2nd part of **unit-5…….**

SOLID STATE WELDING

Solid state welding is a group of **welding** processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined, without the addition of brazing filler metal. Bonding of the materials is a result of diffusion of their interface atoms.

This includes cold welding, diffusion welding, explosion welding, friction welding, hot pressure welding and ultrasonic welding.
In all of these processes time, temperature, and pressure individually or in combination produce coalescence of the base metal without significant melting of the base metals.

Advantages of Solid State Welding:

- Weld (bonding) is free from microstructure defects (pores, non-metallic inclusions, segregation of alloying elements)
- Mechanical properties of the weld are similar to those of the parent metals
- No consumable materials (filler material, fluxes, shielding gases) are required
- Dissimilar metals may be joined (steel - aluminum alloy steel - copper alloy).

Disadvantages of Solid State Welding:

- Thorough surface preparation is required (degreasing, oxides removal, brushing/sanding)
- Expensive equipment.

The following processes are related to Solid State welding:

1. **Forge Welding (FOW)**- Forge Welding is a Solid State Welding process, in which low carbon steel parts are heated to about 1800°F (1000°C) and then forged(hammered).
   Prior to Forge Welding, the parts are scarfed in order to prevent entrapment of oxides in the joint.
   Forge Welding is used in general blacksmith shops and for manufacturing metal art pieces and welded tubes.

2. **Cold Welding (CW)-** Cold Welding is a Solid State Welding process, in which two work pieces are joined together at room temperature and under a pressure, causing a substantial deformation of the welded parts and providing an intimate contact between the welded surfaces.
   As a result of the deformation, the oxide film covering the welded parts breaks up, and clean metal surfaces reveal. Intimate contact between these pure surfaces provide a strong and defectless bonding.
   Aluminum alloys, Copper alloys, low carbon steels, Nickel alloys, and other ductile metals may be welded by Cold Welding.

3. **Friction Welding (FRW)-** Friction Welding **is** a Solid State Welding process, in which two cylindrical parts are brought in contact by a friction pressure when one of them rotates. Friction between the parts results in heating their ends. Forge pressure is then applied to the pieces providing formation of the joint.
   Carbon steels, Alloy steels, Tool and die steels, Stainless steels, Aluminum alloys, Copper alloys, Magnesium alloys, Nickel alloys, Titanium alloysmay be joined by Friction Welding.

4. Explosive Welding (EXW)
5. Diffusion Welding (DFW)
6. Ultrasonic Welding (USW)

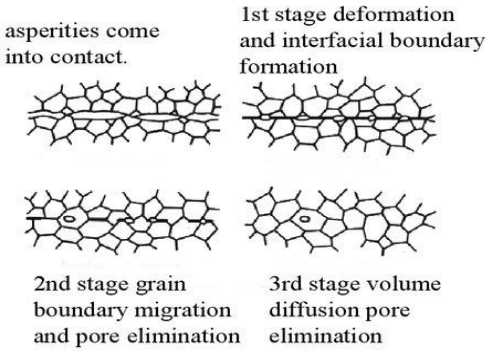
Diffusion Welding (DFW)

Diffusion Welding is a Solid State Welding process, in which pressure applied to two work pieces with carefully cleaned surfaces and at an elevated temperature below the melting point of the metals. Bonding of the materials is a result of mutual diffusion of their interface atoms.

7. Diffusion involves migration of atoms across joint due to concentration gradient.
8. The two atoms are pressed together at an elevated temperature (50%-70% of M.P.)
9. The pressure is gradually applied and temperature is elevated to permit diffusion at atomic level.
10. Due to local deformation at the contact points permits longer areas to be in touch and with time grains diffused closing interfacial voids, remaining voids are shrinks and then disappear slowly.
    In order to keep the bonded surfaces clean from oxides and other air contaminations, the process is often conducted in vacuum.
    No appreciable deformation of the work pieces occurs in Diffusion Welding.

Diffusion Welding Working Principles

- 1st stage
  - deformation forming interfacial boundary.
- 2nd stage
  - Grain boundary migration and pore elimination.
- 3rd stage
  - Volume diffusion and pore elimination.



Diffusion Welding is often referred more commonly as Solid State Welding (SSW).
Diffusion Welding is able to bond dissimilar metals, which are difficult to weld by other welding processes:

- Steel to tungsten, Steel to niobium, Stainless steel to titanium, Gold to copper alloys.

Diffusion Welding is used in aerospace and rocketry industries, electronics, nuclear applications, manufacturing composite materials.

Advantages of Diffusion Welding:

Dissimilar materials may be welded (Metals, Ceramics, Graphite, glass);
Welds of high quality are obtained (no pores, inclusions, chemical segregation, distortions).
No limitation in the work pieces thickness.

Disadvantages of Diffusion Welding:

Time consuming process with low productivity;
Very thorough surface preparation is required prior to welding process;
The mating surfaces must be precisely fitted to each other, Relatively high initial investments in equipment.

Ultrasonic Welding (USW)

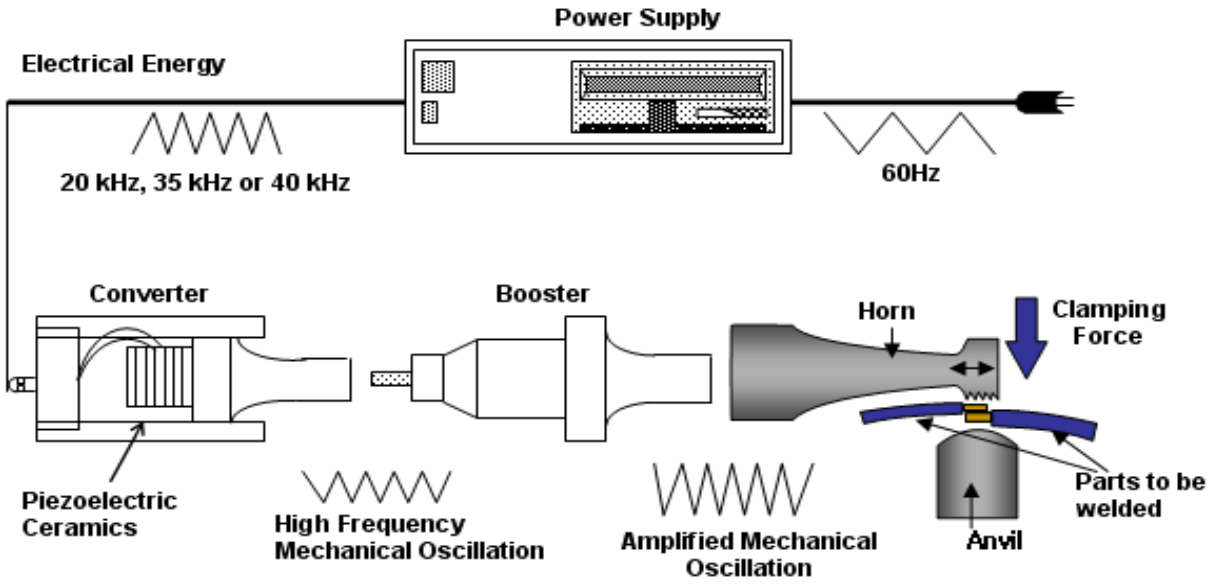
Ultrasonic Welding is a Solid State Welding process, in which two work pieces are bonded as a result of a pressure exerted to the welded parts combined with application of high frequency acoustic vibration (ultrasonic).

Ultrasonic vibration causes friction between the parts, which results in a closer contact between the two surfaces with simultaneous local heating of the contact area. Interatomic bonds, formed under these conditions, provide strong joint.

Ultrasonic cycle takes about 1 sec. The frequency of acoustic vibrations is in the range 20 to 70 KHz.

Thickness of the welded parts is limited by the power of the ultrasonic generator.

Ultrasonic Welding is used mainly for bonding small work pieces in electronics, for manufacturing communication devices, medical tools, watches, in automotive industry.

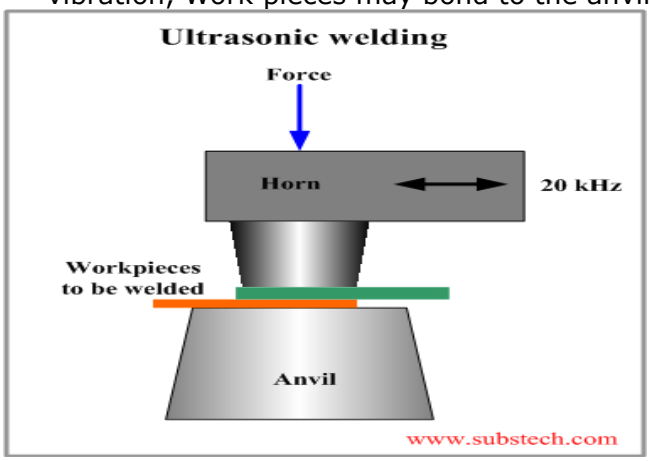


Advantages of Ultrasonic Welding:

- Dissimilar metals may be joined, Very low deformation of the work pieces surfaces;
- High quality weld is obtained, The process may be integrated into automated production lines.
- Moderate operator skill level is enough.

Disadvantages of Ultrasonic Welding:

- Only small and thin parts may be welded;
- Work pieces and equipment components may fatigue at the reciprocating loads provided by ultrasonic vibration, Work pieces may bond to the anvil.



Plasma Arc Welding (PAW)

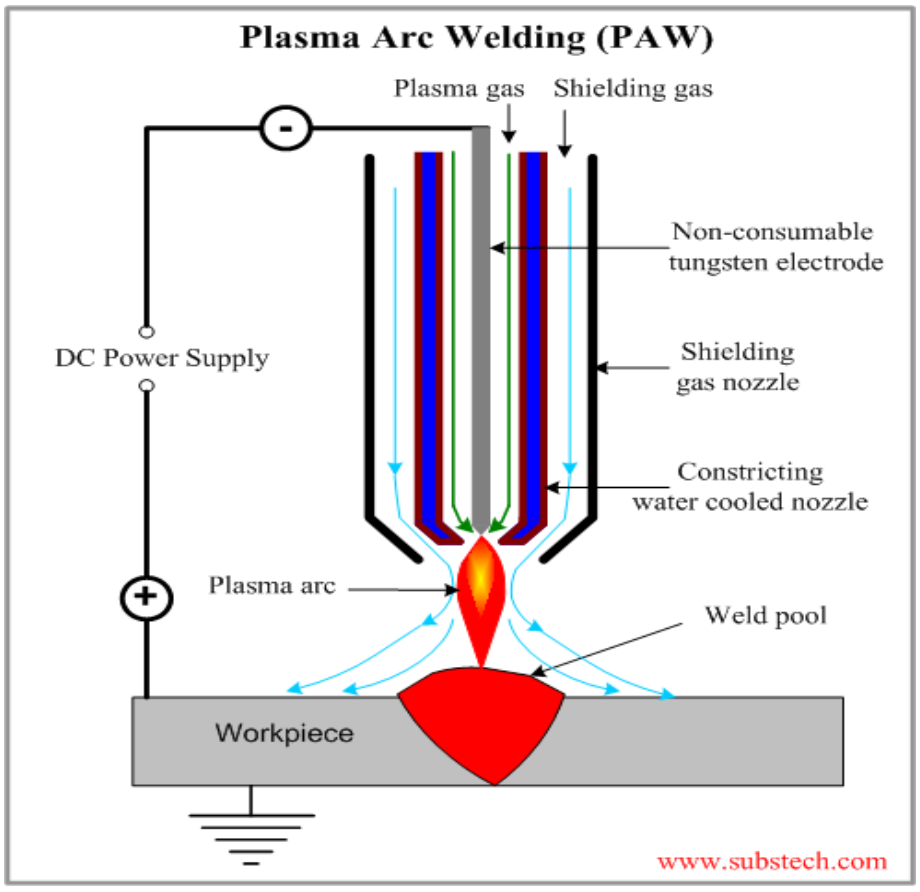
Plasma Arc Welding is the welding process utilizing heat generated by a constricted arc struck between a tungsten non-consumable electrode and either the work piece (**transferred arc process**) or water cooled constricting nozzle (**non-transferred arc process**).

Plasma is a gaseous mixture of positive ions, electrons and neutral gas molecules.

1. Arc is setup between electrode and Anodic nozzle, forced to pass through nozzle.
2. Now plasma gas passing through arc dissociated and ionized resulting in high velocity plasma (Plasma formation)
3. Constriction reduces arc area so increasing velocity and energy density arc thereafter high temperature about 2800 ^{0}C. This heat is used for melting.
4. High energy plasma makes deeper penetration with successful welding of thick sheets.

   Transferred arc process produces plasma jet of high energy density and may be used for high speed welding and cutting of Ceramics, steels, Aluminum alloys, Copper alloys, Titanium alloys, Nickel alloys.

   Non-transferred arc process produces plasma of relatively low energy density. It is used for welding of various metals and for plasma spraying (coating). Since the work piece in non-transferred plasma arc welding is not a part of electric circuit, the plasma arc torch may move from one work piece to other without extinguishing the arc.



Advantages of Plasma Arc Welding (PAW):

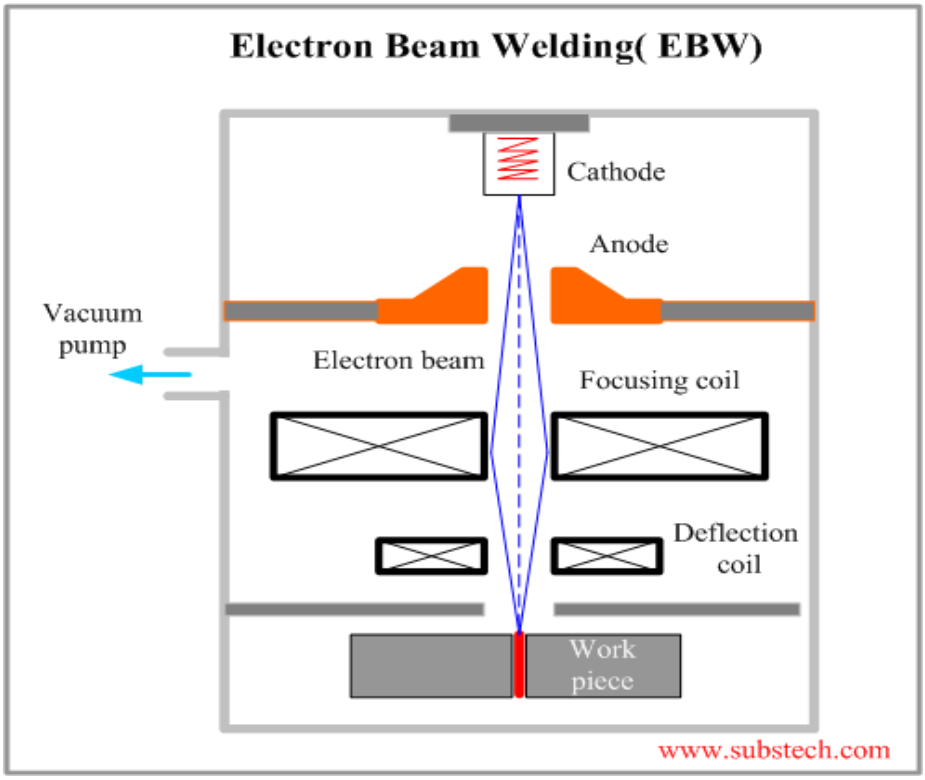
1. Requires less operator skill due to good tolerance of arc to misalignments;
2. High welding rate, High penetrating capability (keyhole effect.

Disadvantages of Plasma Arc Welding (PAW): Expensive equipment, High distortions and wide welds as a result of high heat input (in transferred arc process).

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 process is carried out in a vacuum chamber at a pressure of about $2x10^{-7}$ to $2x10^{-6}$ psi (0.00013 to 0.0013 Pa). Such high vacuum is required in order to prevent loss of the electrons energy in collisions with air molecules.
The electrons are emitted by a cathode (electron gun). Due to a high voltage (about 150 kV) applied between the cathode and the anode the electrons are accelerated up to 30% - 60% of the speed of light. Kinetic energy of the electrons becomes sufficient for melting the targeted weld. Some of the electrons energy transforms into X-ray irradiation.
Electrons accelerated by electric field are then focused into a thin beam in the focusing coil. Deflection coil moves the electron beam along the weld.
Electron Beam is capable to weld work pieces with thickness from 0.0004" (0.01 mm) up to 6" (150 mm) of steel and up to 20" (500 mm) of aluminum. Electron Beam Welding may be used for joining any metals including metals, which are hardly weldable by other welding methods: refractory metals (tungsten, molybdenum, niobium) and chemically active metals (titanium, zirconium, beryllium). Electron Beam Welding is also able to join dissimilar metals.



Advantages of Electron Beam Welding (EBW):

- Tight continuous weld, Low distortion, Narrow weld and narrow heat affected zone.
- Filler metal is not required.

Disadvantages of Electron Beam Welding (EBW):

- Expensive equipment, High production expenses.
- X-ray irradiation.

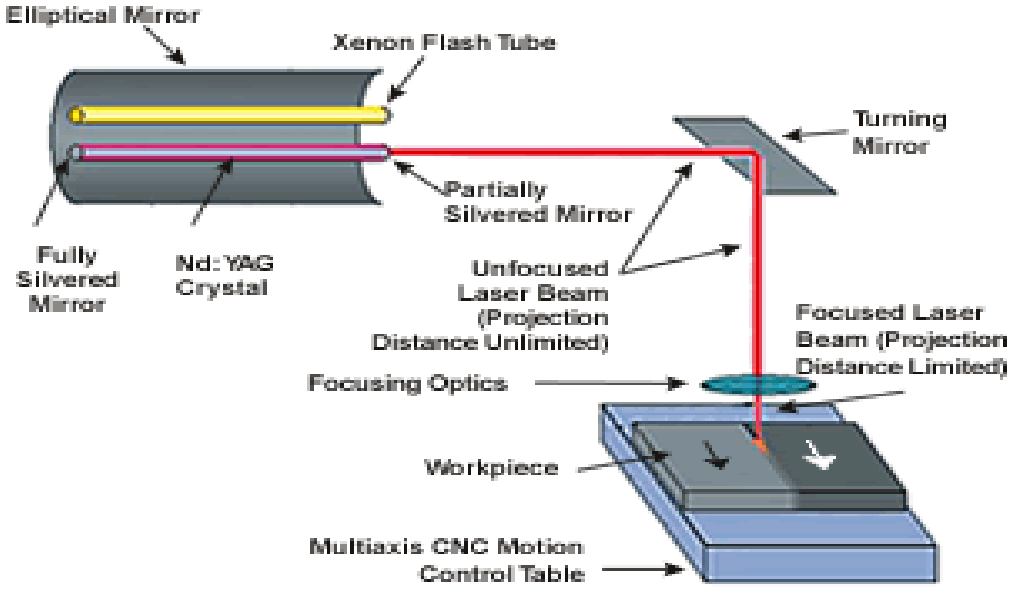
Laser Beam Welding (LBW)

Laser Welding (LW) 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: 10^8-10^{11} W/in^2 (10^8-10^{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 Laser Welding (Laser Beam Welding) is formed either as a sequence of overlapped spot welds or as a continuous weld.

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



Types of LASER- Gas laser (Co_2,) and Solid state laser (Nd YAG = Neo_dymium Yttrium Aluminum Garnet)

Advantages of Laser Welding:

- Easily automated process, Controllable process parameters.
- Very narrow weld may be obtained, High quality of the weld structure.
- Very small heat affected zone, Dissimilar materials may be welded.
- Very small delicate work pieces may be welded, Vacuum is not required.
- Low distortion of work piece.

Disadvantages of Carbon Arc Welding:

- Low welding speed;
- High cost equipment;
- Weld depth is limited.

Explosion welding /Cladding

Explosion welding (EXW) is a solid state (solid-phase) process where **welding** is accomplished by accelerating one of the components at extremely high velocity through the use of chemical **explosives** (Controlled detonation).

- Even heat is not supplied but the metal at interface melts during welding because of heat that comes from several sources (shock waves associated with impact, energy expended in collision) by plastic deformation at the interface.

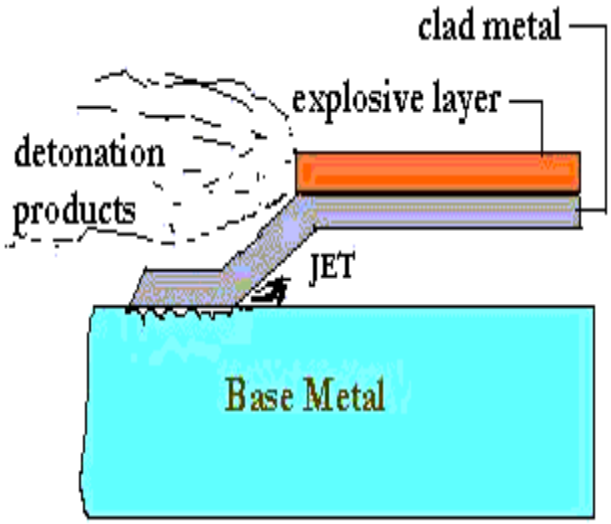
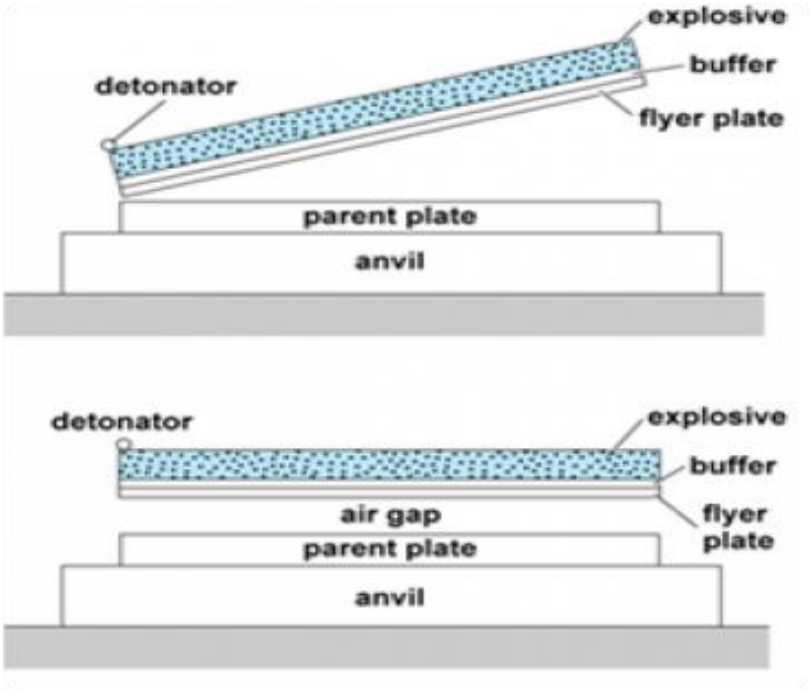


Fig. 1 Explosive Welding



- The basic mechanism is based on molecular bonding as a result of high velocity impact.
- High velocity is promoted by detonated explosives. Detonation velocity should not increased by 120 % of sonic velocity.
- After detonation the surface forms a liquid jet which directed away from welding seam.

Important parameters are critical velocity and critical angle. Well suited for brittle joint.

High velocity explosives (4572-7620 m/s)-TNT, RDX(Nitroamine), PETN(Penta Erithritol Tetra Nitrate)
Medium velocity explosives (1524-4572 m/s)-Ammonium nitrate, Dynamites, Ammonium per chlorate

Advantages- Bond dissimilar mainly unweldable metals, Portable , Inexpensive, NO need of surface preparations. Quickly weld over large areas.

Disadvantages- Metals have high enough impact resistance; Noise and blast require workers protection, for simple geometries.

Application- Spot welding , cladding of base metals with thinner alloys, seam & lap welds, joining of sockets.