

# LECTURE NOTES

## Module-II

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## **SYLLABUS (BPUT)**

### **5th Semester**

## **PC 11: Basic Manufacturing Processes**

### **MODULE - I (10 LECTURES)**

Foundry: Types of patterns, pattern materials and pattern allowances. Moulding Materials - sand moulding, metal moulding, investment moulding, shell moulding. Composition of molding sand, Silica sand, Zircon sand, binders, additives, Binders - clay, binders for CO<sub>2</sub>, sand, binder for shell moulding, binders for core sand. Properties of moulding sand and sand testing, Melting furnaces - cupola, resistance furnace, induction and arc furnace, Solidification of castings, design of risers and runners, feeding distance, centre line freezing resistance chills and chaplets. Degasification and inoculation of metals. Casting methods like continuous casting, centrifugal casting, disc casting. Casting defects.

### **MODULE - II (8 LECTURES)**

Welding and cutting: Introduction to gas welding, cutting, Arc welding and equipment's. TIG (GTAW) and MIG (GMAW) welding, resistance welding and thermit welding. Weldability Modern Welding methods like plasma Arc, Laser Beam, Electron Beam, Ultrasonic, Explosive and friction welding, edge preparation in butt welding. Brazing and soldering, welding defects. Destructive and non-destructive testing of castings and welding.

### **MODULE - III (08 LECTURES)**

Brief introduction to powder metallurgy processes. Plastic deformation of metals: Variables in metal forming and their optimization. Dependence of stress strain diagram on Strain rate and temperature. Hot and cold working of metals, classification of metal forming processes.

Rolling: Pressure and Forces in rolling, types of rolling mills, Rolling defects. Forging: Smith Forging, Drop and Press forging, M/c forging, Forging defects.

### **MODULE - IV (08 LECTURES)**

Extrusions: Direct, Indirect, Impact and Hydrostatic extrusion and their applications, Extrusion of tubes. Wire drawing methods and variables in wire-drawing, Optimum dies shape for extrusion and drawing. Brief introduction to sheet metal working: Bending, Forming and Deep drawing, shearing. Brief introduction to explosive forming, coating and deposition methods.

### **BOOKS**

- [1] Manufacturing technology by P.N.Rao, Tata McGraw Hill publication.
- [2] Welding Technology by R.A. Little, TMH
- [3] Manufacturing Science by A.Ghosh and A K Malick, EWP
- [4] Fundamentals of metal casting technology by P.C. Mukherjee, Oxford PIBI.
- [5] Mechanical Metallurgy by Dieter, Mc-Graw Hill
- [6] Processes and Materials of Manufacture by R.A Lindberg, Prentice hall (India)
- [7] A Text Book of Production Engineering by P.C.Sharma, S.Chand.

### **Digital Learning Resources:**

#### **NPTEL MOOCs:**

Course Name: Fundamentals of Manufacturing Processes

Course Link: <https://nptel.ac.in/courses/108/102/108102047/>

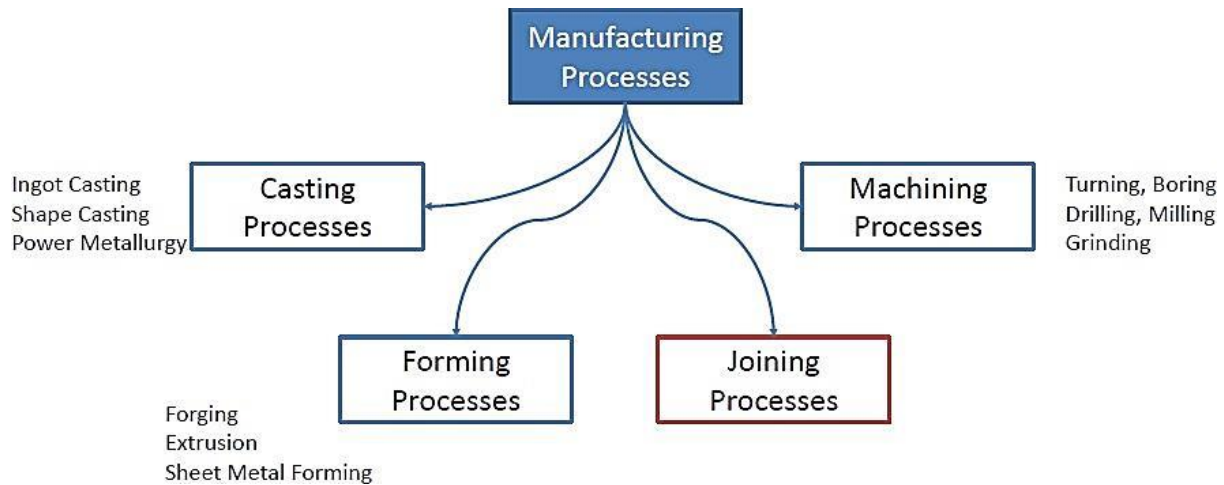
## Module – II

# Welding and Cutting

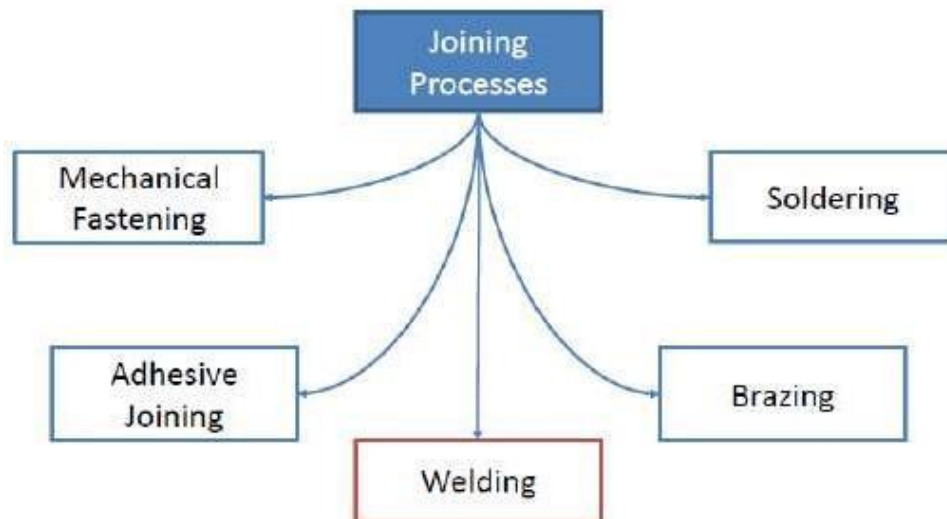
**Module – II Welding and cutting (12 Lectures)**

Fabrication is often known as secondary manufacturing process as the method relies on the raw material obtained from the manufacturing process like extrusion and rolling. Fabrication is a process of joining two or more elements to make a single part. Most common examples are aircraft, ship bodies, bridges, building trusses, welded machine frames, sheet metal parts, etc.

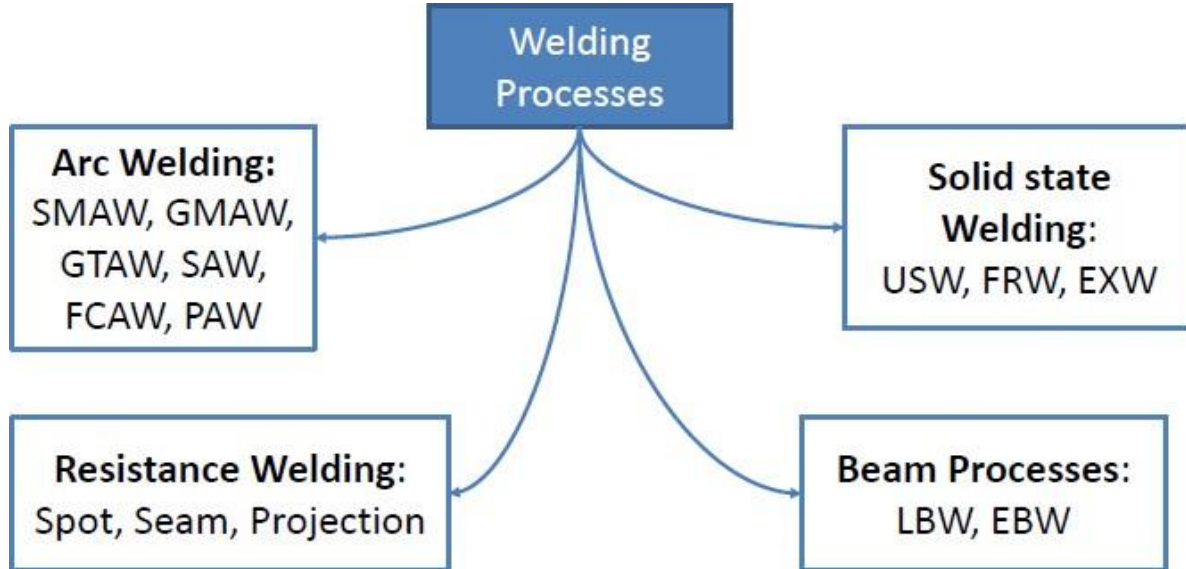
**Classification of Manufacturing Processes**



**Classification of Joining Processes**



### Classification of Welding Processes



A particular fabrication method depends on number of factors

- *Type of assembly*

Permanent, semi permanent or temporary

Joining those obtained by bolts or screws and can be disassembled whenever necessary are temporary in nature. Rivets are semi-permanents fastening devices that involve making holes in the mating parts. Here joints can be separated by destroying the rivet without harming the parent elements.

- *Materials being joined*

Steel, cast irons, aluminium, similar or dissimilar metals

- *Type of service required*

Assembly subjected to heavy loading, impact loading, high temperatures **Principle of**

**welding:** The welding process is a complex process that involves heat and liquid-metal transfer, chemical reactions. A gradual formation of the welded joint is obtained through liquid-metal deposition and subsequently there is a transformation from cooling into the solid state.

**Brazing** Brazing is a coalescence of a joint with the help of a filler metal whose liquidus temperature is above 4500 and is below the solidus temperature of base metal. In brazing the base metal is not melted. Dissimilar metals can be joined by brazing. Except aluminium and magnesium, brazing can join almost all metals. Brazed joint is not useful for high temperature welding because of the low melting temperature of the filler metal. Here the filler metal reaches the joint by capillary action, it is necessary to control the clearance between two parts. The temperature at which filler metal is entering the joint is also important. Too much clearance doesn't allow capillary force to draw the filler metal into the joint and also insufficient clearance may be too small to allow the filler metal to give rise to an effective strength.

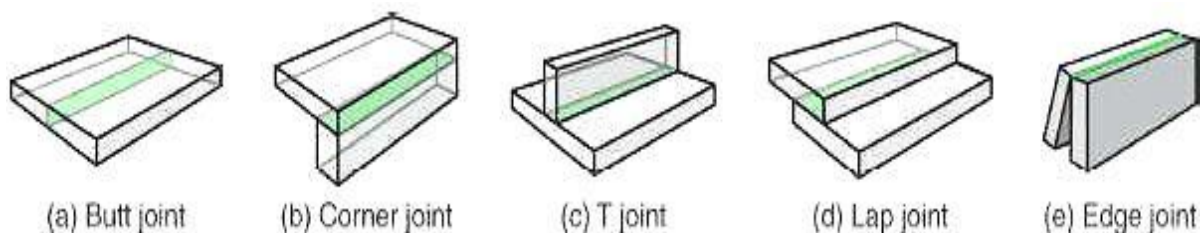
### Soldering

Soldering is the method of joining similar or dissimilar metals by means of a filler metal whose liquidus temperature is below 4500. The joint design used for soldering is similar to that of brazing as in both cases filler metals enter the joint by capillary action. Like brazing, soldering also needs solvent cleaning, acid pickling and mechanical cleaning of the joint surface. In order to remove the oxides from the joint surface for avoiding filler metal from oxidizing, fluxes are generally used in soldering.

*General Considerations:*

### Types of joints

Different types of welding joints are classified as butt, lap, corner, tee and edge joints.

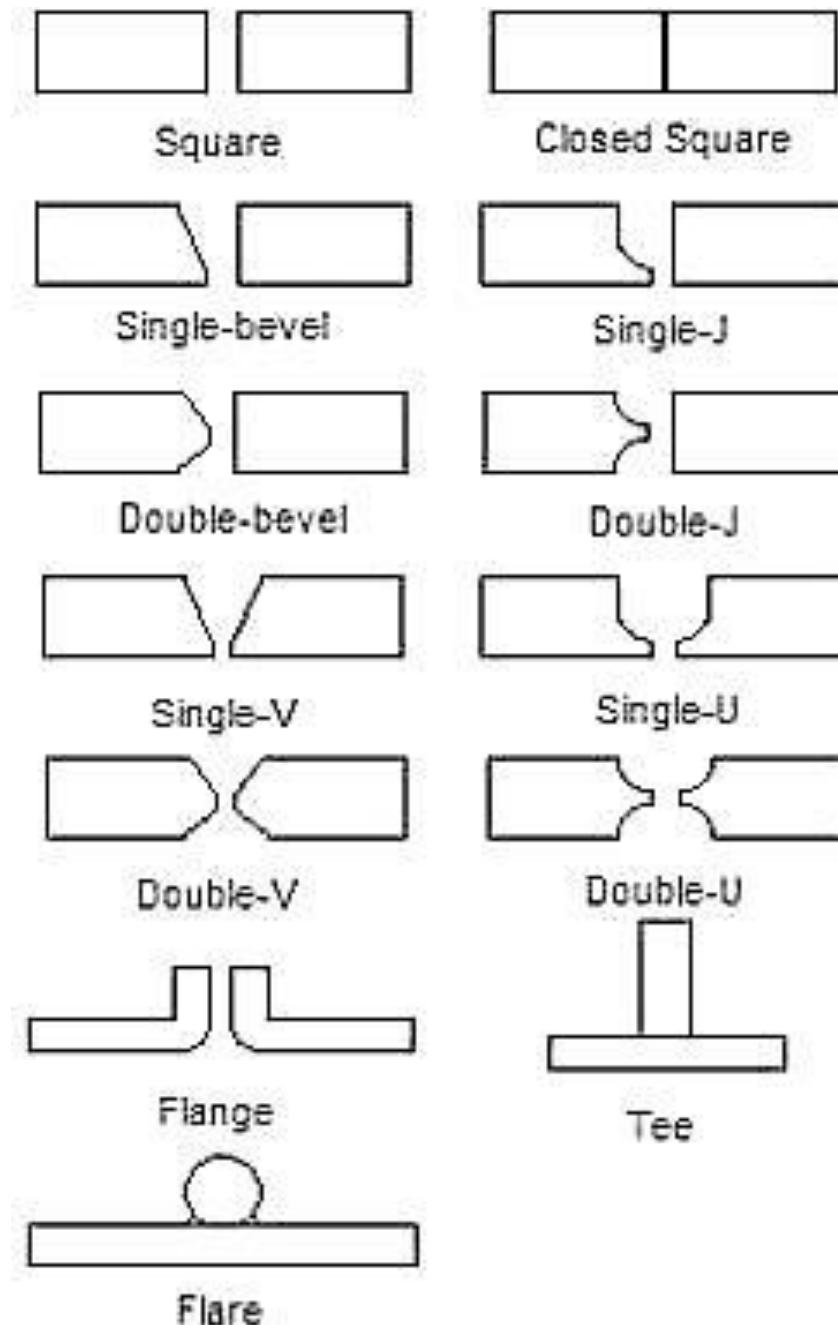


Tensile strength of butt joint depends upon the contact area. In case of lap joint, depending upon the strength requirement, the bonding area chosen. But the limitation of

lap joint is that the thickness of joint increases for overlapping of the parts.

For small thickness, Straight edge joints are done and for that edge is prepared in such a way that heat of welding can penetrate the entire depth. To facilitate the process, the joint is widened.

- For very thick plates, the welding needs to be done from both sides.
- The V- joint is easier to make and the amount of extra metal to be filled in the joint increases greatly with an increase in the thickness.
- A U joint is preferable when t
- Groove preparation



| Comparison of Various Joining Methods |                 |        |             |             |            |             |                     |                    |      |
|---------------------------------------|-----------------|--------|-------------|-------------|------------|-------------|---------------------|--------------------|------|
| Method                                | Characteristics |        |             |             |            |             |                     |                    |      |
|                                       | Strength        | Design | Small parts | Large parts | Tolerances | Reliability | Ease of manufacture | Ease of inspection | Cost |
| Arc welding                           | 1               | 2      | 3           | 1           | 3          | 1           | 2                   | 2                  | 2    |
| Resistance welding                    | 1               | 2      | 1           | 1           | 3          | 3           | 3                   | 3                  | 1    |
| Brazing                               | 1               | 1      | 1           | 1           | 3          | 1           | 3                   | 2                  | 3    |
| Bolts and nuts                        | 1               | 2      | 3           | 1           | 2          | 1           | 1                   | 1                  | 3    |
| Riveting                              | 1               | 2      | 3           | 1           | 1          | 1           | 3                   | 1                  | 2    |
| Fasteners                             | 2               | 3      | 3           | 1           | 2          | 2           | 2                   | 1                  | 3    |
| Seaming and crimping                  | 2               | 2      | 1           | 3           | 3          | 1           | 3                   | 1                  | 1    |
| Adhesive bonding                      | 3               | 1      | 1           | 2           | 3          | 2           | 3                   | 3                  | 2    |

Note: 1 = very good; 2 = good; 3 = poor. For cost, 1 is the lowest.

## GAS WELDING

Gas welding is also named as oxy-fuel gas welding (OFW). Gas welding derives heat from the combustion of fuel gas such as acetylene in combination with oxygen. The process is a fusion welding process where the joint is completely melted to obtain the fusion. **Necessary considerations for gas welding.**

### Fuel Gases

Fuel gas for Gas welding used is acetylene due to its high temperature in the flame. Thereby the gas welding may be known as oxy-acetylene welding (OAW).

Following table shows the useful fuel gases for gas welding with their calorific values and temperatures.

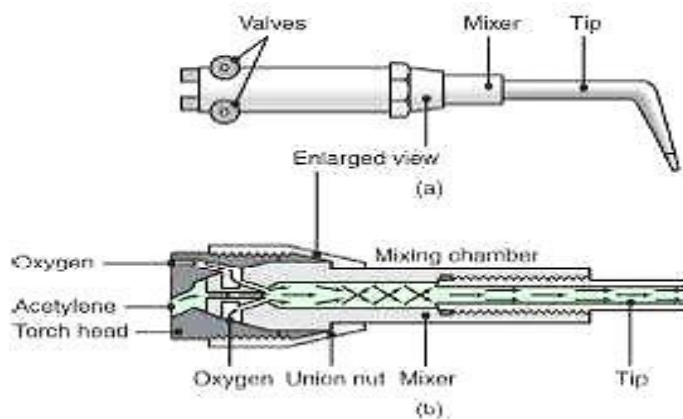
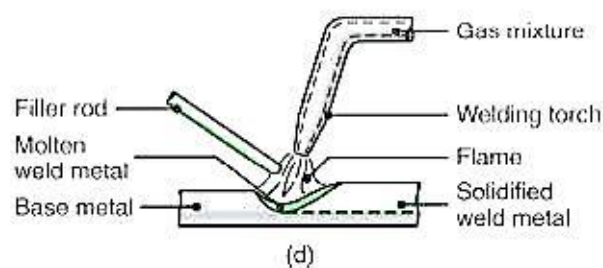
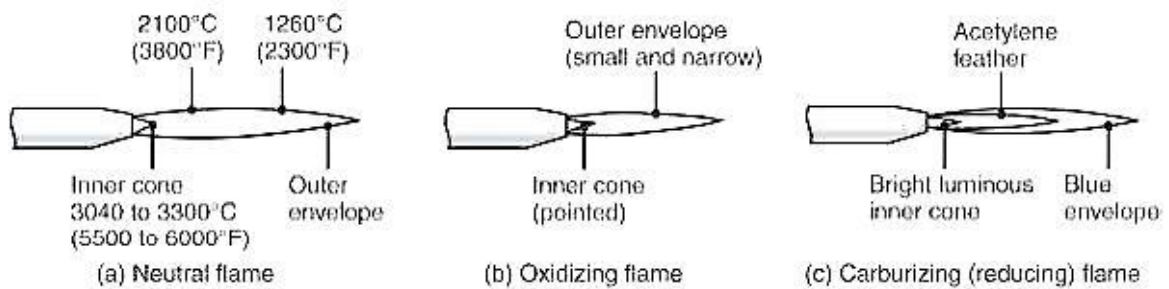
| Table.1. Characteristics of fuel gases Gas |                                 | Chemical Formula |       | Heat content, MJ/m <sup>3</sup> |      | Flame temperature, °C |  |
|--|---------------------------------|------------------|-------|---------------------------------|------|-----------------------|--|
| Primary                                    |                                 | Secondary        |       | Total                           |      |                       |  |
| Acetylene                                  | C <sub>2</sub> H <sub>2</sub>   | 18.97            | 36.03 | 55                              | 3100 |                       |  |
| Propylene                                  | C <sub>3</sub> H <sub>6</sub>   | 16.38            | 71.62 | 88                              | 2500 |                       |  |
| Propane                                    | C <sub>2</sub> H <sub>8</sub>   | 9.38             | 83.62 | 93                              | 2450 |                       |  |
| Methyl acetylene propadiene                | C <sub>3</sub> H <sub>4</sub>   | 21.00            | 70.00 | 91                              | 2927 |                       |  |
| Hydrogen                                   | H <sub>2</sub>                  | -                | -     | 10                              | 2390 |                       |  |
| Natural gas                                | CH <sub>4</sub> +H <sub>2</sub> | 0.41             | 36.59 | 37                              | 2350 |                       |  |

Three basic types of oxyacetylene flames used in oxyfuel–gas welding and cutting operations: (a) neutral flame; (b) oxidizing flame; (c) carburizing, or reducing, flame.



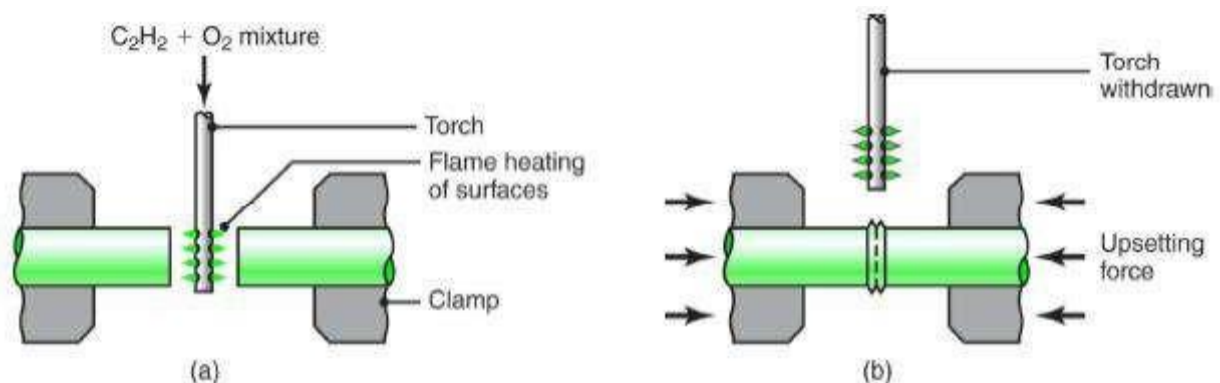
The gas mixture in (a) is basically equal volumes of oxygen and acetylene.

(a) The principle of the oxyfuel–gas welding process.



(a) General view of, and (b) cross section of, a torch used in oxyacetylene welding. The acetylene valve is opened first. The gas is lit with a spark lighter or a pilot light. Then the oxygen valve is opened and the flame adjusted. (c) Basic equipment used in oxyfuel–gas welding. To ensure correct connections, all threads on acetylene fittings are left handed, whereas those for oxygen are right handed. Oxygen regulators usually are painted green and acetylene regulators red.

Schematic illustration of the pressure-gas welding process: (a) before and (b) after. Note the formation of a flash at the joint; later the flash can be trimmed off.



The acetylene valve on the torch is opened slightly with the help of a rickionspark lighter. The acetylene valve is opened to get the required flow of cetylene. The oxygen valve is slowly opened till the intermediate flame feather of the reducing flame.

- The choice of torch size depends upon the thickness of metal to bejoined.
- Torch should be held at an angle of 30 to 50 degrees from the horizontal plane.
- Torch movement either oscillatory or circular.
- Torch tip should be positioned above the metal plate so that the white cone is at a distance of 1.5 to 3.0mm from the plate.
- For forehand welding the torch is moved in the direction of tip.

## Electric arc welding

### *Arc welding*

Arc welding processes uses the heat generated by an electric arc to melt the faying surfaces of the base metal in order to develop a weld joint.

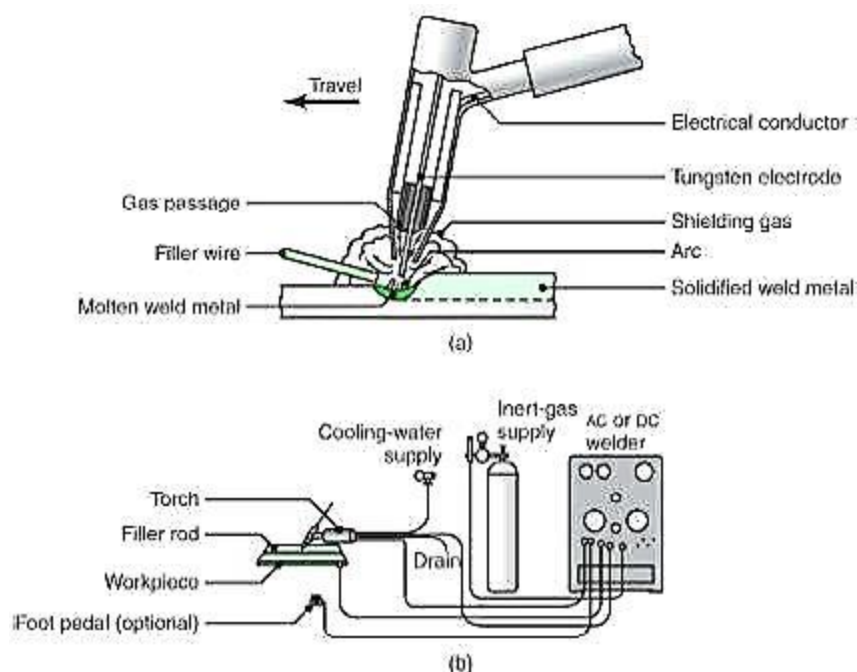
### *Manual metal arc welding*

In this process, the heat is generated by an electric arc between base metal and a consumable electrode. As the electrode movement is manually controlled hence it is termed as manual metal arc welding. This process is extensively used for depositing weld metal because it is easy to deposit the molten weld metal at right place where it is required and it doesn't need separate shielding. This process is commonly used for welding of the metals, which are comparatively less sensitive to the atmospheric

gases. This process can use both AC and DC. The constant current DC power source is invariably used with all types of electrode (basic, rutile and cellulosic) irrespective of base metal (ferrous and non-ferrous). However, AC can be unsuitable for certain types of electrodes and base materials. Therefore, AC should be used in light of manufacturer's recommendations for the electrode application. In case of DC welding, heat liberated at anode is generally greater than the arc column and cathode side. The amount of heat generated at the anode and cathode may differ appreciably depending upon the flux composition of coating, base metal, polarity and the nature of arc plasma. In case of DC welding, polarity determines the distribution of the heat generated at the cathode and anode and accordingly the melting rate of electrode and penetration into the base metal are affected.

### *Tungsten Inert-Gas Welding (TIG)*

Tungsten inert-gas (TIG) welding or gas tungsten arc is an inert gas shielded arc welding using a non-consumable electrode. This electric arc is produced by the passage of current through a conductive ionized inert gas that provides shielding of the electrode, molten weld pool and solidifying weld metal from contamination by the atmosphere. The process may be used with or without the addition of filler metal using metal rods. (a) The gas tungsten-arc welding process, formerly known as TIG (for tungsten-g inert-gas) welding. (b) Equipment for gas tungsten-arc welding operations.

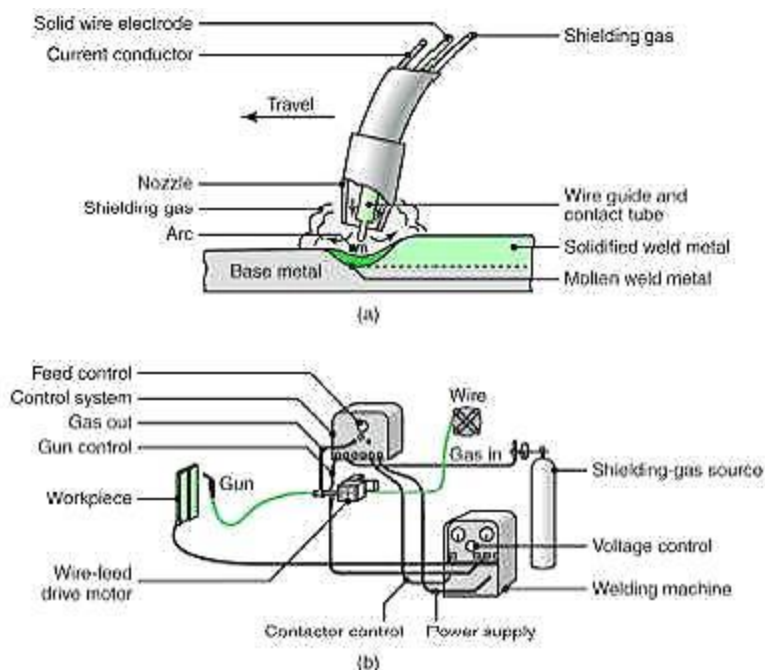


**Electrode:** In TIG welding, tungsten refers to the element used on the electrode. The function of the electrode is to serve as one of the electric terminals which supplies the heat required to the weld. Care must be taken so that the tungsten electrode does not come in contact with the weld pool in any way in order to avoid its contamination resulting in a faulty weld. Pure tungsten is less expensive and will carry less current. Some other elements may be added to the tungsten, like cerium, lanthanum, thorium and zirconium creating electrode alloys in order to improve arc stability, emissivity and bring higher melting points. The electrode may contain 1 to 2% thoria (thorium oxide) mixed along with the core tungsten or tungsten with 0.15 to 0.40% zirconia (zirconium oxide). The thoriated tungsten electrodes carry high current and are more desirable as they can strike and maintain a stable arc. The zirconia added with tungsten is better than pure tungsten but inferior to thoriated tungsten electrode.

### *Tungsten inert gas welding set up:*

It consists of a welding torch at the center of which is the tungsten electrode. The inert gas supplied to the welding zone through the annular path surrounding the tungsten electrode to effectively displace the atmosphere around the weld puddle.

### **GAS METAL ARC WELDING (GMAW)**



This is also known as Metal inert-gas arc welding (MIG) because it utilizes a consumable electrode. There are other gas-shielded arc-welding processes utilizing consumable electrodes such as flux-cored arc welding, all of which coming under MIG. It's quite suitable for thicker sheets because filler metal requirement in welding process makes gas-tungsten arc welding (GTAW or TIG ) difficult to use, which is more suitable for thin sheets. (a) Schematic illustration of the gas metal-arc welding process, formerly known as MIG (for metal inert-gas) welding. (b) Basic equipment used in gas metal-arc welding operations. The consumable electrode is in the form of wire reel fed at a constant rate through the feed rollers. The welding torch is connected to the gas supply cylinder, which provides the necessary inert gas. The electrode and the work piece are connected to the welding power supply. The power supply is always of the constant voltage type. The current from the welding machine is changed by the rate of feeding of electrode wire. Normally, DC arc-welding machine are used for GMAW with electrode positive (DCEP). The DCEP increases the metal- deposition rate and also provides a stable arc and smooth electrode metal transfer. With DCEN the arc become highly unstable and also results in spatter. But special electrodes having calcium and titanium oxide mixtures as coatings are found to be good for steelwith DCEN.

### *Metal Transfer*

- Metal transfer takes place from the electrode to the joint in GMAW process. The metal transfer is done in different ways depending on the current and voltage used for a given electrode.
  - Short circuit or dip transfer,
  - Spray transfer,
  - Pulsed spray transfer, and
  - Rotating spray transfer.

The short-circuiting metal transfer occurs with relatively low current settings of the order of 75 to 175 A for an electrode diameter of 0.9 mm. The number of times that

the pinching takes place depends on the inductance of welding machine used and the parameters set. The rate at which the short-circuiting current increases is controlled by inductance of the welding machines. Too low an inductance gives rise to very high short-circuiting current and consequently high pinching rate. With high inductance, the short-circuiting becomes low and results in somewhat lower pinching force. The effect of inductance is measured in terms of response rate (raising rate of current due to short-circuiting, kA/s). It can be observed that the optimum response rate depends on electrode wire size. Hence, the welding machines to be used for short-circuiting transfer make use of a variable choke system which can be tuned for different wire sizes. The frequency of metal transfer may be of the order of 50 to 200 per second. This rate also depends on the open-circuit voltage and wire-feed rate employed.

### *Shielding Gases*

Argon, helium, nitrogen, oxygen, carbon dioxide and mixture of the above gases in various proportions are used in GMAW as shielding gases.

Argon is the most widely used of all the shielding gases, because it reduces the spatter and concentrates the arc, which in turn gives deep penetration welds. In addition, argon ionizes easily requiring smaller arc voltages and also has lower thermal conductivity and hence conducts heat very slowly from the arc to the weld zone. Thus, it is good for welding thin sheets. Because of the lower voltages employed, it is suitable for out-of-position welding. For spray transfer of metal a large percentage of argon is required. Helium is the most expensive of all the shielding gases. Due to its better thermal conductivity it is suitable for thicker sheets as well as for metals having higher thermal conductivity such as copper and aluminium. The filler metal-deposition rate by helium is much higher compared to argon because of the higher current-carrying capacity.

The arc in carbon dioxide shielding gas is unstable and therefore a shortarc is to be used to reduce the metal spatter. It is the least expensive of all the shielding gases. Since about 7.5% of the carbon dioxide decomposes into carbon monoxide and oxygen in the arc, deoxidizers such as aluminium and silicon are to be used while using carbon dioxide. It is a heavy gas and therefore it covers the weld



zone very well. The metal transfer is globular only with the carbon dioxide shielding gas.

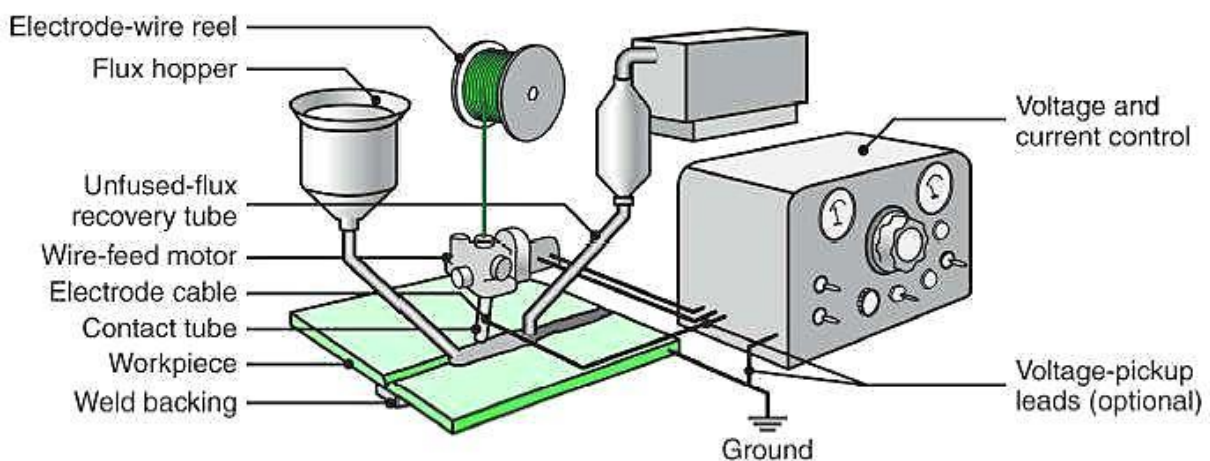
Sometimes the mixtures of gases such as argon-helium, argon-carbon dioxide, argon-oxygen are used for special applications. Shielding gases should always flow in a laminar manner without causing any turbulence because turbulence causes weld contamination. The gas flow rates to be used depend upon the thickness of the sheet being welded, the position of the weld as well as the base material.

### ***ELECTRODES***

The electrode wire comes generally in the form of coils and of normal sizes may be of the order of 0.5 to 3.2 mm. Depending upon the base material, various wire compositions are available. For steels, electrodes wire having deoxidizers are used because, the deoxidizers help in the reduction of oxidation of the weld metal as well as the porosity. The electrode wire is produced by wire drawing, and uniform diameter throughout otherwise the arc may saunter.

### ***SUBMERGED ARC WELDING (SAW)***

It is used for faster welding jobs. It is possible to use larger welding electrodes (12 mm) as well as very high currents (4000 A) so that very high metal deposition rates of the order of 20 kg/h or more can be achieved with this process. Also, very high welding speeds (5 m/min) are possible in saw. Some submerged arc welding-machines are able to weld plates of thicknesses as high as 75 mm in butt joint in a single pass. Though it can weld very small thickness, of the order of 1 mm, it is very economical for larger welds only. Schematic illustration of the submerged-arc welding process and equipment. The un-fused flux is recovered and reused.



The arc is produced in the same manner as in GMAW. The welding zone is completely covered by means of large amount of granulated flux, which is delivered ahead of welding electrode by means of flux-feed tube. The arc between the electrode and the work-piece is completely submerged under the flux and is not visible from outside. A part of the flux melts and forms the slag, which covers the weld metal. The unused flux can be recycled.

The power source used with submerged arc welding can either be AC or DC. Both constant voltage and constant current type machines can effectively used though, for larger electrode a constant current type power supply is used. The current ratings of the SAW machines are, in general, two to three times higher than that of the GMAW machines.

Arc blow is not encountered with AC supply with a single wire SAW. But sometimes two wires may be used to deposit larger amounts of metal. These two electrodes being connected to two separate power sources, the arc blow is likely to occur because of the interference of the two magnetic fields surrounding the two electrodes, if the two currents are in phase. In order to avoid the setting of opposite magnetic fields, the two power supplies are adjusted in such a way that, one of the supply is in peak, and the other is set to zero current. One of the electrodes is called leading and the other called trailing. In this way the aforementioned problem is reduced. There is no spatter of the molten metal since the arc is completely submerged in the flux. Because of the usage of loose granulated flux to cover the joint, it is difficult to carry out in any position other than the flat or down-hand position. Also, because of large metal pools generation in the SAW process, the out-of-position welds are difficult to carry out.

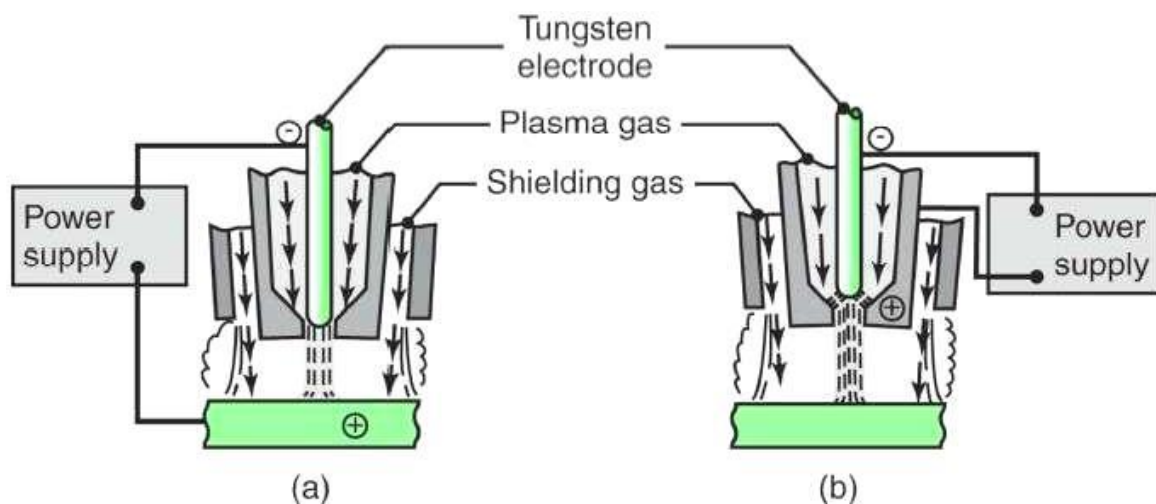
The electrode wires normally used are of sizes 1.6, 2, 2.5, 3.15, 4, 5, 6.3 and 8mm. The wires should be smooth with no surface imperfections or contaminants. It is difficult to manually feed the wire into the joint because of very high wire-feed rate. As SAW process produces large amount of molten weld metal, it takes sometimes for solidification. Hence, it is imperative in SAW to provide some way of containing this molten metal. Weld metal backing is normally used. The backing slabs can be



with or without grooves, but in general, copper plates are used, which can easily be cooked with internal running water, when necessary. For thin plates, plain copper backing plates without any cooling water, would be enough. Pure copper removes heat quickly from the molten weld pool because of its high thermal conductivity.

### **PLASMA ARC WELDING**

Plasma is the state of matter present in between electrodes in any arc. In this part, gas is ionized to make it a conductor of electric current. - PAW uses a non-consumable tungsten electrode and a shielding gas such as argon, helium or a mixture of both with hydrogen. - Plasma torch:- Pure argon gas is allowed through the inner orifice surrounding the tungsten electrode to form plasma gas. The constraining nozzle squeezes the gas to form a concentrated and straight arc and also increases the heat contained per unit volume of the arc (~110000C). Ionization of the arc occurs through a low current pilot arc between electrode and constricting nozzle. This initiates the PAW arc. Due to constriction the plasma gas attains a very high temperature and also provides a low resistance path to initiate the welding arc between electrode and work piece. This is called transferred arc. Inert shielding gas is allowed to flow through outer gas nozzle which protects the weld metal. Higher ampere rating Constant current or drooper type of dc power supplies are used as



power sources. Electrode is taken as negative. PAW is done by "key hole" technique. Due to high temperature the base metal beneath the arc melts completely forming a thin keyhole. With the advancement of the torch the metal melted ahead (down hand welding position) flows into the keyhole. Thus the keyhole travels continuously along the torch direction. Advantages:- Because of arc concentration heat input can be

properly controlled and the heat affected zone around the weld metal is small. - Uniform deep penetration can be obtained. - Greater distance between electrode tip and work piece makes use of filler metal rod easier without contamination of electrode. Higher metal deposit rate. Disadvantages:- Expensive frequent replacement requirement of nozzle. Two types of plasma-arc welding processes: (a) transferred and (b) non- transferred. Deep and narrow welds can be made by these processes at high welding speeds.

### ***THERMIT WELDING***

In thermit welding, weld metal is melted externally using exothermic heat generated by chemical reactions and the melt is supplied between the components to be joined.

### ***ELECTROSLAG WELDING***

In electroslag welding weld metal is melted by electrical resistance heating and then it is allowed to cool very slowly for solidification similar to that of casting.

### ***ELECTRON BEAM WELDING***

Electron Beam Welding (EBW) is a fusion welding in which coalescence is produced by heating the work piece due to impingement of the concentrated electron beam of high kinetic energy on the work piece. 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.

#### ***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

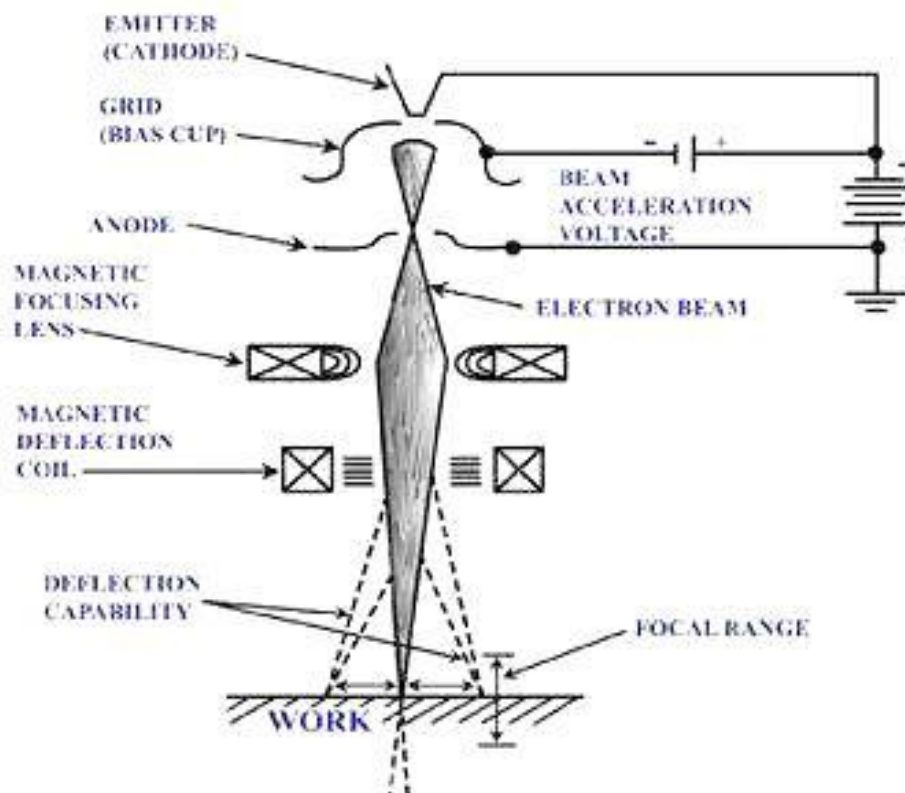
forms the weld joint.

### **EBW Equipment:**

An EBW set up consists of the following major equipment:

- Electron gun
- Power supply
- Vacuum Chamber
- Work piece handling device.

**Electron -Gun:** An electron gun generates, accelerates and aligns the electron beam in required direction and spots onto the work piece. The gun is of two types: Self accelerated and work accelerated. The work accelerated gun accelerates the electrons by providing potential difference between the workpiece and cathode. In the self accelerate gun, the electrons are accelerated by applying potential difference between cathode and 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. Major parts of an electron gun are briefly introduced in the following sections.



**Fig. Schematic of an electron beam gun used in EBW**

**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 of the 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.

**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:***

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

***Disadvantages of EBW:***

- Very high equipment cost.
- High vacuum is required.
- High safety measures are required.
- Large jobs are difficult to weld.
- Skilled man power is required.

***Applications of EBW:***

- Electron beam welding process is mostly used in joining of refractive materials like columbium, tungsten, ceramic etc. which are used in missiles.

- In space shuttle applications wherein reactive materials like beryllium, zirconium, titanium etc. are used.
- In high precision welding for electronic components, nuclear fuel elements, special alloy jet engine components and pressure vessels for rocket plants.
- Dissimilar material can be welded like invar with stainless steel.

### ***LASER BEAM WELDING PROCESS***

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 work piece 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  $\mu\text{m}$  wavelength CO<sub>2</sub> laser, with the active elements most commonly employed in these two varieties of lasers being the neodymium (Nd) ion and the CO<sub>2</sub> molecules respectively.

## **Cutting:**

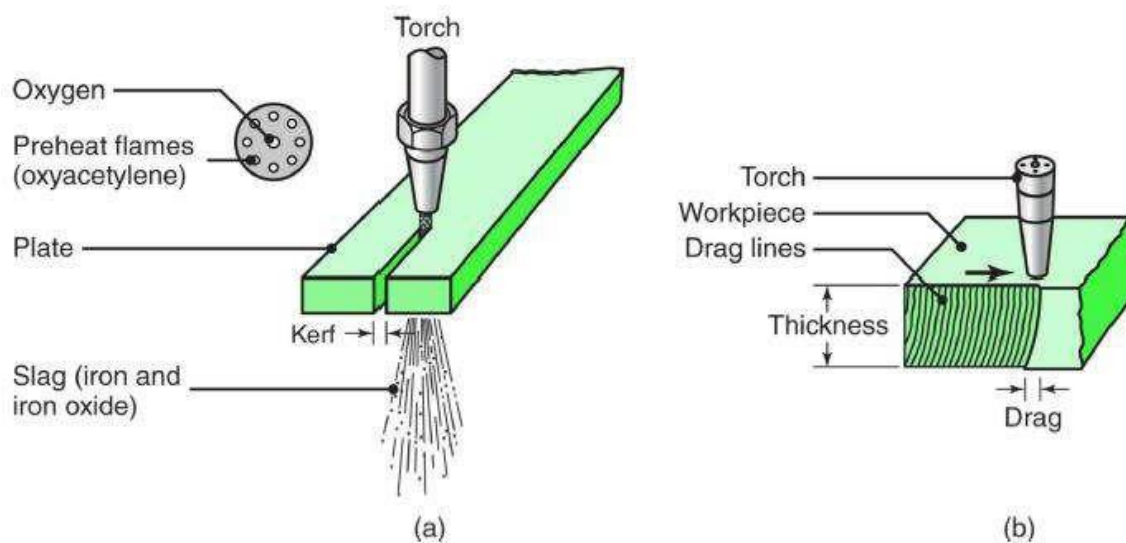
Material can be cut with the use of a heat source that melts and removes a narrow zone in the workpiece.

- Can cut contours
- Heat source may be:
  - Torch
  - Electric arc
  - Laser

### Oxyfuel-gas Cutting (OFC)

- Similar to Oxyfuel-gas Welding
- Process is particularly suited for steels
- A two-stage chemical process
- Iron combines with oxygen exothermically to oxidize the metal
- Need additional preheat, provided by the fuel gas, to reach melting point

(a) Flame cutting of a steel plate with an oxyacetylene torch, and a cross section of the torch nozzle. (b) Cross section of a flame-cut plate, showing drag lines.



### Arc Cutting

- Based on same principles as arc-welding processes
- Can cut a variety of materials at high speeds
- Creates heat affected zone Air carbon-arc Cutting (CAC-A)
- Use carbon electrode
- Air jet blows away molten metal (no oxidation necessary) Need to contain blown molten metal
- Good for gouging & scarfing Noisy Plasma-arc Cutting (PAC)
- Produces highest temperatures
- For rapid cutting of non-ferrous & SS plates
- Higher productivity than OFC methods
- Produces good surface finish & narrow kerfs
- Most common manufacturing process utilizing programmable controllers Electron Beams and Lasers
- Can accurately cut many metals
- Narrow kerf
- Better surface finish than other thermal cutting processes