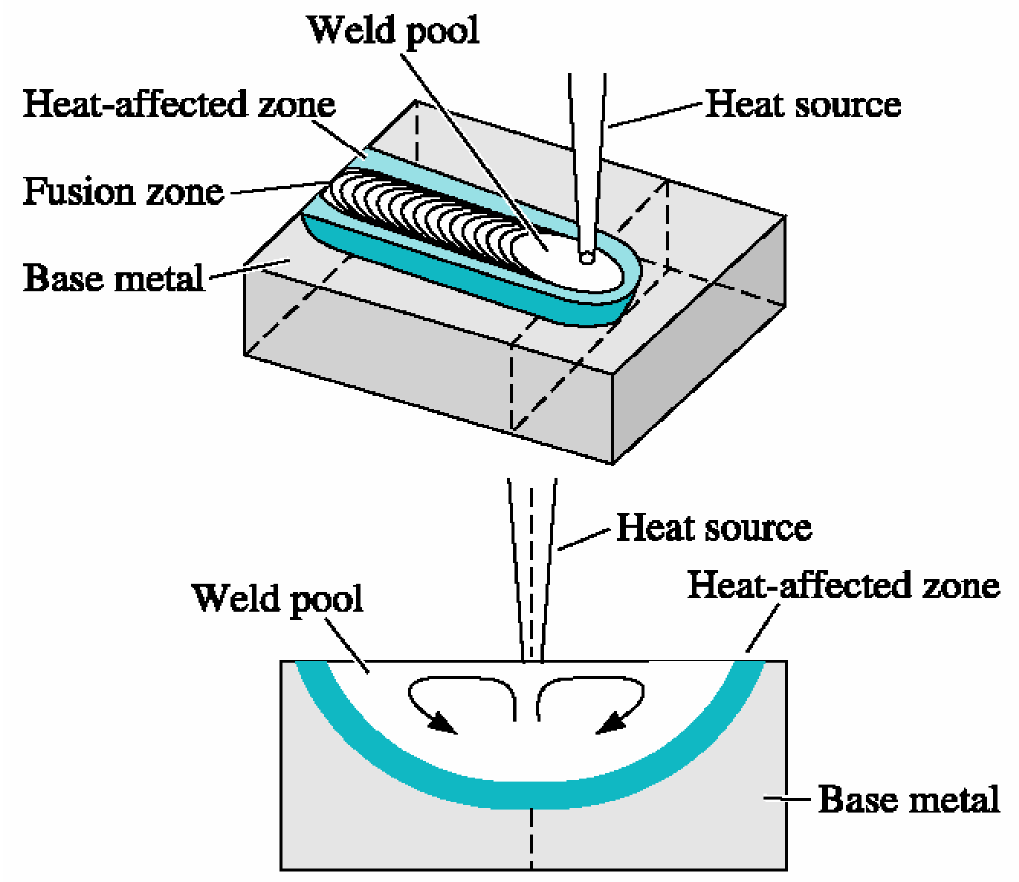
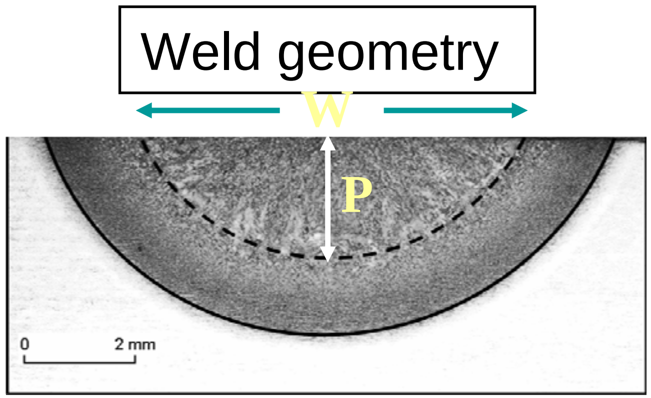
# Common Challenges in Fusion Welding




High peak temperature and velocity
Rapid change in thermal cycle
Continuous change in S-L boundary

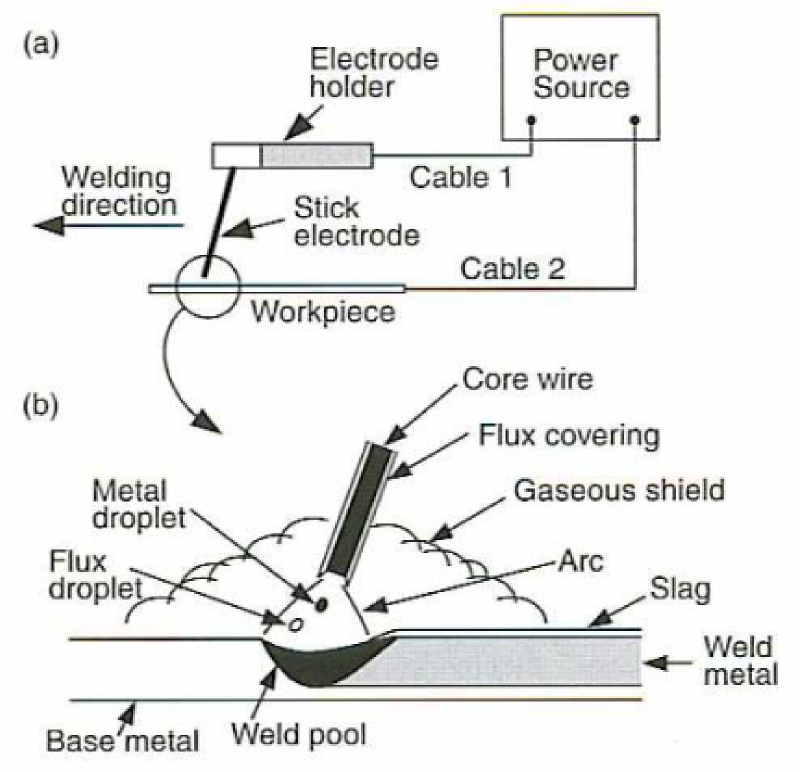
Decide final structure and properties of weld - often difficult to measure

# Fusion Arc Welding Processes

- Welding processes that employ an electric arc
- Used primarily on metals
  - Shielded Metal Arc Welding (SMAW)
  - Gas Metal Arc Welding (GMAW)
  - Flux Cored Arc Welding (FCAW)
  - Submerged Arc Welding (SAW)
  - Gas Tungsten Arc Welding (GTAW
  - Plasma Arc Welding (PAW)

- Melting of Materials (metal) is inherent.

# SMAW (Shielded Metal Arc Welding)



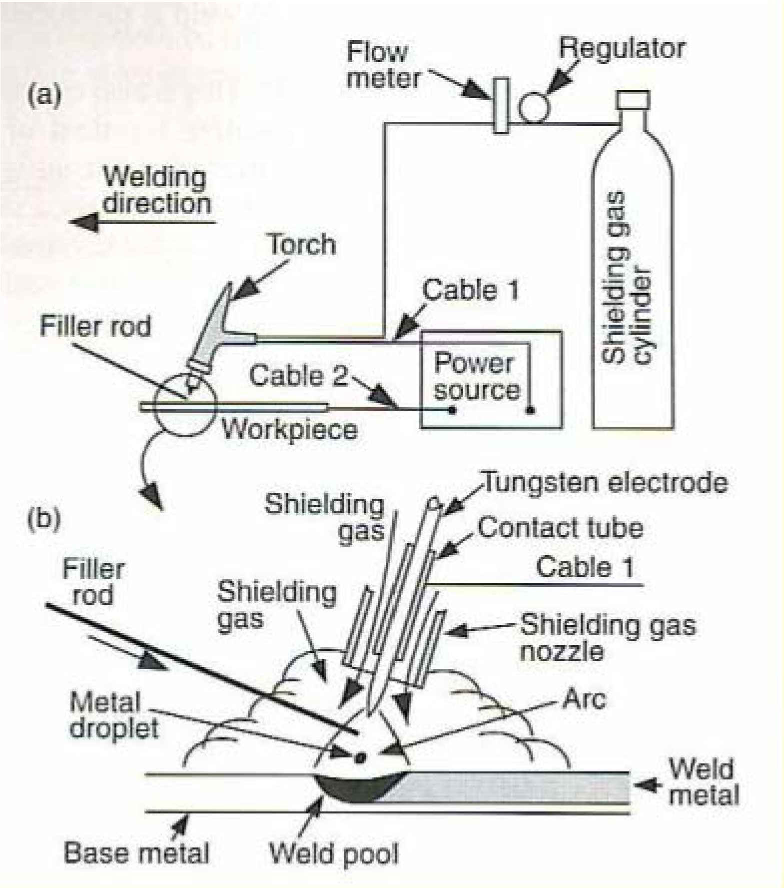

The core wire conducts electric current to the arc and provides filler metal for the joint.

Electrode holder is a metal clamp with an electrically insulated outside shell for welder's safety.

Arc heat melts work-piece, core wire and flux covering the electrode tip into metal droplets.

Molten metal in weld pool solidifies in weld metal while lighter molten flux floats on top surface and solidifies as a slag layer.

# GTAW (Gas Tugnsten Arc Welding)




GTAW involves an arc established between workpiece and a non-consumable tungsten electrode.

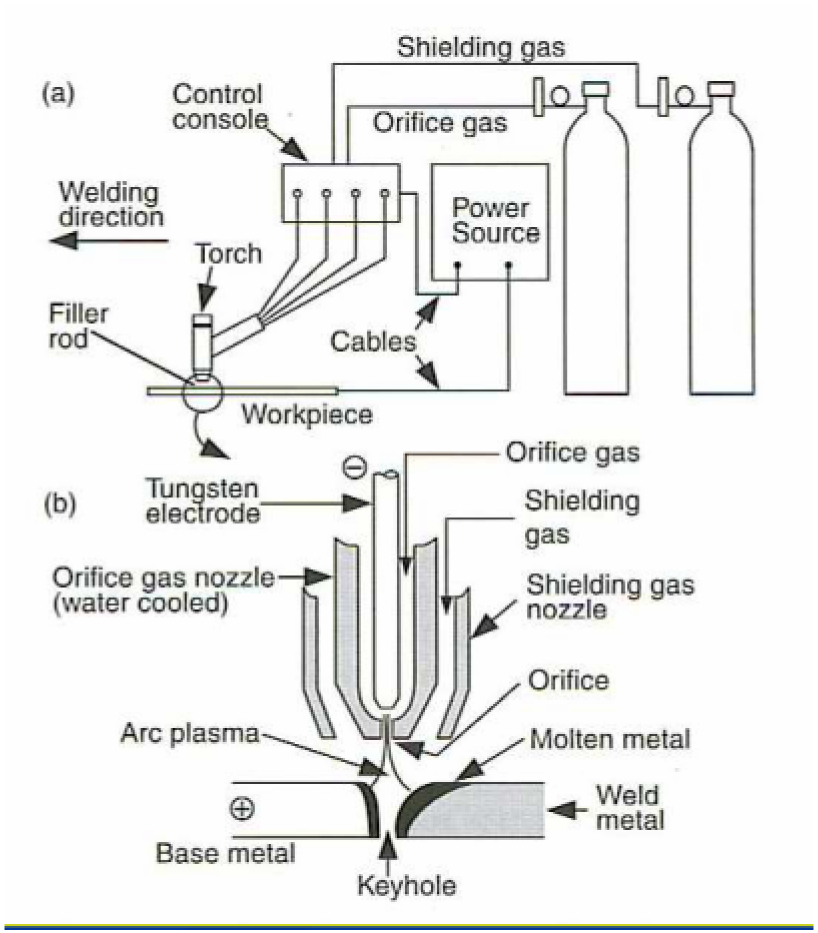
Tungsten electrode remains in contact with a water cooled copper tube which is connected to welding cable to prevent **overheating**.

**Tungsten with 2% cerium or thorium** is used for electrode for greater electron emissivity, current-carrying capacity and resistance to contamination and better arc stability.

Shielding gas (Ar, He) goes through the torch body and nozzle toward the weld pool to protect it from air.

Filler metal can be fed for joining of thicker parts.

# PAW (Plasma Arc Welding)



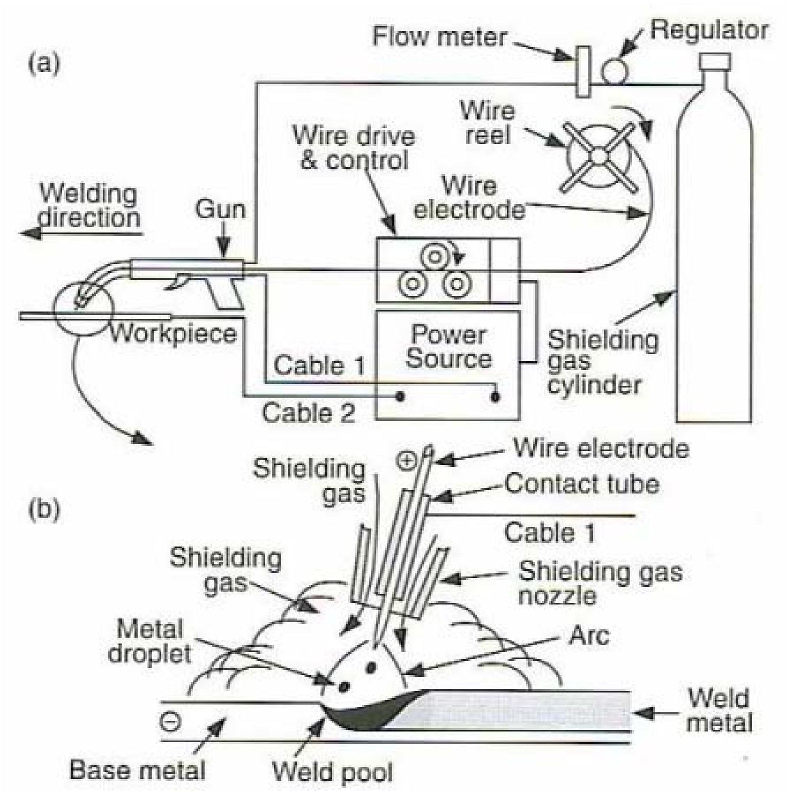

PAW involves a constricted arc established between workpiece (or nozzle) and a tungsten electrode.

PAW is similar to GTAW except a shielding gas and an orifice gas. The arc is constricted due to covering action of the orifice gas nozzle.

Tungsten electrode is recessed in the orifice gas nozzle.

The arc is initiated by applying a high voltage at high frequency betn. electrode tip and water cooled orifice gas nozzle.

# GMAW (Gas Metal Arc Welding)

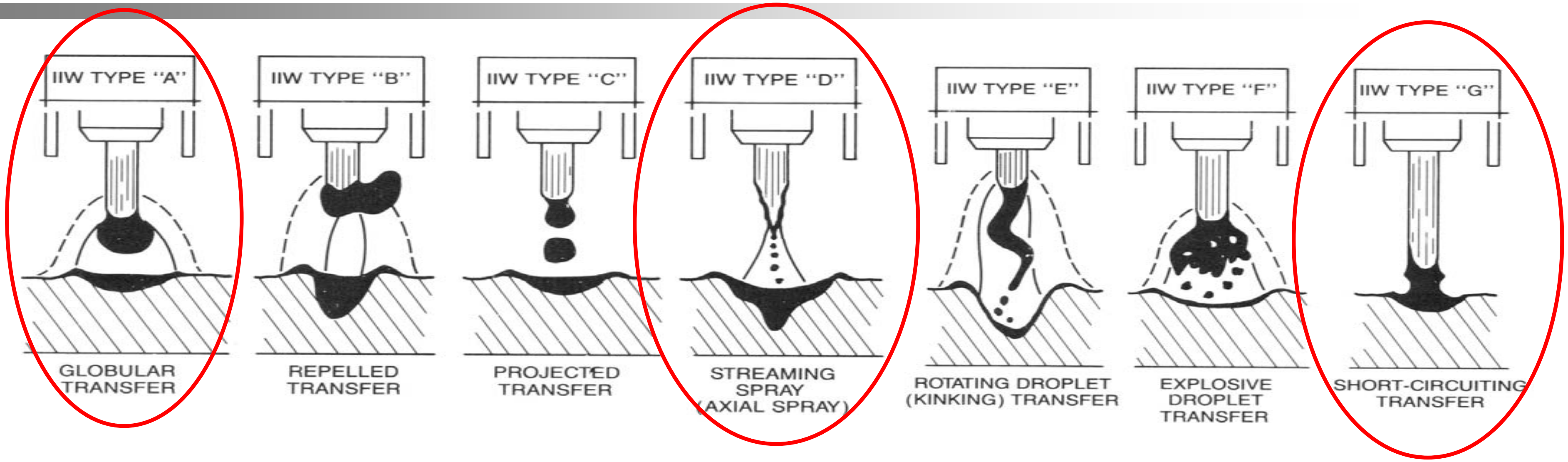



An arc is established between a continuously fed electrode wire and the workpiece.

Ar, He or “Ar (25%) + He (75%)” mixture is used as shielding gas for non-ferrous metals (Al), stainless and alloy steels. “Ar (20%) + $CO_2$ (80%)” is used for low carbon steels.

Ar arc plasma provides the most stable atmosphere for droplet transfer.

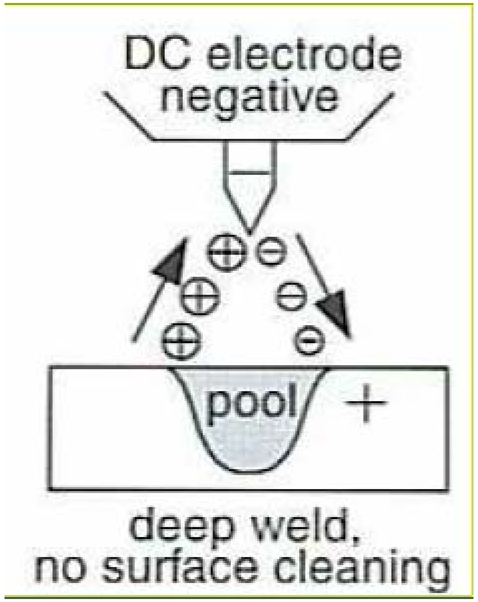
# Types of Metal Transfer in GMAW Process




- **Globular Transfer:** Metal droplets travel across the arc gap under the influence of gravity and arc plasma flow; not smooth and results in spatter; typical in low welding current (< 180 A).
- **Spray Transfer**: Small metal droplets travel under the influence of electromagnetic force at much higher speed and frequency; more stable and spatter free; happens in higher current (220 ~ 320 A)
- **Short-circuit Transfer:** Liquid bridge is transferred as electrode tip touches the weld pool under the action of surface tension; necking and detachment occur under the influence of electromagnetic force; low welding current.

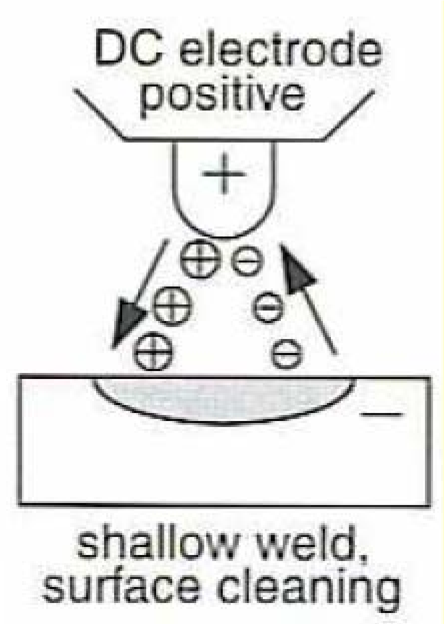
# Polarity - Direct Current Electrode Negative (DCEN)

- Also called **straight polarity.**
- Electrons are emitted from the **negative tungsten electrode** and accelerated while travelling through the arc,
- Most commonly used in **GTAW,**
- Relatively **narrow and deep weld pool** is produced due to high energy
- **DCEN in GMAW** makes the **arc unstable** and causes **excessive spatter**.
  - **Large droplet size of metal and arcs forces the droplets away from the workpiece →** This is due to a low rate of electrode emission from the negative electrode.

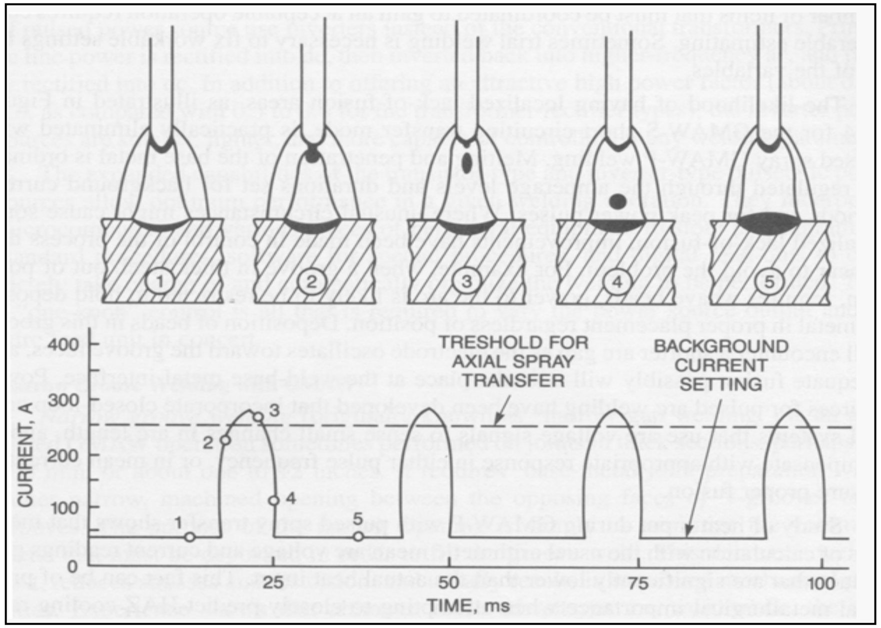


# Direct Current Electrode Positive (DCEP)

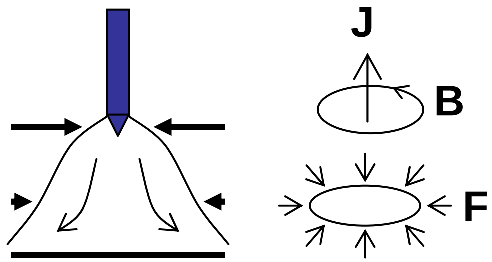
- Also called **reverse polarity.**
- The electrode is connected to the +ve terminal of the power source → the heating effect is now on the tungsten electrode rather than on the workpiece → shallow welds,
- At low current in ***Ar***, the size of droplet ~ the size of electrode → globular transfer
- The droplet size is inversely proportional to the current and the droplets are released at the rate of a few per second.
- At above the critical current → the droplets are released at the rate of hundreds per second (spray mode)
    - **Postive ions clean off the oxide surface.**



# Pulsed Current Transfer – GMAW-P

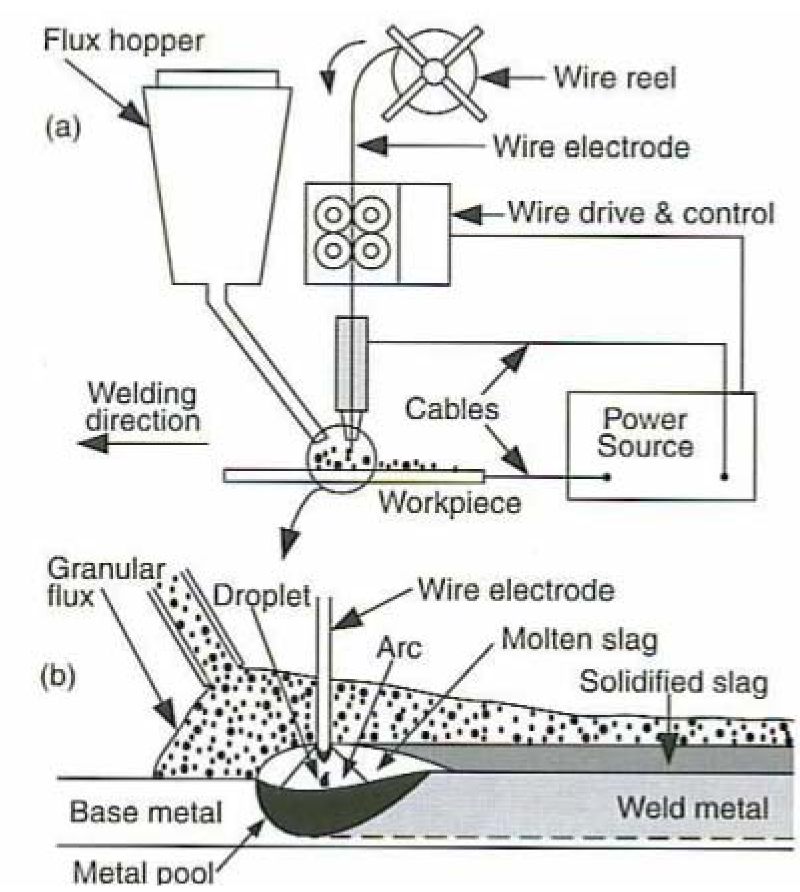



- GMAW-P allows application of one base current of smaller magnitude to maintain the arc and a controlled pulse current of higher magnitude to create and transport a small droplet towards the melt pool.
- The detachment of droplet is primarily dictated by electro-magnetic force at high pulse current.
- Facilitates fairly controlled rate of spray-type metal transfer at relatively reduced value of average heat input compared to a conventional GMAW.




$$\vec{\mathbf{F}} = \vec{\mathbf{J}} \times \vec{\mathbf{B}} \Rightarrow \mathbf{F} \propto \mathbf{J}^2$$

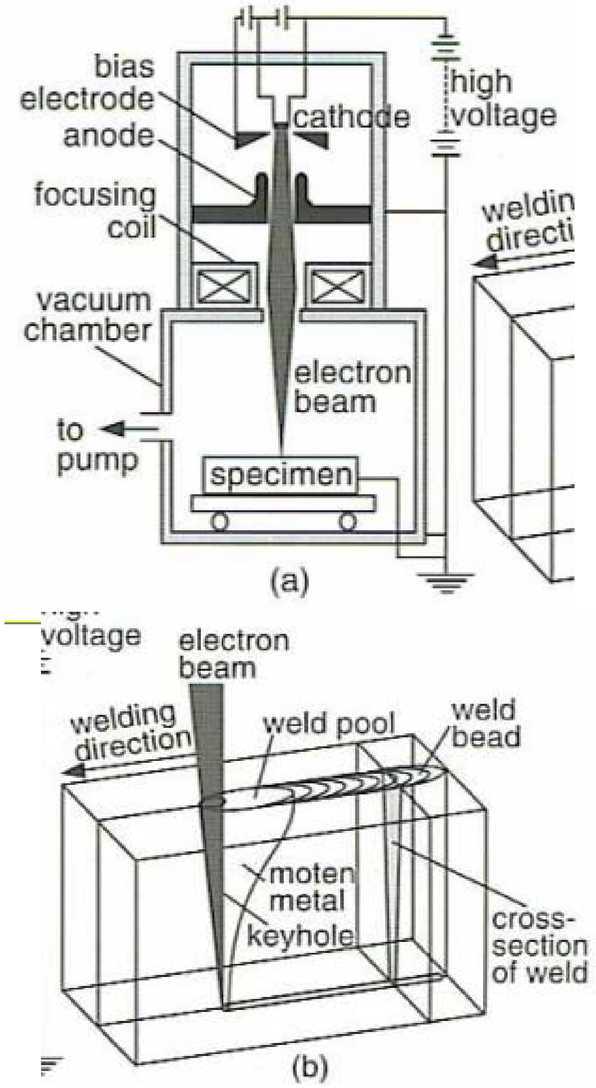
# SAW (Submerged Arc Welding)




**Arc** is submerged and invisible. **Flux** is supplied from a hopper that travels with the torch. **Shielding Gas** is not required as the molten metal is separate from the air by molten slag and granular flux.

The arc is always established between a consumable electrode wire and base metal and submerged completely inside the flux cover.

# EBW (Electron Beam Welding)



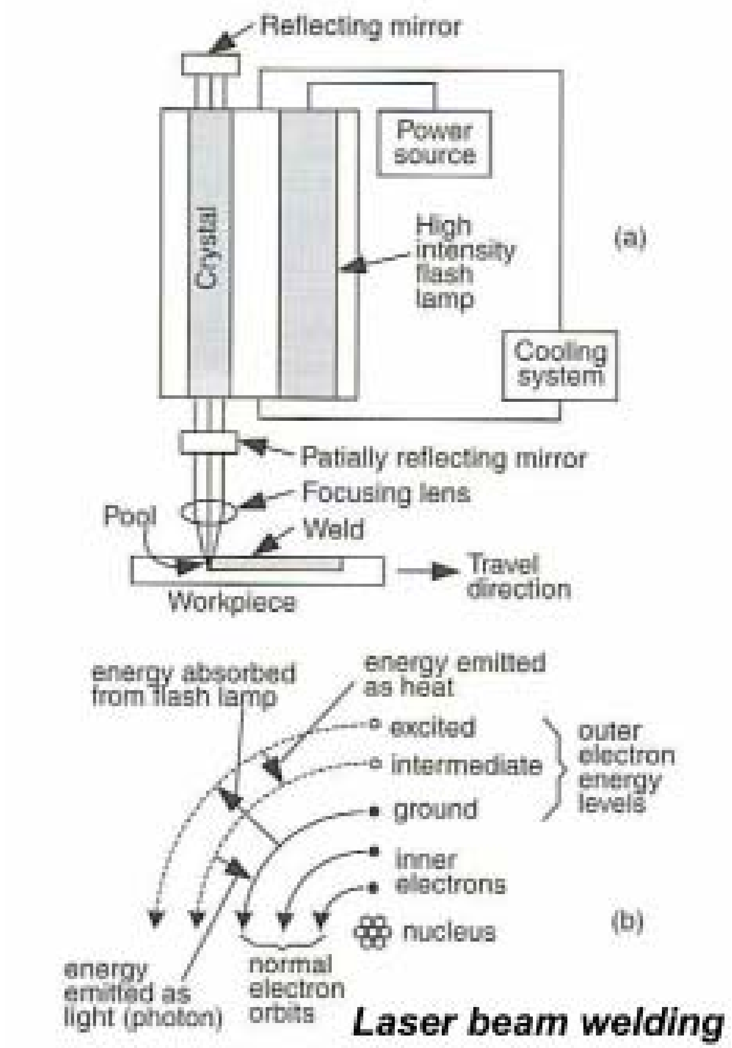

**EBW** is a process that melts and joins metals by melting them with an electron beam.

**When** the filament in the electron beam is negatively charged, it emits electron that is accelerated by the **electric field.**

**These electrons** go through the anode and are focused (0.3 ~ 0.8 mm diam.) by an **electromagnetic coil** on w/s surface with a high power density (~ $10^{10}$ W/m$^2$).

The **high intensity beam** forms a deep penetrating keyhole.

# LBW (Laser Beam Welding)



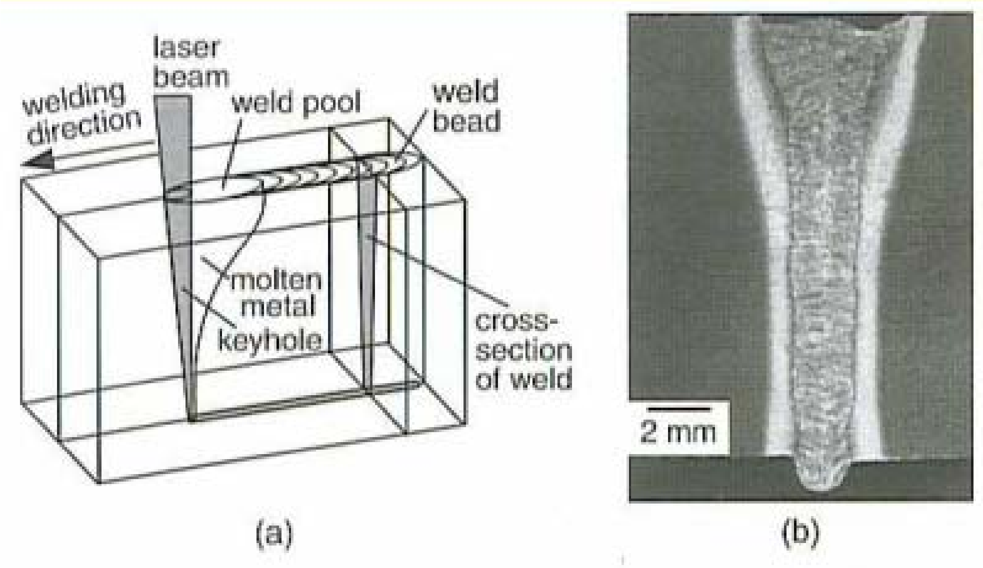

**LBW** is a process that melts and joins metals by melting them with a laser beam.

**Laser beam** can be produced by a solid state laser **(YAG – Yttrium-Aluminum-Garnet Crystal)** or a gas **(CO2)** laser, which is focused and directed by optical means to achieve high power density.

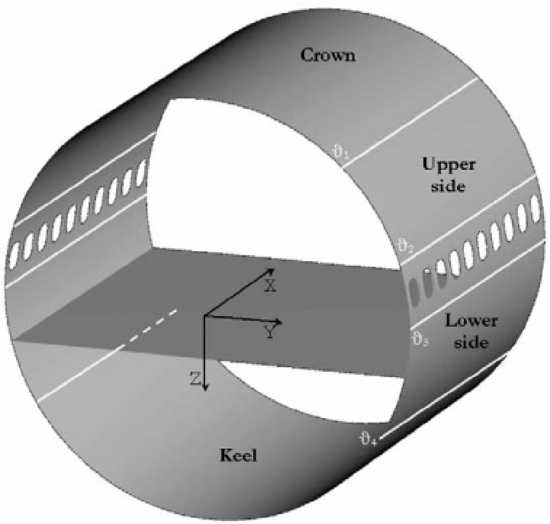
**Laser** is produced when excited electrons return to their normal state.

**Plasma (an ionic gas)** produced during welding can absorb and scatter the laser beam and reduce weld penetration. An inert gas (**He, Ar**) is often used.

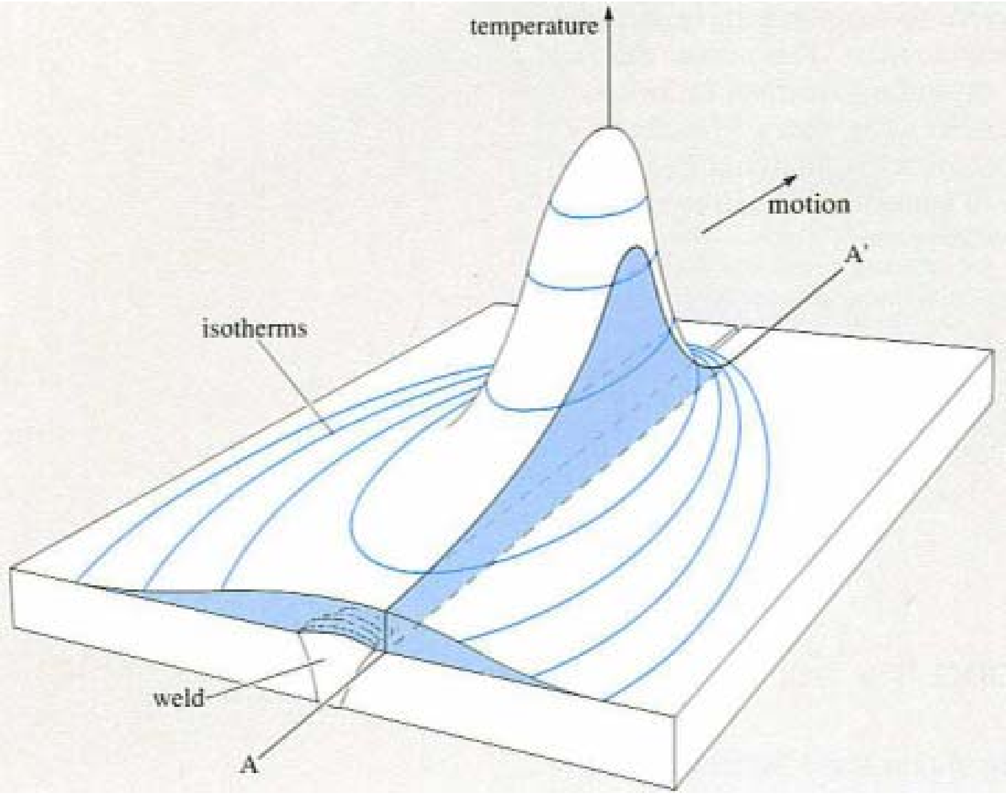
# LBW is used for deep penetration or controlled melting




Deep penetration with a small aspect ratio of weld bead is the main characteristic. Porosity is a problem although weld induced thermal distortion is reduced.

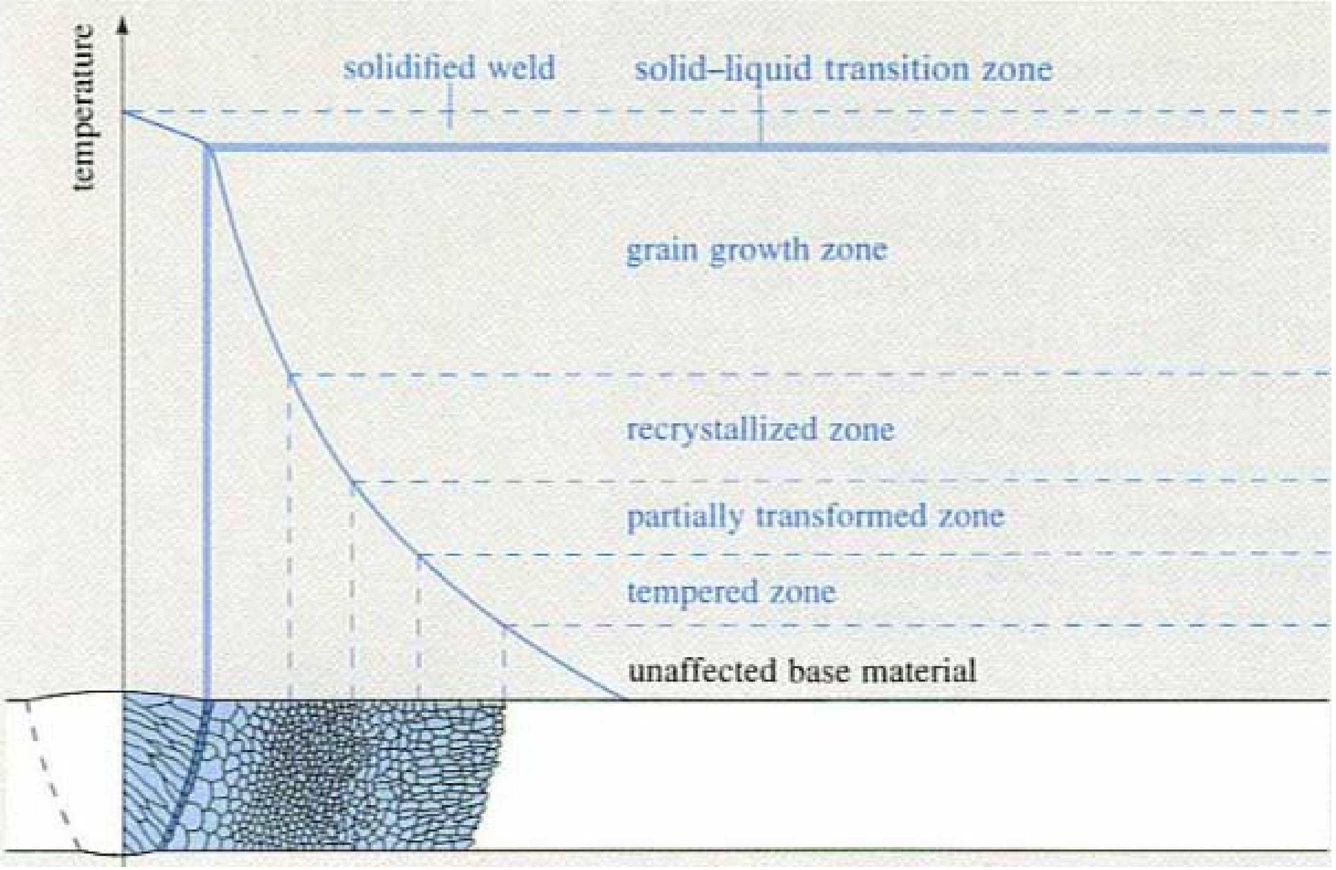



# Critical Issues in Fusion Welding



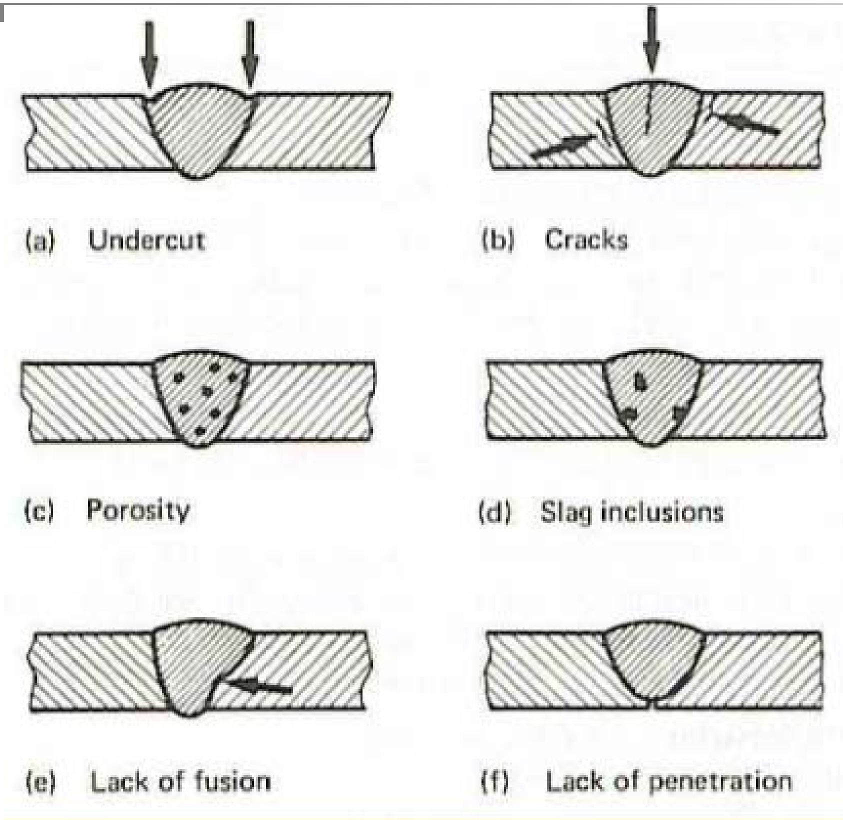

- As the heat source moves on, the cooling rate around the weld becomes very high.
- A steeper source will provide a steeper profile and the HAZ will remain confined to a smaller region.
- The peak temperature, the temperature distribution and the cooling rate also depend on the several material properties such as thermal conductivity, specific heat and density.

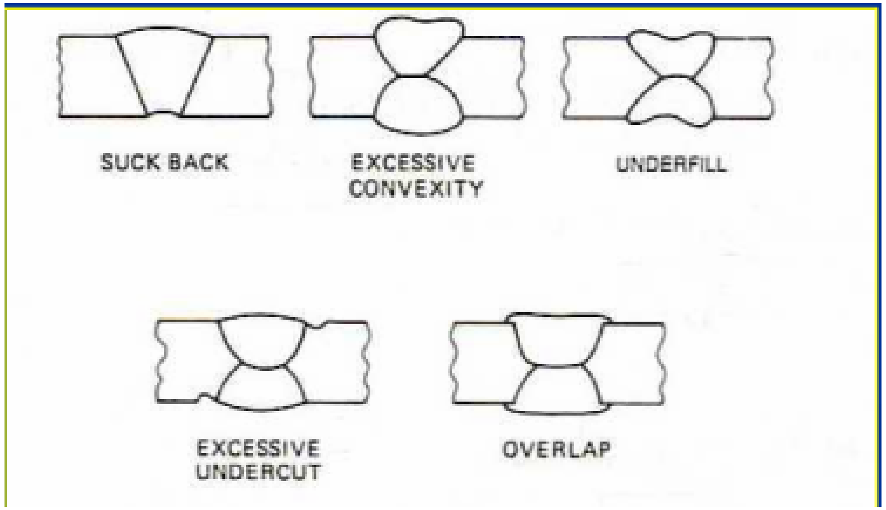
# Critical Issues in Fusion Welding

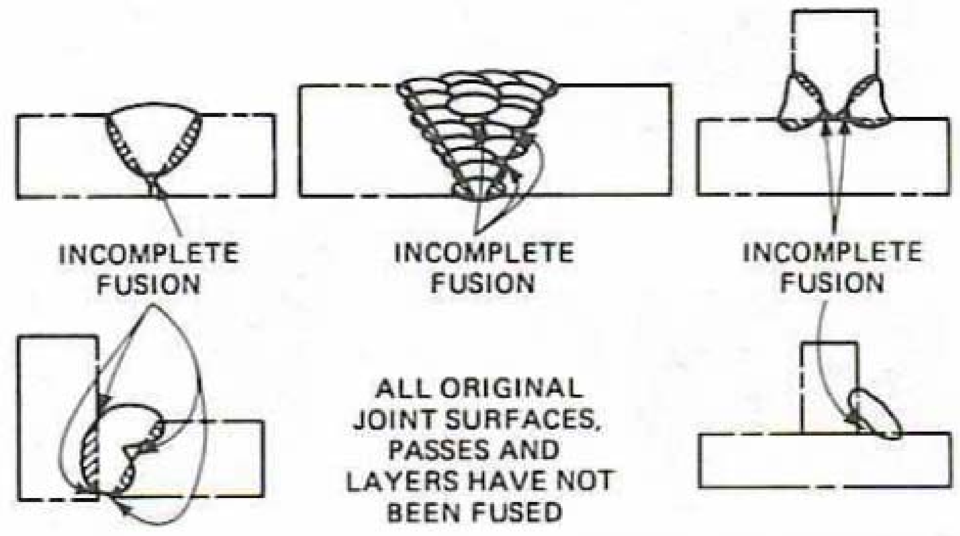



- Temperature gradients in fusion weld pool and HAZ usually are substantially high resulting in higher solidification rate and a fine dendrite structure.

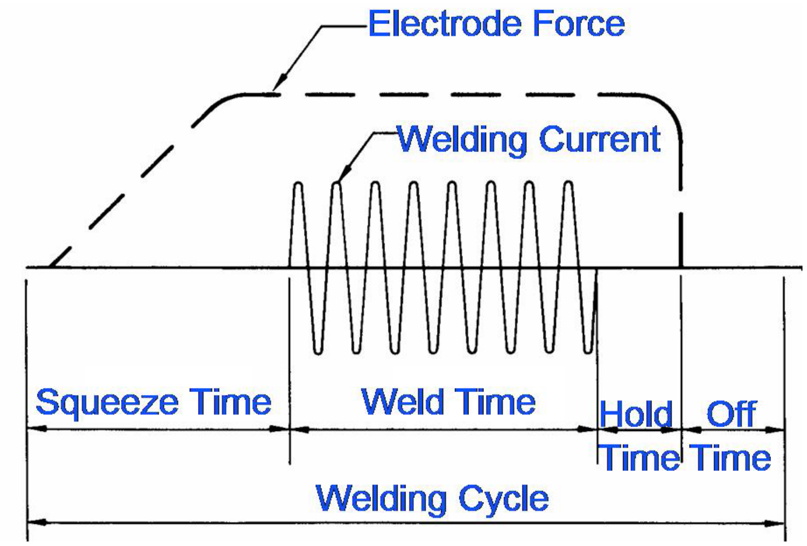
# General Defects in Fusion Welding

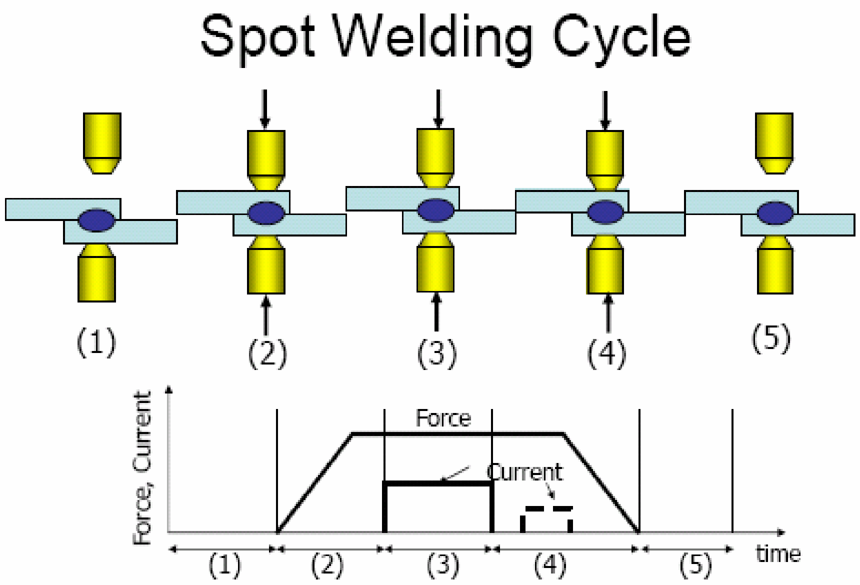


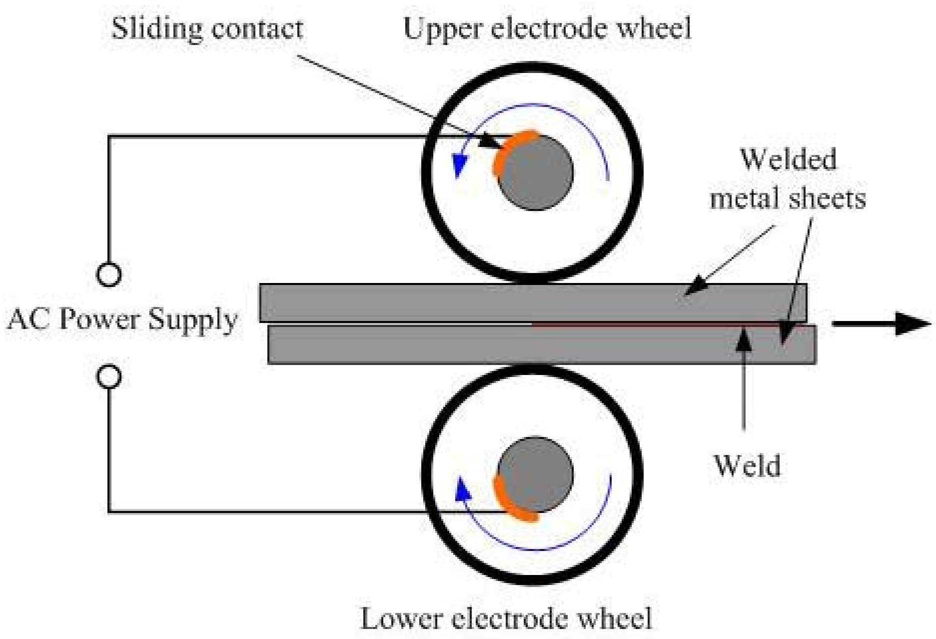
# Resistance Spot Welding (RSW) - Principle




- Passage of high current between metallic sheets that are held by a pair of copper electrodes results in rapid melting along the sheet-sheet interface,
- Weld joint / nugget is formed as the melt pool at sheet-sheet interface solidifies.
- Usually resistive heating along electrode-sheet interface is dissipated due to high thermal conductivity of copper and flow of cooling water through electrodes,
- RSW is a very fast process, easy to automate and has remained the main joining process in automotive and other sheet fabrication industries.

# RSEW - Principles

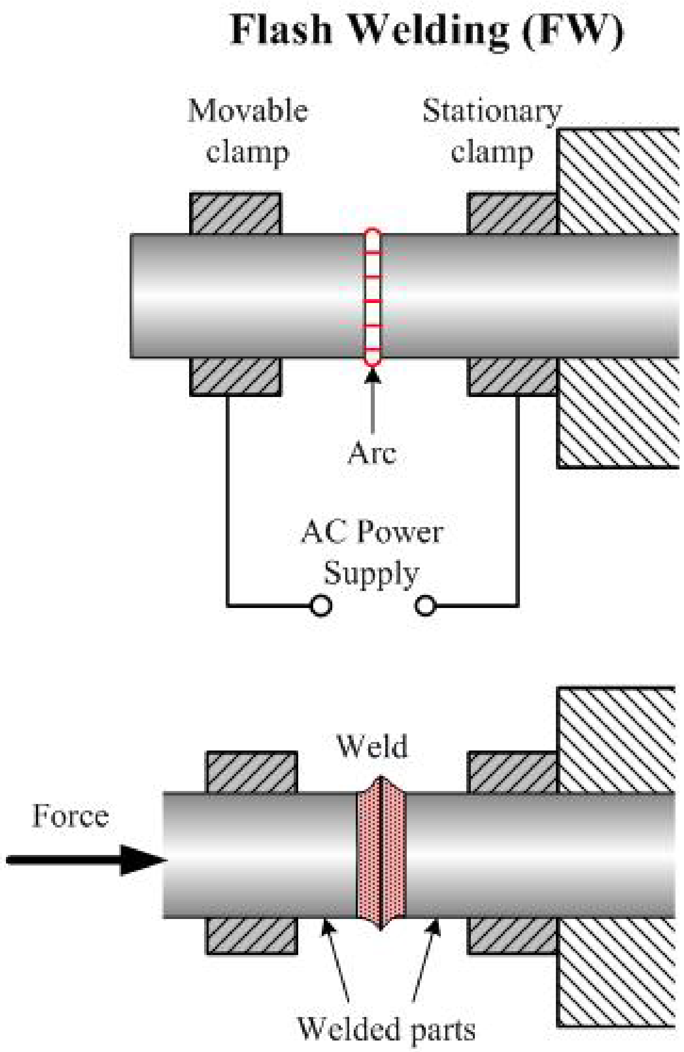



RSEW is a high speed and clean process, which is used when continuous tight weld is required (fuel tanks, drums, domestic radiators).

(a) RSEW is a process of continuous joining of overlapping sheets by passing them between two rotating electrode wheels.

(b) Heat generated by the electric current flowing through the contact area and pressure provided by the wheels are sufficient to produce a leak-tight weld.

# Flash Welding - Principles




(a) Ends of rods (tubes, sheets) are heated and fused by an electric arc and then forged (brought in contact under a pressure) producing a weld.

(b) The welded parts are held in electrode clamps, one of which is stationary and the second is movable.

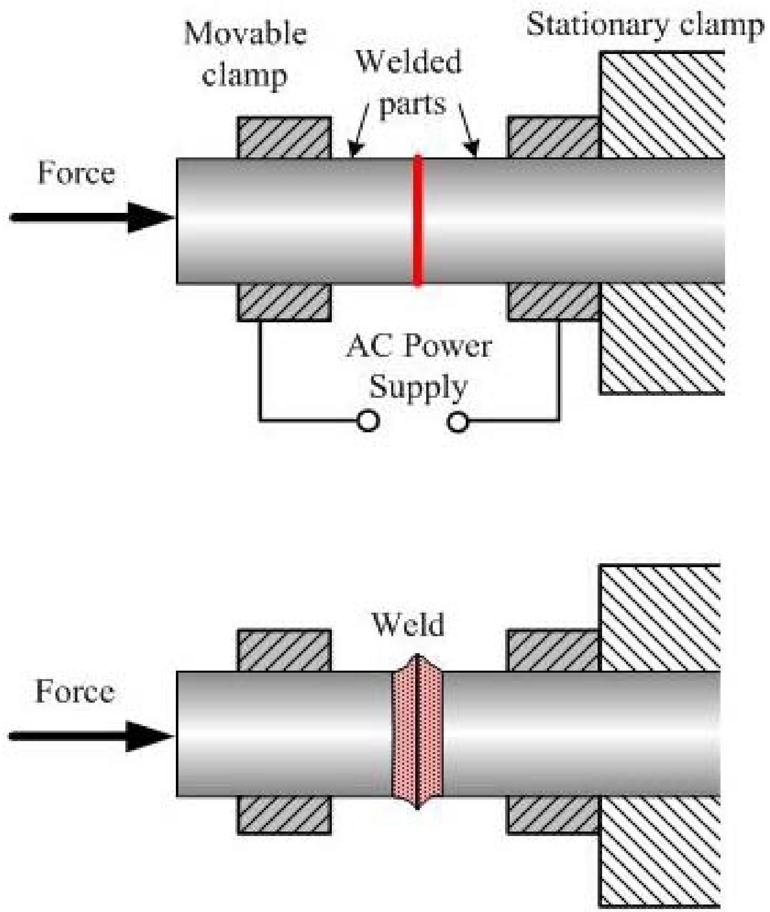
(c) Permits fast (about 1 min.) joining of large and complex parts.

(d) Welded part are often annealed to improve toughness of the weld.

(e) Steels, Al-alloys, Cu-alloys, Mg-alloys, and Ni-alloys can be welded.

(f) Thick pipes, ends of band saws, frames, aircraft landing gears are produced by Flash Welding.

# Butt Welding - Principles



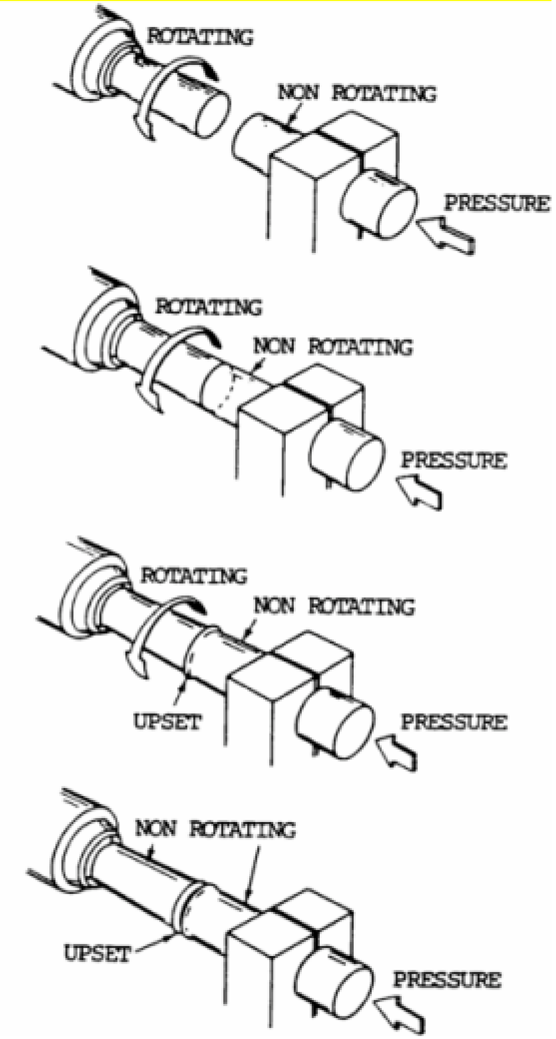

(a) Ends of wires or rods are held under a pressure and heated by an electric current passing through the contact area and producing a weld.

(b) In UW, both pressure and electric current are applied simultaneously; but in FW electric current is followed by forging pressure application.

(c) UW is used for welding small parts.

(d) UW is highly productive and clean. In contrast to FW, no loss of the welded materials occurs in UW.

# Inertia Friction Welding

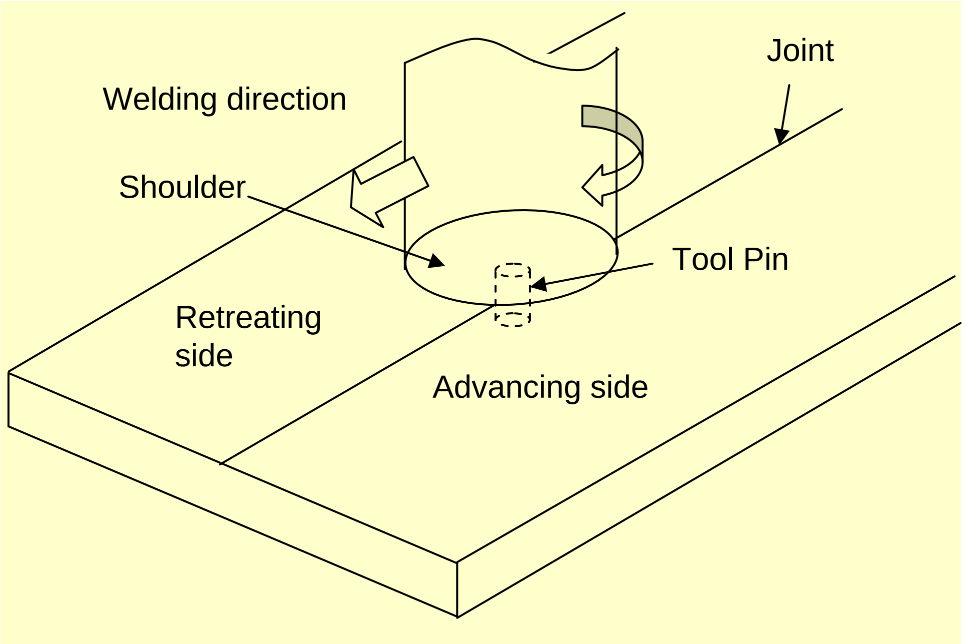



**Friction Welding** is a mechanical solid-phase .welding process in which heat generated by friction is used to create high-integrity joint between similar or dissimilar metals.

**Energy** ***needed*** *to make the weld is supplied primarily by stored rotational kinetic energy of the welding machine.*

*One piece is attached to a flywheel and the other is restrained from rotating. Flywheel is predetermined rotational speed storing the energy. Motor is then disengaged and the w/p are forced together by the friction welding force.*

# What is Friction Stir Welding (FSW)




Solid state welding process developed at TWI in 1991

The tool usually has a large-diameter shoulder and a smaller threaded pin.

Pin is inserted between the rigidly clamped weld plates.

Tool is rotated to generate heat, creating a thin plasticized zone around the pin.

Material is transported from the front to rear.