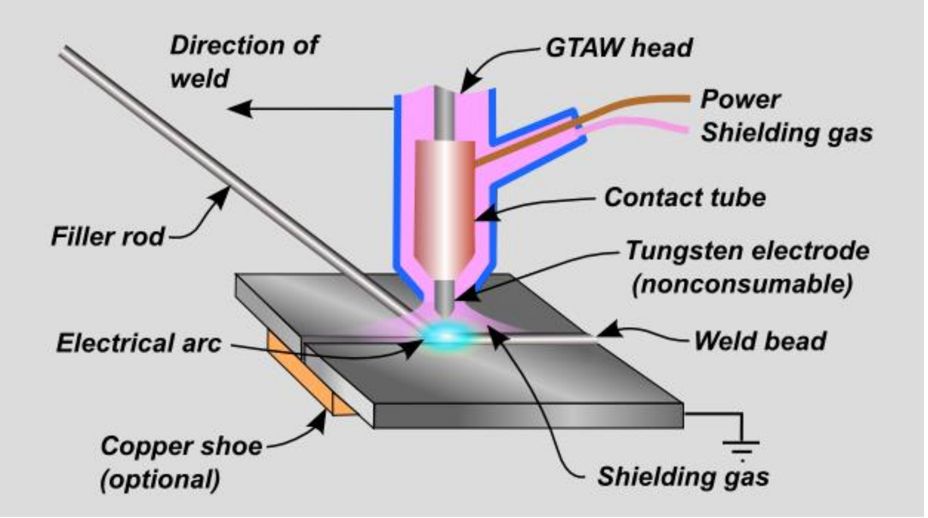
- Mechanization is difficult because of the limited length of electrode
- The process is discontinuous due to limited length of the electrodes
- Because of flux coated electrodes, the chances of slag entrapment is more
- Fumes make difficult the process control.

Applications of SMAW

- SMAW is used both as a fabrication process and for maintenance and repair jobs. The process finds applications in Boiler fabrications, Ship building, Building and Bridge construction, Automotive and Aircraft industry, etc.

Tungsten Inert Gas (TIG) Welding

- Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas (argon), and a filler metal is normally used. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma.
- TIG welding is often considered the most difficult of all the welding processes commonly used in industry. Because the welder must maintain a short arc length, great care and skill are required to prevent contact between the electrode and the workpiece.



Advantages of TIG Welding

- No flux is used, hence there is no danger of flux entrapment
- Weld in all positions & produces smooth & sound welds with fewer spatters
- It is very much suitable for high quality welding of thin (0.125mm) materials
- It is a very good process for welding nonferrous metals and stainless steel.

Disadvantages of TIG Welding

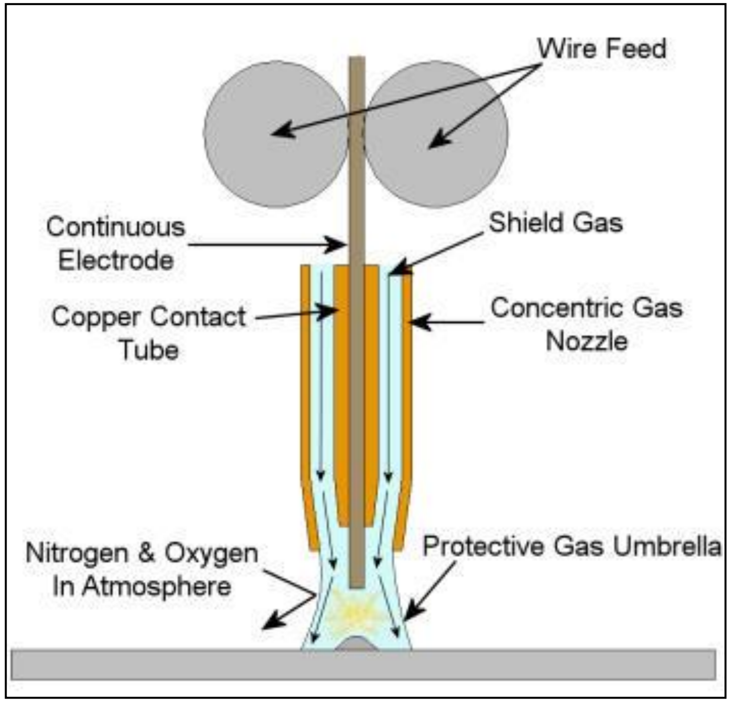
- Low welding rate
- Tungsten if it transfers to molten weld pool can contaminate the same.
- Equipment costs are higher than that for flux shielded metal arc welding.

Applications of TIG Welding

- Welding sheet metal and thinner sections
- Welding of transistor cases, instrument diaphragms, and can-sealing joints
- Precision welding in atomic energy, aircraft, chemical and instrument industries. Rocket motor chamber fabrications in launch vehicles.

Metal Inert Gas (MIG) Welding

- Gas Metal Arc Welding (GMAW) is frequently referred to as MIG welding is a commonly used high deposition rate welding process. Wire is continuously fed from a spool. MIG welding is therefore referred to as a semiautomatic welding process. Before igniting the arc, gas and water flow is checked. Proper current and wire feed speed is set and the electrical connections are ensured.
- The electrode is made to touch the job, is retracted and then moved forward to carry out welding; but before striking the arc, shielding gas, water and current is switched on. About 15 mm length of the electrode is projected from the torch before striking the arc. Arc length is maintained constant by using the principles of self-adjusted arc, and self-controlled arc in semi-automatic and automatic welding sets respectively.



Advantages of MIG Welding

- Continuous weld may be produced
- Both thick and thin workpieces can be welded effectively
- Large metal deposition rates are achieved by MIG welding process
- The process can be easily mechanized

Disadvantages of MIG Welding

- Expensive and non-portable equipment is required
- Welding equipment is more complex, more costly and less portable
- Since air drafts may disperse the shielding gas, MIG welding may not work well in outdoor welding applications

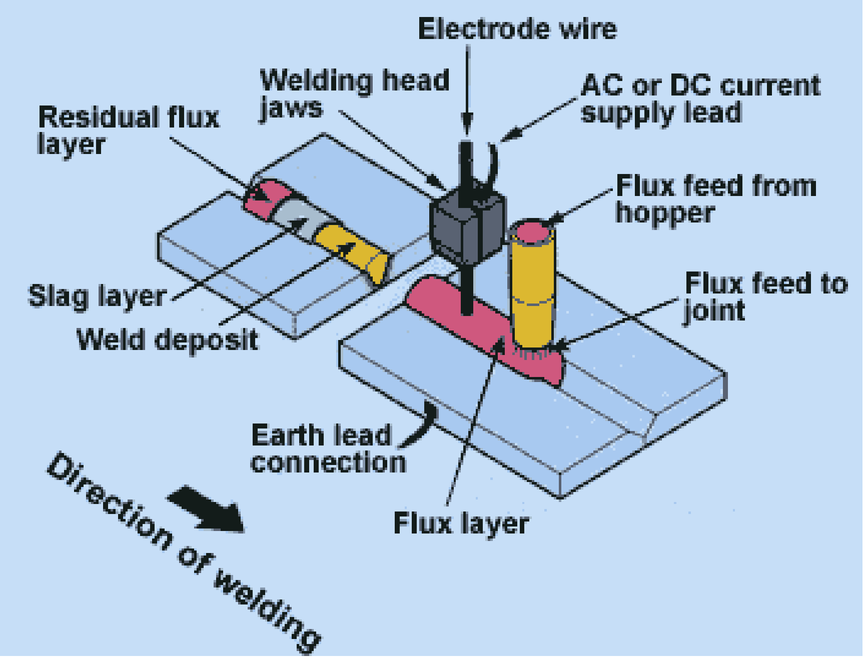
Applications of MIG Welding

- For welding tool steels and dies. MIG welding has been used successfully in industries like aircraft, automobile and shipbuilding.

Submersed Arc Welding (SAW)

- Submerged Arc Welding (SAW) is a common arc welding process. It requires a continuously fed consumable solid or tubular electrode. The molten weld and the arc zone are protected from atmospheric contamination by being submerged under a blanket of granular fusible flux. When molten, the flux becomes conductive, and provides a current path between the electrode and the work.

SAW is normally operated in the automatic or mechanized mode, however, semi-automatic SAW guns with pressurized or gravity flux feed delivery are available. DC or AC power can be utilized. Constant Voltage welding power supplies are most commonly used, however constant current systems in combination with a voltage sensing wire-feeder are available.



Advantages

- Deep weld penetration and sound welds are readily made
- High speed welding of thin sheet steels at over 2.5 m/min is possible
- The process is suitable for both indoor and outdoor works.
- The process is suitable for automation
- As the arc is covered under a blanket of flux, so there is no spatter of weld.

Disadvantages

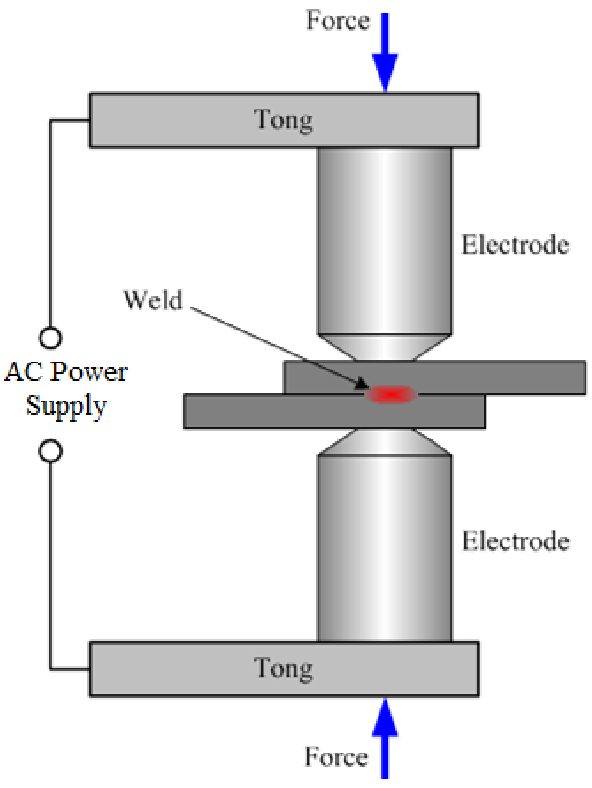
- Limited to ferrous (steel or stainless steels) and some nickel based alloys;
- Normally limited to long straight seams or rotated pipes or vessels;
- Flux and slag residue can present a health & safety issue

Applications

- Fabrication of pressure vessels, boilers, structural shapes, rail road and earth moving equipment, cranes and under structure of railway coaches and locomotives, automotive, aviation, ship-building and nuclear power industry.

Resistance Spot Welding (RSW)

- Spot welding is a popular resistance welding method used to join two to four overlapping metal sheets which are up to 3 mm thick each. In some applications with only two overlapping metal sheets, the sheet thickness can be up to 6 mm. Two copper electrodes are simultaneously used to clamp the metal sheets together and to pass current through the sheets.
- When the current is passed through the electrodes to the sheets, heat is generated in the air gap at the contact points. At the contact points between electrodes and workpiece the heat dissipates throughout the copper electrodes quickly, since the copper is an excellent conductor. However at the air gap between metal sheets the heat has no where to go, as the metal is a poor conductor of heat by comparison. Therefore the heat remains in the one location, which melts the metal at that spot. As the heat dissipates throughout the workpiece over a second or so, it cools the spot weld, causing the metal to solidify.



Advantages of RSW

- Low cost
- High speed of welding
- More general elimination of warping or distortion of parts
- Operation may be made automatic or semi-automatic.

Disadvantages of RSW

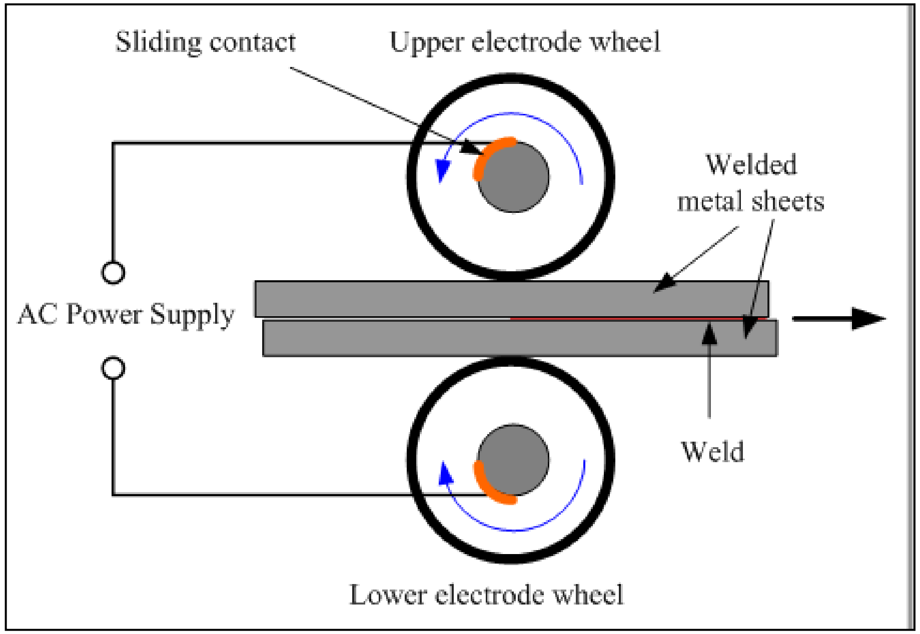
- The initial cost of equipment is high
- Skilled persons are needed for the maintenance of equipment and its controls
- In some materials, special surface preparation is required
- Bigger job thickness' cannot be welded

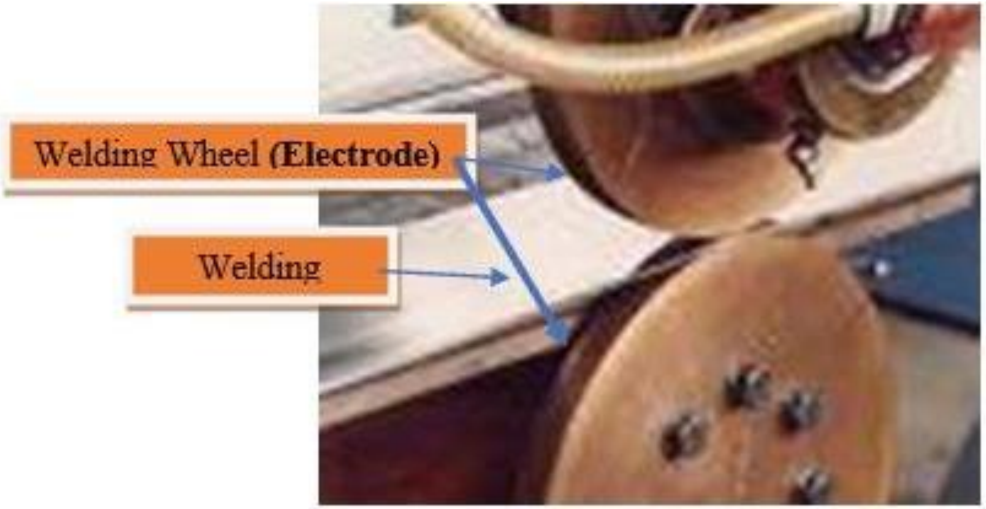
Applications of RSW

- The attachment of braces, brackets, pads or clips to formed sheet-metal parts such as cases, covers, bases or trays is another application of spot welding. Spot welding finds application in automobile and aircraft industries.

Resistance Seam Welding (RSEW)

- The seam-welding form of the resistance process is a series of overlapping welds. Two or more sheets of base metal are usually passed between electrode rollers, as shown in following Figure, which transmit the current and also the mechanical pressure required for producing a welded seam which is normally gas-tight or liquid-tight.





Advantages of RSEW

- It can produce gas tight or liquid-tight joints
- Overlap can be less than for spot or projection welds
- A single seam or several parallel seams may be produced simultaneously

Disadvantages of RSEW

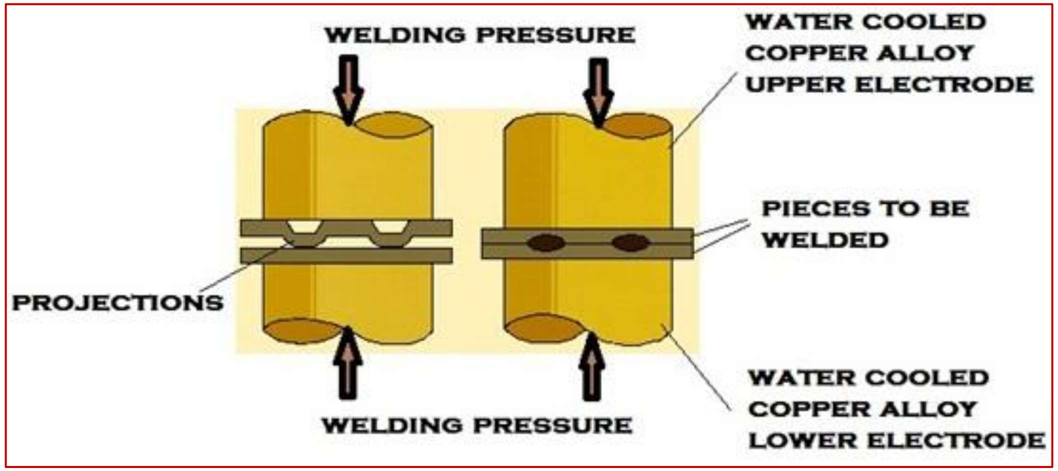
- Welding can be done only along a straight or uniformly curved line
- It is difficult to weld thicknesses greater than 3mm
- A change in the design of electrode wheels is required to avoid obstructions along the path of the wheels during welding.

Applications of RSEW

- Except for copper and high copper alloys, most other metals of common industrial use can be seam welding.
- Besides lap welds, seam-welding can be used for making butt seam welds.

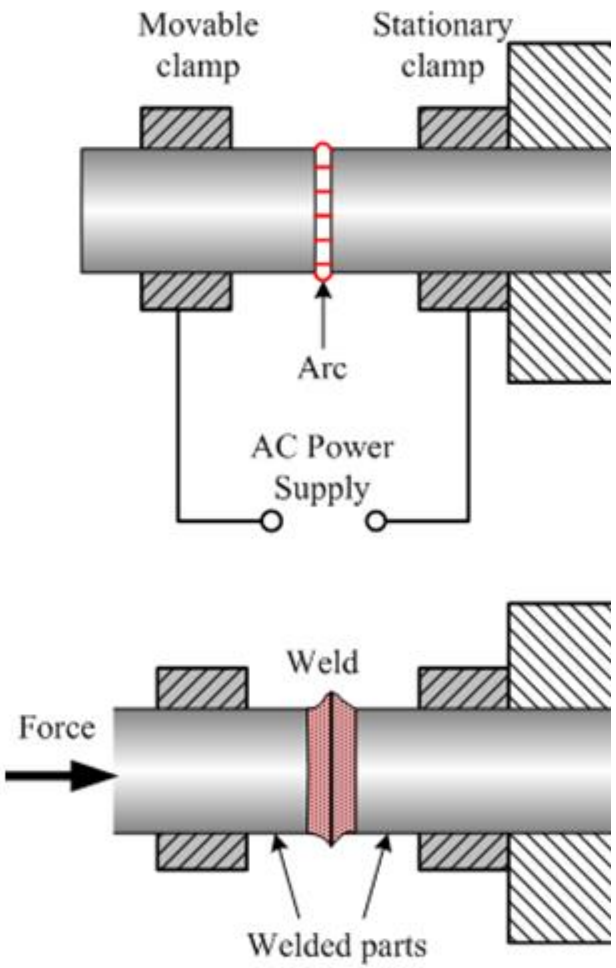
Resistance Projection Welding (RPW)

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



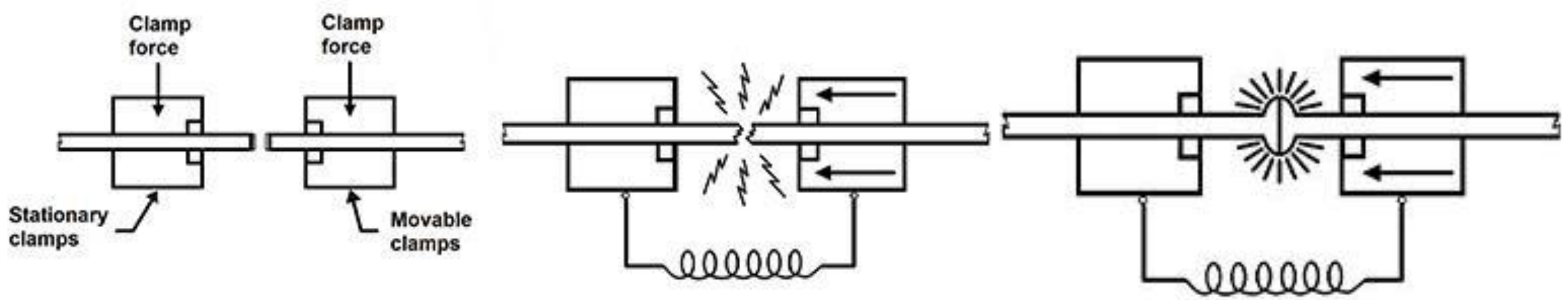
Flash Welding (FW)

- Flash Welding is a resistance welding process which produces coalescence simultaneously over the entire area of abutting surfaces, by the heat obtained from resistance to electric current between the two surfaces, and by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint. During the welding operation there is an intense flashing arc and heating of the metal on the surface abutting each other. After a predetermined time the two pieces are forced together and coalescence occurs at the interface, current flow is possible because of the light contact between the two parts being flash welded.



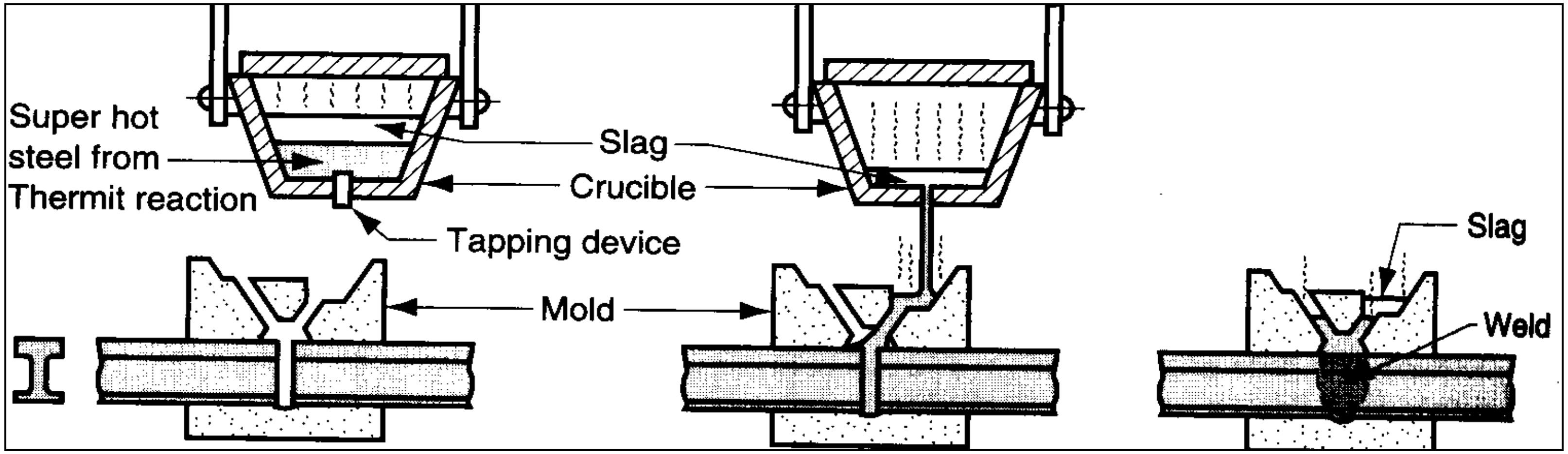
Percussion Welding (PEW)

- Percussion welding is a resistance welding process which produces coalescence of the abutting members using heat from an arc produced by a rapid discharge of electrical energy. Pressure is applied progressively during or immediately following the electrical discharge.
- This process is quite similar to flash welding and upset welding, but is limited to parts of the same geometry and cross section. It is more complex than the other two processes in that heat is obtained from an arc produced at the abutting surfaces by the very rapid discharge of stored electrical energy across a rapidly decreasing air gap. This is immediately followed by application of pressure to provide an impact bringing the two parts together in a progressive percussive manner.



Thermit Welding (TW)

- Thermit welding is a welding process utilizing heat generated by exothermic chemical reaction between the components of the thermit (a mixture of a metal oxide and aluminum powder) The molten metal, produced by the reaction, acts as a filler material joining the work pieces after solidification.
- Thermit welding is mainly used for joining steel parts, therefore common thermit is composed from iron oxide (78%) and aluminum powder (22%). The proportion 78-22 is determined by the chemical reaction of combustion of aluminum: **$8Al + 3Fe_3O_4 = 9Fe + 4Al_2O_3$**



Advantages of Thermit Welding

- No external power source is required (heat of chemical reaction is utilized);
- Very large heavy section parts may be joined.

Disadvantages of Thermit Welding

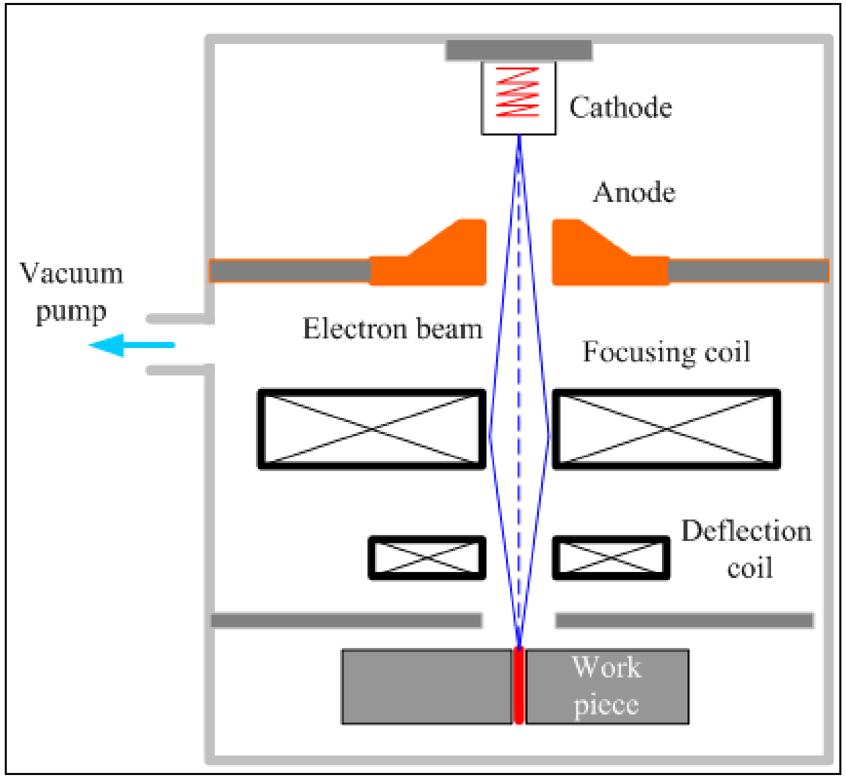
- Only ferrous (steel, chromium, nickel) parts may be welded
- Slow welding rate
- High temperature process may cause distortions and changes in grain structure in the weld region.
- Weld may contain gas (Hydrogen) and slag contaminations.

Applications of Thermit Welding

- For repairing fractured rails and butt-welding pipes end to end.
- For welding large fractured crankshafts, broken frames of machines, broken teeth on large gears, cables for electrical conductors, reinforcing bars to be used in concrete (building) construction.)

Electron Beam Welding (EBW)

- Electron Beam Welding is a welding process utilizing a heat generated by a beam of high energy electrons. The electrons strike the work piece and their kinetic energy converts into thermal energy heating the metal so that the edges of work piece are fused and joined together forming a weld after solidification. The electron beam is produced in a high vacuum environment by an electron gun, usually consisting of a tungsten or tantalum cathode, forming electrode and an anode. A stream of electrons is giving off from a tungsten filament heated to about 2200°C.



The electrons are gathered, accelerated to a high velocity and shaped into a beam by the potential difference between cathode and anode. The beam is collimated and focusing by passing through the field of an electro-magnetic focusing coil. Beams typically are focused to about 0.25 to 1 mm diameter and have a power density of 10 kW/mm^2, which is sufficient to melt and vaporize any metal.

Advantages of EBW

- Tight continuous clean and sound welds
- Low distortion, narrow weld and narrow heat affected zone
- Filler metal is not required

Disadvantages of EBW

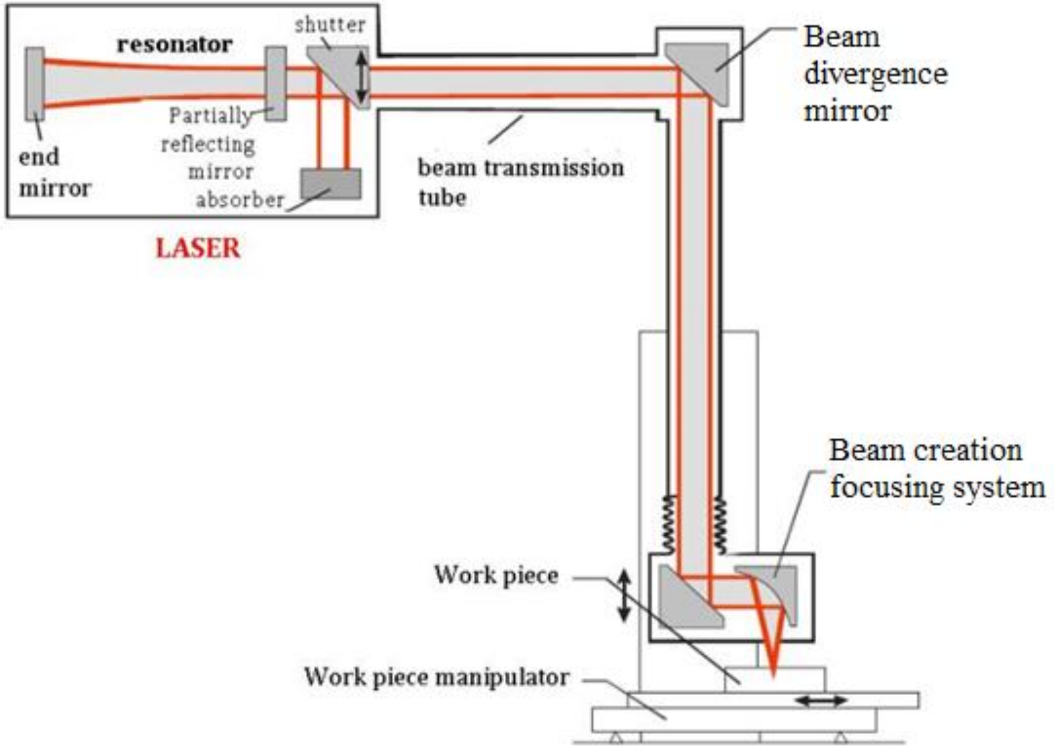
- The equipment is expensive and high operating cost
- Work size is limited by the size of the chamber
- High production expenses
- X-ray irradiation

Applications of EBW

- Materials that are difficult to weld by other processes, can be welded successfully. Narrow weld can be obtained with remarkable penetrations
- The high power and heat concentrations can produce fusion zones with depth-to-width ratios of 25:1.
- Heat sensitive materials can be welded without damage to the base metal.

Laser Beam Welding (LBW)

- LBM is a welding process, in which heat is generated by a high energy laser beam targeted on the work piece. The laser beam heats and melts the work pieces edges, forming a joint. Energy of narrow laser beam is highly concentrated: 10^8-0^{10} W/cm^2, therefore diminutive weld pool forms very fast (for about 10^{-6} sec.).



Solidification of the weld pool surrounded by the cold metal is as fast as melting. Since the time when the molten metal is in contact with the atmosphere is short, no contamination occurs and therefore no shields (neutral gas, flux) are required. The joint in LBM is formed either as a sequence of overlapped spot welds or as a continuous weld.

Advantages of LBM

- Easily automated process and controllable process parameters
- Very narrow weld may be obtained with very small heat affected zone
- High quality of the weld structure
- Dissimilar materials may be welded
- Very small delicate work pieces may be welded
- Vacuum is not required and low distortion of work piece

Disadvantages of LBM

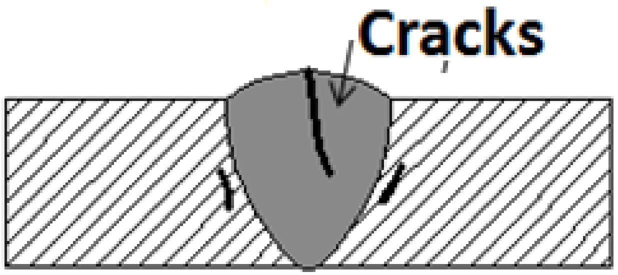
- Low welding speed
- High cost equipment
- Weld depth is limited
- Reflected or scattered laser beams can be quite dangerous to human eyes.

Applications of LBM

- Laser welding is used in electronics, communication and aerospace industry, for manufacture of medical and scientific instruments, for joining miniature and microminiaturized components.

Defects in Welding

- Weld Crack: The most serious type of welding defect is a weld crack and it's not accepted almost by all standards in the industry. It can appear on the surface, in the weld metal or the area affected by the intense heat. There are different types of cracks, depending on the temperature at which they occur:



  - Hot cracks: These can occur during the welding process or during the crystallization process of the weld joint.
  - Cold cracks: These cracks appear after the weld has been completed and the temperature of the metal has gone down. The cause of this defect is usually deformities in the structure of steel.
  - Crater cracks: These occur at the end of the welding process before the operator finishes a pass on the weld joint. They usually form near the end of the weld. When the weld pool cools and solidifies, it needs to have enough volume to overcome shrinkage of the weld metal. Otherwise, it will form a crater

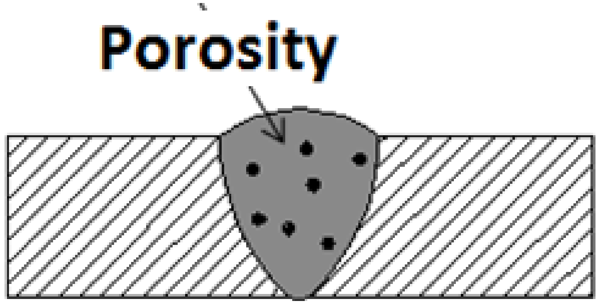
Causes of Cracks:

- Use of hydrogen when welding ferrous metals.
- Residual stress caused by the solidification shrinkage.
- Base metal contamination.
- High welding speed but low current.
- No preheat before starting welding.
- Poor joint design.
- A high content of sulfur and carbon in the metal.

Remedies:

- Preheat the metal as required.
- Provide proper cooling of the weld area.
- Use proper joint design.
- Remove impurities.
- Use appropriate metal.
- Make sure to weld a sufficient sectional area.
- Use proper welding speed and amperage current.
- To prevent crater cracks make sure that the crater is properly filled.

Porosity: Porosity occurs as a result of weld metal contamination. The trapped gases create a bubble-filled weld that becomes weak and can with time collapse.



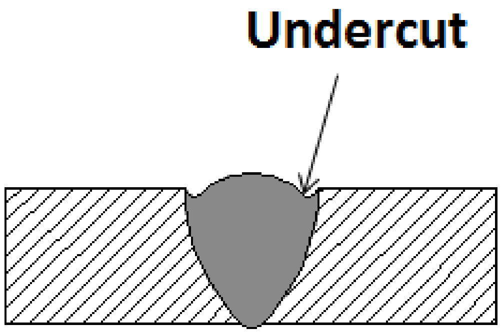
Causes of Porosity:

- Inadequate electrode deoxidant.
- Using a longer arc.
- The presence of moisture.
- Improper gas shield and incorrect surface treatment.
- Use of too high gas flow.
- Contaminated surface.
- Presence of rust, paint, grease or oil etc.

Remedies:

- Clean the materials before you begin welding.
- Use dry electrodes & materials, correct arc distance and right electrodes
- Reduce arc travel speed, which will allow the gases to escape.
- Use a proper weld technique.

Undercut: This welding imperfection is the groove formation at the weld toe, reducing the cross-sectional thickness of the base metal. The result is the weakened weld and workpiece.



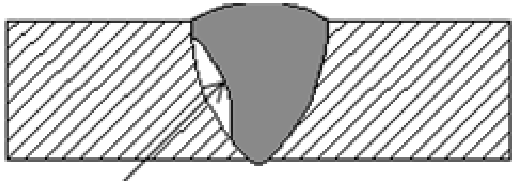
Causes of Undercut:

- Low heat input.
- Surface contamination.
- Electrode angle is incorrect.
- The electrode diameter is incorrect for the material thickness you're welding.
- Travel speed is too fast.
- The weld pool is too large and it runs ahead of the arc.

Remedies:

- Use a sufficiently high welding current with the appropriate arc voltage.
- Before you begin welding, clean the metal.
- Avoid molten pool from flooding the arc.
- Use correct electrode diameter and angle.
- Reduce deposition rate.

Incomplete Fusion: This type of welding defect occurs when there's a lack of proper fusion between the base metal and the weld metal. It can also appear between adjoining weld beads. This creates a gap in the joint that is not filled with molten metal.



Incomplete Fusion

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Remedies:

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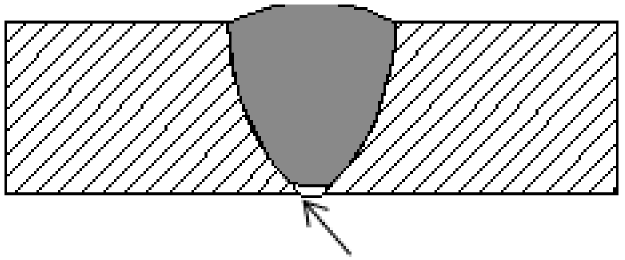
- Before you begin welding, clean the metal.
- Avoid molten pool from flooding the arc.
- Use correct electrode diameter and angle.
- Reduce deposition rate.

Incomplete Penetration: Incomplete penetration occurs when the groove of the metal is not filled completely, meaning the weld metal doesn't fully extend through the joint thickness.



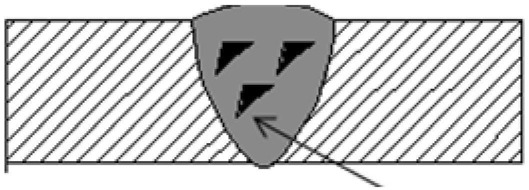
Causes of Incomplete penetration :

- There was too much space between the metal you're welding together.
- Moving the bead too quickly, which doesn't allow enough metal to be deposited
- Using a too low amperage setting, which results in the current not being strong enough to properly melt the metal.
- Large electrode diameter.
- Misalignment and improper joint.

Remedies:

- Use proper joint geometry and check for proper alignment.
- Use a properly sized electrode.
- Reduce arc travel speed.
- Choose proper welding current.

Slag Inclusion: Slag inclusion is one of the welding defects that are usually easily visible in the weld. Slag is a vitreous material that occurs as a byproduct of stick welding, flux-cored arc welding and submerged arc welding.



Slag inclusion

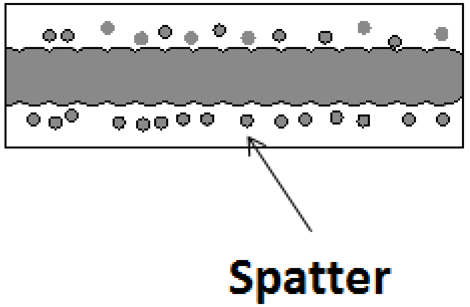
Causes of Slag inclusion:

- Improper cleaning.
- The weld speed is too fast.
- Not cleaning the weld pass before starting a new one.
- Incorrect welding angle.
- The weld pool cools down too fast.
- Welding current is too low.

Remedies:

- Increase current density.
- Reduce rapid cooling.
- Adjust the electrode angle and the welding speed.
- Remove any slag from the previous bead.

Spatter: Spatter occurs when small particles from the weld attach themselves to the surrounding surface. It's an especially common occurrence in gas metal arc welding. No matter how hard you try, it can't be completely eliminated.



Causes of Spatter

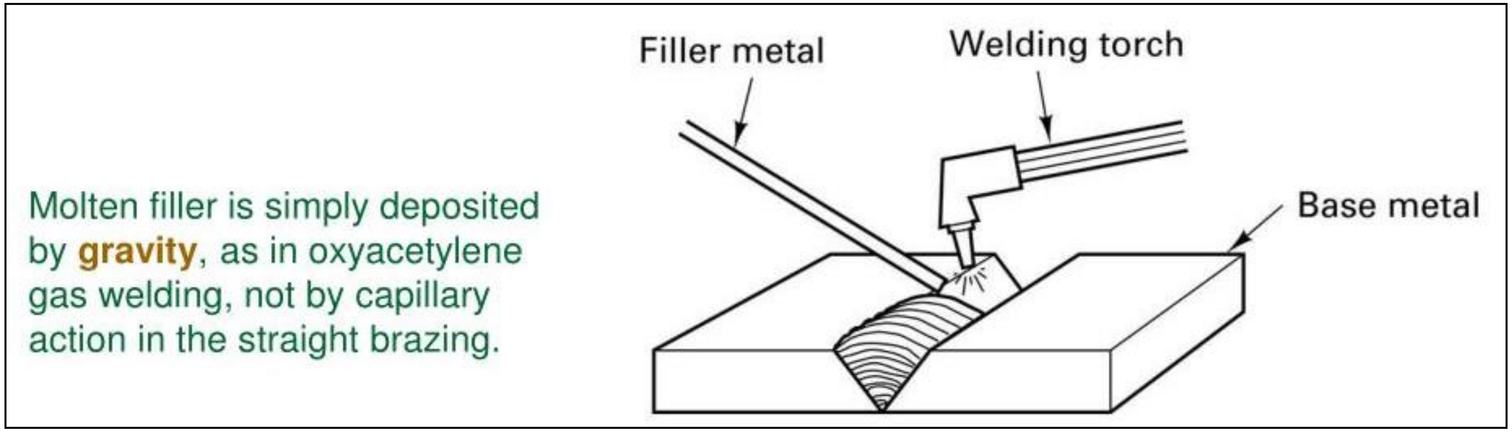
- The running amperage and voltage are too high.
- The work angle of the electrode is too steep.
- The surface is contaminated.
- The arc is too long.
- Incorrect polarity and erratic wire feeding.

Remedies:

- Clean surfaces prior to welding.
- Reduce the arc length.
- Adjust the weld current.
- Increase the electrode angle.
- Use proper polarity.

Braze-welding Process

- Brazing is a method of joining two metal work pieces by means of a filler material at a temperature above its melting point but below the melting point of either of the materials being joined.
- Flow of the molten filler material into the gap between the work pieces is driven by the capillary force. The filler material cools down and solidifies forming a strong metallurgical joint, which is usually stronger than the parent (work piece) materials. The parent materials are not fused in the process.
- Brazing is similar to Soldering. The difference is in the melting point of the filler alloy: brazing filler materials melt at temperatures above 840°F (450°C); soldering filler materials (solders) melt at temperatures below this point.



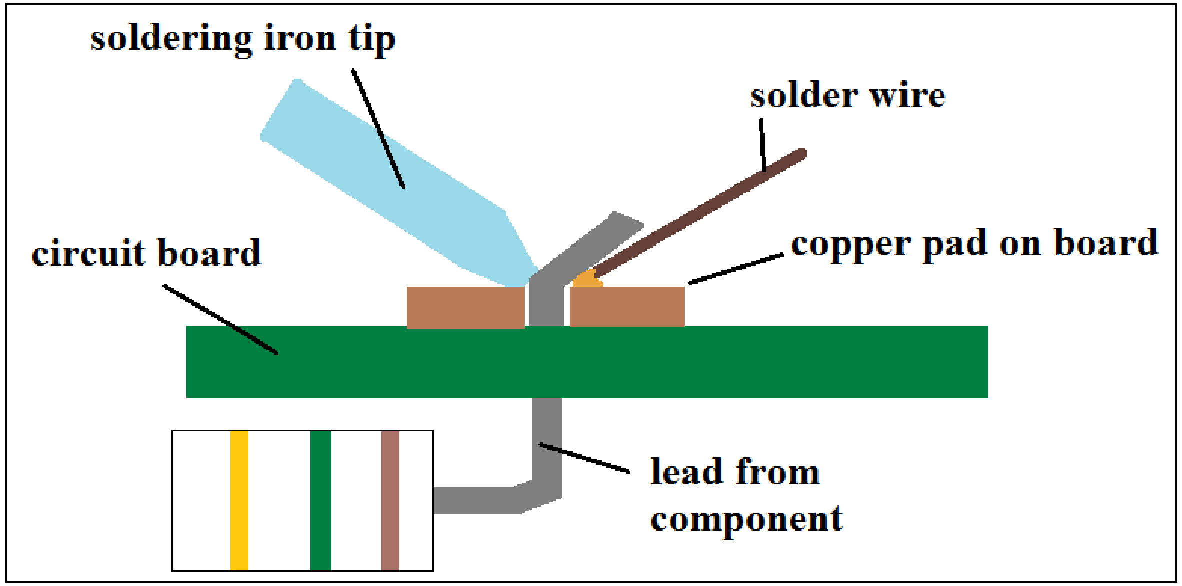
Advantages of Brazing

- Low thermal distortions and residual stresses in the joint parts
- Microstructure is not affected by heat
- Easily automated process
- Dissimilar materials may be joined
- High variety of materials may be joined
- Thin wall parts may be joined
- Moderate skill of the operator is required.

Disadvantages of Brazing

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

- Soldering is a method of joining two metal work pieces by means of a third metal (solder) at a relatively low temperature, which is above the melting point of the solder but below the melting point of either of the materials being joined. Flow of the molten solder into the gap between the work pieces is driven by the capillary force. The solder cools down and solidifies forming a joint. The parent materials are not fused in the process.
- Soldering is similar to Brazing. The difference is in the melting point of the filler alloy: solders melt at temperatures below 840°F (450°C); brazing filler materials melt at temperatures above this point.



Advantages of Soldering

- Low power and process temperature are required
- No thermal distortions and residual stresses in the joint parts
- Microstructure is not affected by heat
- Easily automated process
- Dissimilar materials may be joined
- High variety of materials may be joined
- Thin wall parts may be joined
- Moderate skill of the operator is required

Disadvantages of Soldering

- Careful removal of the flux residuals is required in order to prevent corrosion
- Large sections cannot be joined
- Fluxes may contain toxic components
- Soldering joints can not be used in high temperature applications
- Low strength of joints.