3- Unique processes.

3-1 Electron Beam Welding (EBW)

Electron Beam Welding (EBW) is a fusion welding in which coalescence is produced by heating the workpiece due to impingement of the concentrated electron beam of high kinetic energy on the workpiece. As the electron beam impinges the workpiece, kinetic energy of the electron beams converts into thermal energy resulting in melting and even evaporation of the work material.

An electron beam gun creates a stream of electrons (by causing a heated cathode to discharge in a near-vacuum tube.) The beam is focused electro-magnetically, and hits upon the metal, where the kinetic energy of the electrons is converted to heat, causing melting. The process is useful for narrow, deep welds, but is expensive.

Principles:

In general, electron beam welding process is carried out in vacuum. In this process, electrons are emitted from the heated filament called electrode. These electrons are accelerated by applying high potential difference (30 kV to 175 kV) between cathode and anode. The higher the potential difference, the higher would be the acceleration of the electrons. The electrons get the speed in the range of 50,000 to 200,000 km/s. The electron beam is focused by means of electromagnetic lenses. When this high kinetic energy electron beam strikes on the workpiece, high heat is generated on the work piece resulting in melting of the work material. Molten metal fills into the gap between parts to be joined and subsequently it gets solidified and forms the weld joint

EBW Equipment:

An EBW set up consists of the following major equipment:

a) Electron gun,

b) Power supply,

c) Vacuum Chamber, and

d) Work piece handling device.

Electron-Gun: An electron gun generates, accelerates and aligns the electron beam in required direction and spots onto the workpiece. The gun is of two types: Self accelerated and work accelerated. The work accelerated gun accelerates the electrons by providing potential difference between the work piece and cathode. In the self accelerate gun, electrons are accelerated by applying potential difference between the cathode and the anode. The anode and cathode are enclosed within the gun itself. The control of electron density is better in this type of electron gun. A schematic of an electron beam gun used in EBW is shown in Fig. 4.5.1. Major parts of an electron gun are briefly introduced in the following sections.

Emitter/Filament: It generates the electrons on direct or indirect heating.

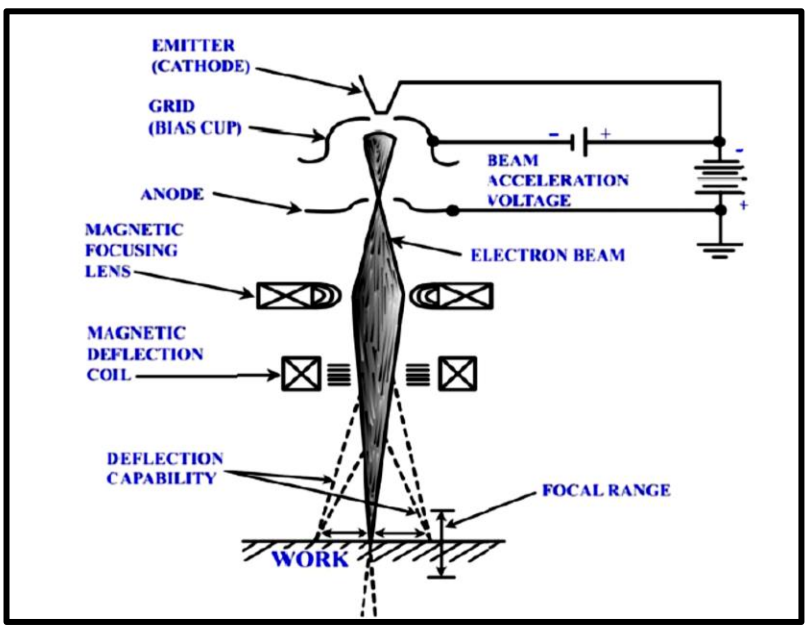
Anode: It is a positively charged element near cathode, across which the high voltage is applied to accelerate the electrons. The potential difference for high voltage equipment ranges from 70-150 kV and for low voltage equipment from 15-30 kV.

Grid cup: Grid cup is a part of triode type electron gun. A negative voltage with respect to cathode is applied to the grid. The grid controls the beam.

Focusing unit: It has two parts: Electron focusing lens and deflection coil. Electron focusing lens focuses the beam into work area. The focusing of the electrons can be carried out by deflection of beams. The electromagnetic lens contains a coil encased in iron. As the electrons enter into the magnetic field, the electron beam path is rotated and refracted into a convergent beam. The extent of spread of the beam can be controlled by controlling the amount of DC voltage applied across the deflection plates.

Electron gun power supply: It consists of mainly the high voltage DC power supply source, emitter power supply source, electromagnetic lens and deflection coil source. In the high voltage DC power supply source the required load varies within 3-100 kW. It provides power supply for acceleration of the electrons. The potential difference for high voltage equipment ranges from 70-150 kV and for low voltage equipment 15-30 kV. The current level ranges from 50-1000 mA.

In emitter power supply, AC or DC current is required to heat the filament for emission of electrons. However DC current is preferred as it affects the direction ofthe beam. The amount of current depends upon the diameter and type of the filament. The current and voltage varies from 25-70 A and 5-30 V respectively. The power to the electromagnetic lens and deflection coil is supplied through a solid state device.



Schematic of an electron beam gun used in EBW.

Vacuum Chamber: In the vacuum chamber pressure is reduced by the vacuum pump. It consists of a roughing mechanical pump and a diffusion pump. The pressure ranges from 100 kPa for open atmosphere to 0.13-13 Pa for partial

vacuum and 0.13-133 mPa for hard vacuum.

As the extent of vacuum increases, the scattering of the electrons in the beam increases. It causes the increase in penetration.

Work Piece Handling Device: Quality and precision of the weld profile depends upon the accuracy of the movement of work piece. There is also provision for the movement of the work piece to control the welding speed. The movements of the work piece are easily adaptable to computer numerical control.

Advantages of EBW:

1) High penetration to width can be obtained, which is difficult with other welding processes.
2) High welding speed is obtained.
3) Material of high melting temperature can be welded.
4) Superior weld quality due to welding in vacuum.
5) High precision of the welding is obtained.
6) Distortion is less due to less heat affected zone.
7) Dissimilar materials can be welded.
8) Low operating cost.
9) Cleaning cost is negligible.
10) Reactive materials like beryllium, titanium etc. can be welded.
11) Materials of high melting point like columbium, tungsten etc. can be welded.
12) Inaccessible joints can be made.
13) Very wide range of sheet thickness can be joined (0.025 mm to 100 mm)

Disadvantages of EBW:

1) Very high equipment cost.
2) High vacuum is required.

3) High safety measures are required.

4) Large jobs are difficult to weld.

5) Skilled man power is required.

Applications of EBW:

1. Electron beam welding process is mostly used in joining of refractive materials like columbium, tungsten, ceramic etc. which are used in missiles.
2. In space shuttle applications wherein reactive materials like beryllium, zirconium, titanium etc. are used.
3. In high precession welding for electronic components, nuclear fuel elements, special alloy jet engine components and pressure vessels for rocket plants.
4. Dissimilar material can be welded like invar with stainless steel.

3-2 Plasma Arc Welding (PAW)

Plasma is high temperature ionized gas composed of electrons and ions. Plasma arcs are formed by creating the plasma gas by using an arc, and forcing it out as a focused beam through a tiny nozzle. It is useful for deep, narrow welds. The shielding of the weld pool is obtained by the hot ionized gas produced by passing inert gas through the arc and constricted nozzle. Filler material may or may not be applied.

Principles of Operation:

In the PAW fusion welding process, the workpiece is cleaned and edges are prepared. An arc is established between a non consumable tungsten electrode and workpiece or between a non consumable electrode and constricted nozzle. An inert gas is passed through the inner orifice surrounding the tungsten electrode and subsequently the gas is ionized and conducts electricity. This state ofionized gas is known as plasma. The plasma arc is allowed to pass through the constricted nozzle causing high energy and current density.

Subsequently high concentrate heat and very high temperatures are reached. The low flow rate (0.25 to 5 l/min) of the orifice gas is maintained as excessive flow rate may cause turbulence in the weld pool. However the orifice gas at this flow rate is insufficient to shield the weld pool effectively. Therefore inert gas at higher flow rate (10- 30 l/min) is required to pass through outer gas nozzle surrounding the inner gas nozzle to protect the weld pool. A typical manual torch used in PAW is as shown in Fig. (2).

Plasma arc welding is of two types: Non-transferred plasma arc welding process and transferred arc welding process. In the former, the arc is established between the electrode and the nozzle and in the latter process the arc is established between the electrode and the workpiece. The differences between these two processes are presented in the Table (1).

Table (1): Difference between the transferred and non-transferred arc welding processes

Transferred plasma arc welding process	**Non-transferred plasma arc welding process**
Arc is established between electrode and workpiece	Arc is established between electrode and nozzle.
The work piece is part of the electrical circuit and heat is obtained from the anode spot and the plasma jet. Therefore, higher amount of energy is transferred to work. This is useful for welding.	The work piece is not part of the electrical circuit and heat is obtained from the plasma jet. Therefore, less energy is transferred to work. This is useful in cutting.
Higher penetration is obtained, so thicker sheets can be welded.	Less penetration is obtained, so thin sheets can be welded.
Higher process efficiency.	Less process efficiency.

PAW Operation:

In the PAW process, arc can not be initiated by touching the work piece as electrode is recessed in the inner constricted nozzle. Therefore, a low current pilot arc is established in the constricted inner nozzle and electrode. The pilot arc is generally initiated by the use of high frequency AC or high voltage DC pulse superimposed on the main welding current. It causes the ionization of the orifice gas and high temperature which contributes to easy initiation of the main arc between the

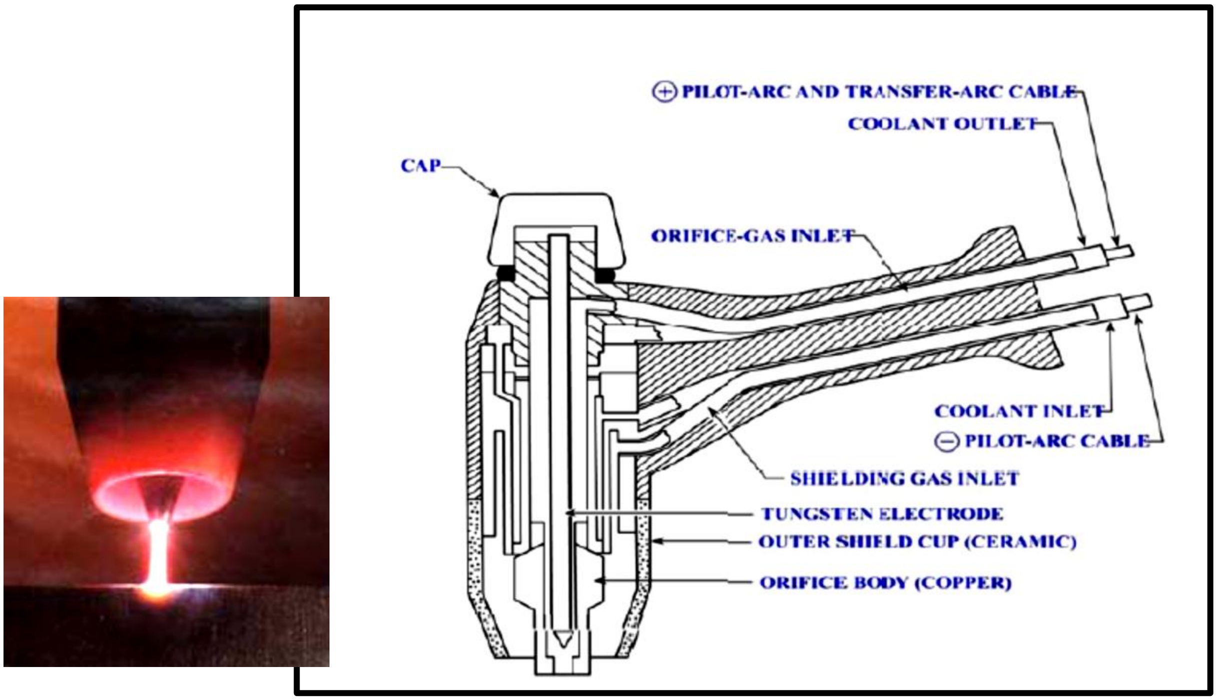


Figure (2): Plasma arc welding, **Typical manual torch used in PAW**

electrode and work piece. After the initiation of the main arc, the pilot arc may be extinguished. This is followed by adding the filler material as in TIG welding process. Next, the welding torch is moved manually or automatically in the direction of welding. There are two techniques: (i) Key hole technique and (ii) Non key hole technique. In the key hole technique, due to constricted arc, high temperature and high gas flow; small weld pool with high penetration (up to 100%) to width is obtained, resulting in complete melting of the base material beneath the arc. As the arc moves forward, the material is melted and fills the hole produced due to arc force. The power

supply and gas flow rate are turned off once the key hole is filled appropriately in the end of welding. The workpiece is suitably cleaned after cooling.

Equipment and Consumables:

Power source: A conventional DC current power supply with drooping V-I characteristics is required. Both rectifier or generator type power source may be used; however, rectifier type power source is preferred. The general range of the open-circuit voltage and current is 60-80V and 50-300A respectively.

Plasma torch: It consists of non consumable tungsten electrode, inner nozzle (constricting nozzle) and outer gas nozzle. The torch is water cooled to avoid heating of the nozzle. It is of two types: transferred arc and non transferred arc welding torch.

Filler material and shielding gases:

Filler material used in this process is the same as those used in the TIG and MIG welding processes. The selection of the gases depends upon the martial to be welded. The orifice gas must be an inert gas to avoid contamination of the electrode material. Active gas can be used for shielding provided it does not affect the weld quality. In general, the orifice gas is the same as the shielding gas.

Applications of PAW:

This process is comparatively new and hence the potential of the process is yet to be understood/ accepted. This process can be used to join all the materials those can be welded by welding TIG process. Present applications of the process include:

1) Piping and tubing of stainless and titanium,

2) Submarine, aeronautical industry and jet engine manufacturing,

3) Electronic components.

Advantages of PAW:

1) Welding speed is higher.

2) Penetration is more.

3) Higher arc stability.

4) The distance between torch and workpiece does not affect heat concentration on the work up to some extent.

5) Addition of filler material is easier than that of TIG welding process.

6) Thicker job can be welded.

7) Higher depth to width ratio is obtained resulting in less distortion.

Disadvantages of PAW:

1) Higher radiations.

2) Noise during welding.

3) Process is complicated and requires skilled manpower.

4) Gas consumption is high.

5) Higher equipment and running cost.

6) Higher open circuit voltage requiring higher safety measures to take.

3-3 Laser Beam Welding

A high power laser can be used to melt metal, and therefore can be used to cut, weld, etc. Typical high power lasers include Nd:Nag and CO_2 lasers, with power levels up to 100kW. This is a very versatile welding process, and can be used for high speed, narrow, deep, welds; it is also useful for high precision, low distortion welds.

Principles:

Laser is an acronym for light amplification by stimulated emission of radiation. Laser Beam Welding (LBW) is a fusion joining process that produces coalescence of materials with the heat obtained from a concentrated beam of

coherent, monochromatic light impinging on the joint to be welded. In the LBM process, the laser beam is directed by flat optical elements, such as mirrors and then focused to a small spot (for high power density) at the workpiece using either reflective focusing elements or lenses. It is a non-contact process, requiring no pressure to be applied. Inert gas shielding is generally employed to prevent oxidation of the molten puddle and filler metals may be occasionally used. The Lasers which are predominantly being used for industrial material processing and welding tasks are the Nd-YAG laser and 1.06 µm wavelength CO2 laser, with the active elements most commonly employed in these two varieties of lasers being the neodymium (Nd) ion and the CO2 molecules respectively.

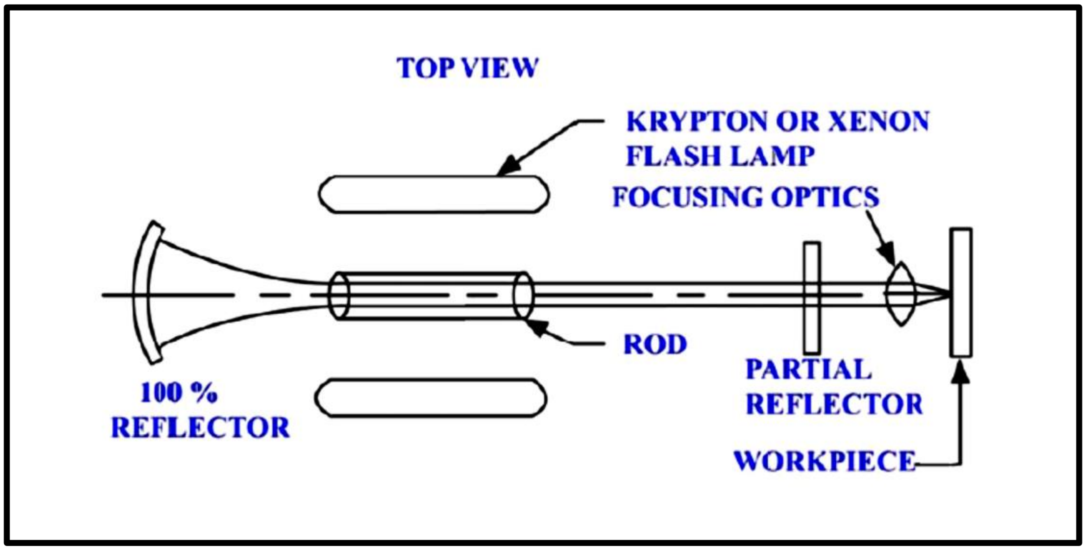
Laser Types:

Solid-State laser:

It utilizes an impurity in a host material as the active medium. Thus, the neodymium ion (Nd+++) is used as a 'dopant', or purposely added impurity in either a glass or YAG crystal and the 1.06 µm output wave length is dictated by the neodymium ion. The lasing material or the host is in the form of a cylinder of about 150 mm long and 9 mm in diameter. Both ends of the cylinder are made flat and parallel to very close tolerances, then polished to a good optical finish and silvered to make a reflective surface. The crystal is excited by means of an intense krypton or xenon lamp. A simplified schematic arrangement of the rod, lamp and mirrors is as shown in Fig. 4.6.1

Gas Lasers:

The electric discharge style CO_2 gas lasers are the most efficient type currently available for high power laser beam material processing. These lasers employ gas mixtures primarily containing



l Schematic of lasant rod, lamp and mirror used in laser beam welding.

nitrogen and helium along with a small percentage of carbon dioxide, and an electric glow discharge is used to pump this laser medium (i.e., to excite the CO_2 molecule). Gas heating produced in this fashion is controlled by continuously circulating the gas mixture through the optical cavity area and thus CO_2 lasers are usually categorized according to the type of gas flow system they employ; slow axial, fast axial or transverse.

Slow Axial Flow Gas Laser:

They are the simplest of the CO_2 gas lasers. Gas flow is in the same direction as the laser resonator's optical axis and electric excitation field, or gas discharge path. These are capable of generating laser beams with a continuous power rating of approximately 80 watts for every meter of discharge length. A folded tube configuration is used for achieving output power levels of 50 to 1000 watts, maximum.

Fast Axial Flow (FAF) Gas Laser:

They have similar arrangement of components as that of slow axial flow gas laser, except that in the case of the FAF Laser, a roots blower or turbo pump is used to circulate the laser gas at high speed through the discharge region and corresponding

heat exchangers. The FAF lasers with continuous wave (CW) output power levels of between 500 to 6000 watts are available.

Transverse Flow:

These lasers operate by continuously circulating gas across the resonator cavity axis by means of a high speed fan type blower, while maintaining an electric discharge perpendicular to both the gas flow direction and the laser beam's optical axis. Transverse flow lasers with output power levels between 1 and 25 kW are available.

LBW Process Advantages:

Major advantages of Laser Beam Welding include the following:

1) Heat input is close to the minimum required to fuse the weld metal, thus heat affected zones are reduced and workpiece distortions are minimized.
2) Time for welding thick sections is reduced and the need for filler wires and elaborate joint preparations is eliminated by employing the single pass laser welding procedures.
3) No electrodes are required; welding is performed with freedom from electrode contamination, indentation or damage from high resistance welding currents.
4) LBM being a non-contact process, distortions are minimized and tool wears are eliminated.
5) Welding in areas that are not easily accessible with other means of welding can be done by LBM, since the beams can be focused, aligned and directed by optical elements.
6) Laser beam can be focused on a small area, permitting the joining of small, closely spaced components with tiny welds.
7) Wide variety of materials including various combinations can be welded.

8) Thin welds on small diameter wires are less susceptible to burn back than is the case with arc welding.

9) Metals with dissimilar physical properties, such as electric resistance can also be welded.

10) No vacuum or X-Ray shielding is required.

11) Laser welds are not influenced by magnetic fields, as in arc and electron beam welds. They also tend to follow weld joint through to the root of the work-piece, even when the beam and joint are not perfectly aligned.

12) Aspect ratios (i.e., depth-to-width ratios) of the order of 10:1 are attainable in LBM.

Limitations of the LBM Process:

1) Joints must be accurately positioned laterally under the beam and at a controlled position with respect to the beam focal point.

2) In case of mechanical clamping of the weld joints, it must be ensured that the final position of the joint is accurately aligned with the beam impingement point.

3) The maximum joint thickness that can be welded by laser beam is somewhat limited. Thus weld penetrations of larger than 19 mms are difficult to weld.

4) High reflectivity and high thermal conductivity of materials like Al and Cu alloys can affect the weldability with lasers.

5) An appropriate plasma control device must be employed to ensure the weld reproducibility while performing moderate to high power laser welding.

6) Lasers tend to have fairly low energy conversion efficiency, generally less than 10 percent.

7) Some weld-porosity and brittleness can be expected, as a consequence of the rapid solidification characteristics of the LBM.

Laser welding of a gear