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Welding Technology (Elective-I)

Course Code: 23BTMEL307

B. Tech - V Semester

Prepared by:

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Teaching and Evaluation Scheme

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Course Title: **Welding Technology (Elective-I)**										
Semester	V	Teaching Scheme				Evaluation Scheme				
						Theory			Practical	
Term	Odd	Th	Tu	Pr	Credits	TAE	CAE	ESE	INT	EXT
Course Category	PEC 1	3 Hrs	-	2	04	10	15	50	25	-
Course Code	23BTMEL307 23BTMEP307									
Teaching Mode	Offline	3 Hrs.			Total	75			25	
Duration of ESE	2.5 Hrs.					75				

Course Objectives and Outcomes

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Course Objectives	1. To identify the different sources of energy for welding.
	2. To understand different types of welding and its applications
	3. To get acquainted with different weld testing methods.
Course Outcomes	Upon successful completion of this course, student shall be able to:
	CO 1. Evaluate the concept of Arc welding and its working.
	CO 2. Compare different welding methods.
	CO 3. Analyze weldability of the metal.
	CO 4. Apply various parameters for advance welding processes.
	CO 5. Understand the nondestructive testing for welding.

Syllabus

Unit	Contents
Unit 1	**Introduction of Welding:** AWS Definition of welding, Classification of welding processes, Source of energy for welding, heat input, power density, Physics of Welding Arc; voltage distribution along the arc, polarities, theories of cathode and anode mechanism; arc characteristics and application of consumables.
Unit 2	**Fusion Welding Processes:** Selection of process and parameters - Gas welding, shielded metal arc welding (SMAW), Gas metal arc welding (GMAW), Gas tungsten arc welding (GTAW), Submerged arc welding (SAW), Plasma arc welding (PAW), Laser beam welding (LBW) and Electron beam welding (EBW).
Unit 3	**Welding Metallurgy:** Basics of Welding metallurgy, different zones in fusion welding, basics of weld metal solidification, welding defects, weldability; definition, factor affecting the weldability of steels.
Unit 4	**Advanced Welding technique:** Solid state welding; parameters and tool selection for friction stir welding, cold metal transfer welding process, wire arc additive manufacturing, laser-arc hybrid welding, impelled arc butt welding and explosive welding process.
Unit 5	**Non-Destructive Testing of Weldments:** Ultrasonic inspection-principle of ultrasonic testing, N.D.T. Standard procedure for specification and qualification of welding procedure; Welding process sheet (WPS), Welding performance qualification (WPQ).

Study Material

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Text Books	1.	Welding Fundamental, William A Bowditch A & Kevin A Bowditch, Good heart-Willcox, 1991.
	2.	Welding Metallurgy &Weldaility of Stainless Steel, John C Lippold, 2th Edition, 2014.
E-Books	1.	Welding Metallurgy, Sindo Kou, Wiley Publishers, 2016, 2nd edition.
	2.	Welding Technology and Design, V.M. Radhakrishnan, New Age International (P) Limited, Pub., 2005.
Reference Books	1.	Metallurgy of Welding, J. F. Lancaster, William Andrew Publishing. 6th Edition.
	2.	Principles of Welding (Processes, Physics, Chemistry and Metallurgy), Robert W Messler, Wiley Publishers.
	3.	Welding Hand Book, Publisher. American Welding Society; 7th edition.

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Unit 1

Introduction to Welding

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- Welding is one of the most widely used fabrication processes in manufacturing and construction industries. It is a **permanent joining process** in which two or more parts—usually metals or thermoplastics—are fused together using heat, pressure, or both. Unlike other joining methods such as bolting or riveting, welding creates a strong metallurgical bond and often results in joints as strong as or stronger than the base materials.
- Welding plays a critical role in industries such as **automotive, aerospace, shipbuilding, construction, pipelines, railways**, and **heavy machinery manufacturing**. With advancements in technology, modern welding also includes robotic welding, laser welding, and welding under extreme environments such as underwater and space.

Definition of Welding

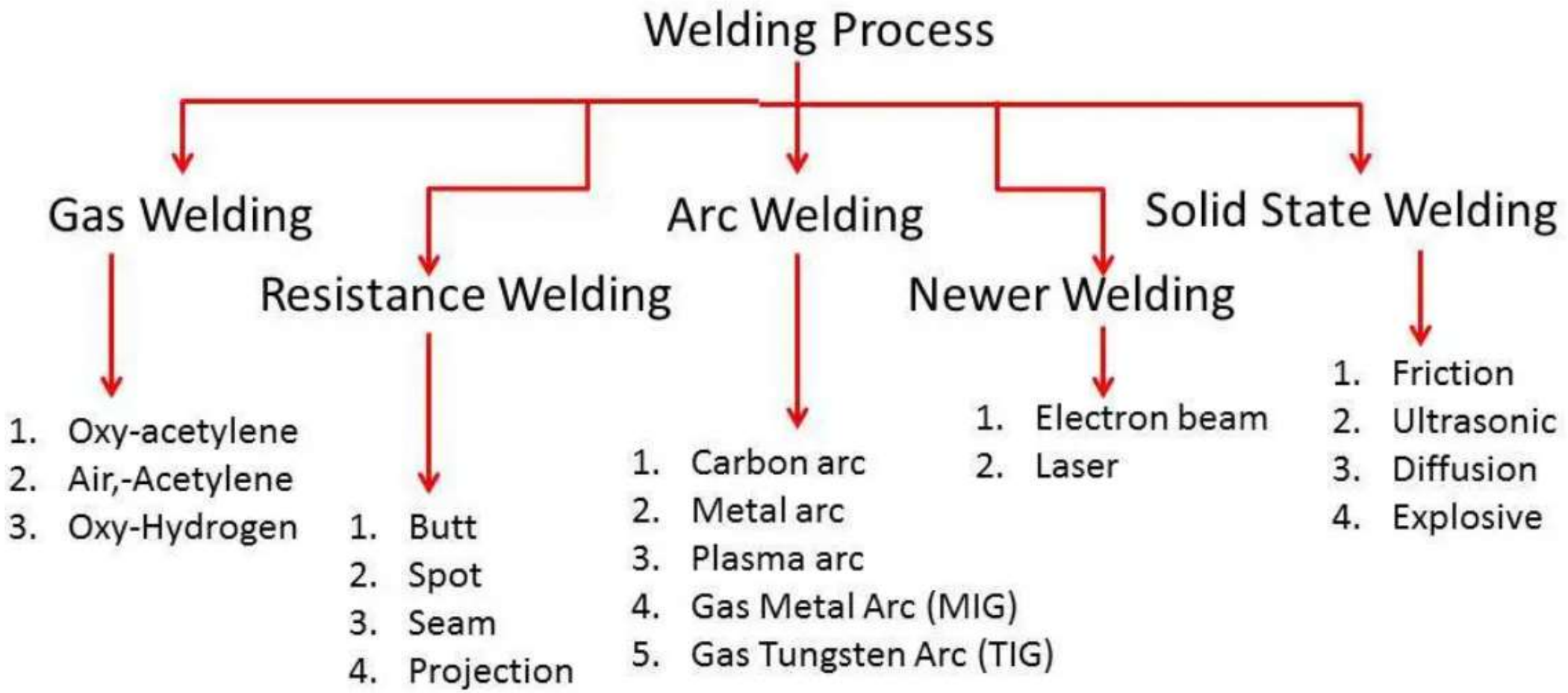
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- **Welding** is defined as:

"A fabrication process that joins materials, usually metals or thermoplastics, by causing coalescence, typically using high heat to melt the parts together and allowing them to cool, causing fusion."

This process may or may not require a **filler material** and is often performed with or without the application of **pressure**.

Classification of welding:



1. Gas Welding

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- Uses a flame produced by burning a gas (usually acetylene) with oxygen or air to melt and join metals.
- **Oxy-Acetylene Welding**: Most common; high flame temperature (~3200°C); used for steels and cutting.
- **Air-Acetylene Welding**: Lower temperature; suitable for soldering and brazing.
- **Oxy-Hydrogen Welding**: Uses hydrogen and oxygen; clean flame, used for delicate operations like glasswork.

2. Resistance Welding

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- Heat is generated by electrical resistance and pressure is applied to make the joint.
- **Butt Welding**: Ends of components are joined by pressing them together with electric current.
- **Spot Welding**: Used for thin sheets; weld is made at small contact spots.
- **Seam Welding**: Overlapping sheets are joined with continuous welds using rotating electrodes.
- **Projection Welding**: Localized welds made at raised sections (projections) of one part.

3. Arc Welding

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- An electric arc is used to melt the base and filler metals.
- **Carbon Arc Welding**: Uses a carbon electrode; obsolete but historically significant.
- **Metal Arc Welding (SMAW)**: Common stick welding; uses flux-coated electrodes.
- **Plasma Arc Welding**: Highly focused arc; suitable for precision welding and cutting.
- **Gas Metal Arc Welding (MIG)**: Uses a continuously fed wire; good for high-speed production.
- **Gas Tungsten Arc Welding (TIG)**: Uses a non-consumable tungsten electrode; clean and precise.

4. Newer Welding Techniques

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- Advanced processes using high-energy beams.
- **Electron Beam Welding**: Uses a focused electron beam in vacuum; deep, narrow welds with minimal distortion.
- **Laser Welding**: Uses concentrated laser beam; precise and fast, ideal for micro-welding and automation.

5. Solid State Welding

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- Joining without melting the base materials, using pressure and sometimes heat.
- **Friction Welding**: Heat is generated by rubbing parts together; then pressure is applied.
- **Ultrasonic Welding**: High-frequency vibrations under pressure; used for plastics and thin metals.
- **Diffusion Welding**: Atoms diffuse across the joint at high temperature and pressure.
- **Explosive Welding**: Shock waves from explosives bond metals; used for dissimilar metals.

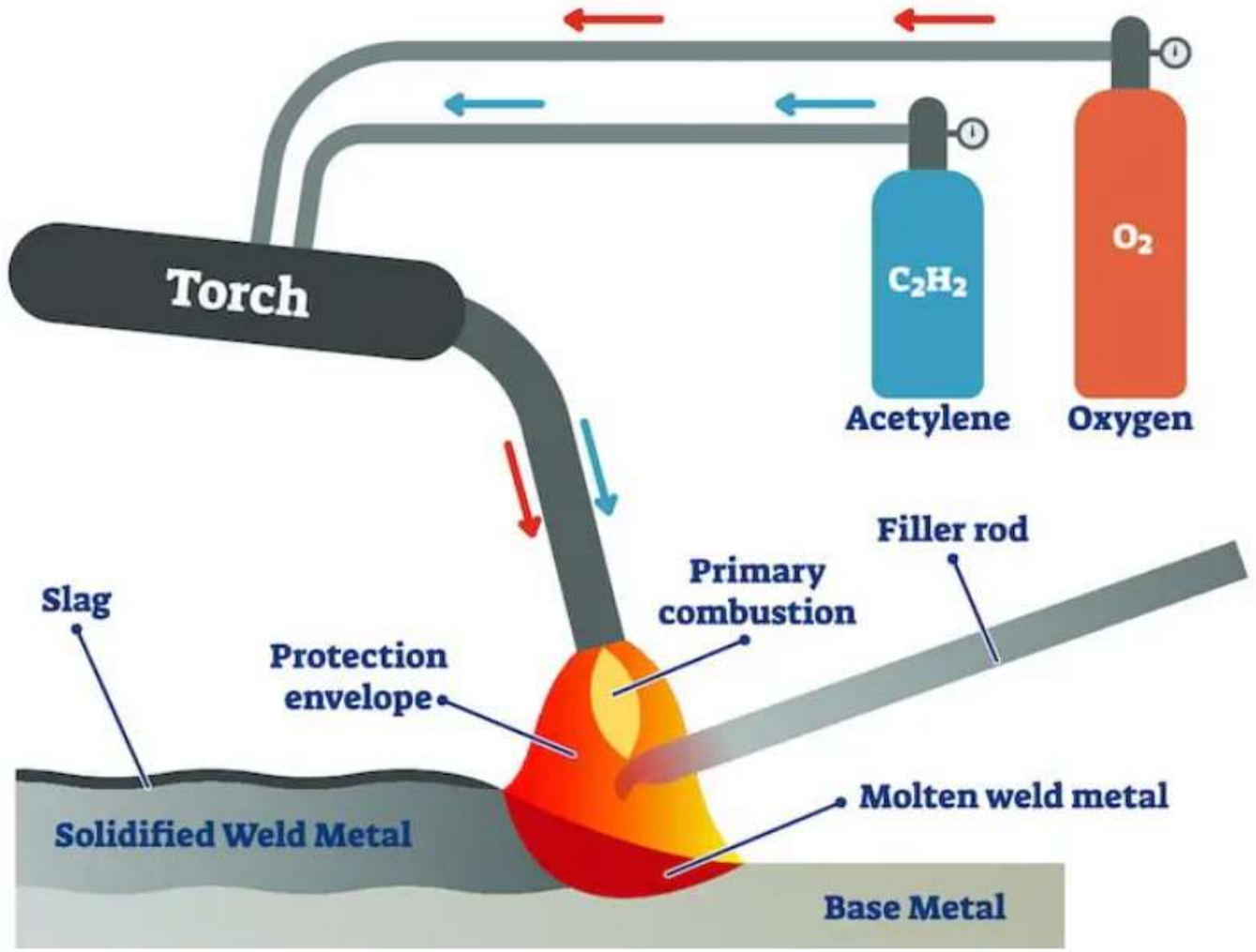
Sources of Energy for Welding

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- Welding requires a source of energy to produce the heat necessary to join materials. The energy source plays a crucial role in determining the type of welding process, the quality of the weld, and the materials that can be welded. The energy must be sufficient to melt the base metals and, if required, the filler material. In solid-state welding, the energy is used to generate heat and/or pressure without melting the metals.
- The **sources of energy for welding** can be broadly classified into the following categories:

1. Chemical Energy (Combustion of Gases)

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- *a. Oxy-Acetylene Welding*
- Uses acetylene (C_2H_2) and oxygen (O_2).
- Produces a flame temperature of about **3200°C**, sufficient to melt steel and other metals.
- The flame has three zones: inner cone, acetylene feather, and outer envelope.
- The energy is used both for melting the base metal and for heating filler rods.
- *b. Oxy-Hydrogen Welding*
- Uses hydrogen and oxygen.
- Flame temperature is lower than oxy-acetylene (~2800°C).
- Clean flame, suitable for delicate work such as glassware and aluminum.
- *c. Air-Acetylene Welding*
- Uses air instead of oxygen.
- Produces a lower flame temperature.
- Often used for brazing and soldering rather than fusion welding.

Advantages:

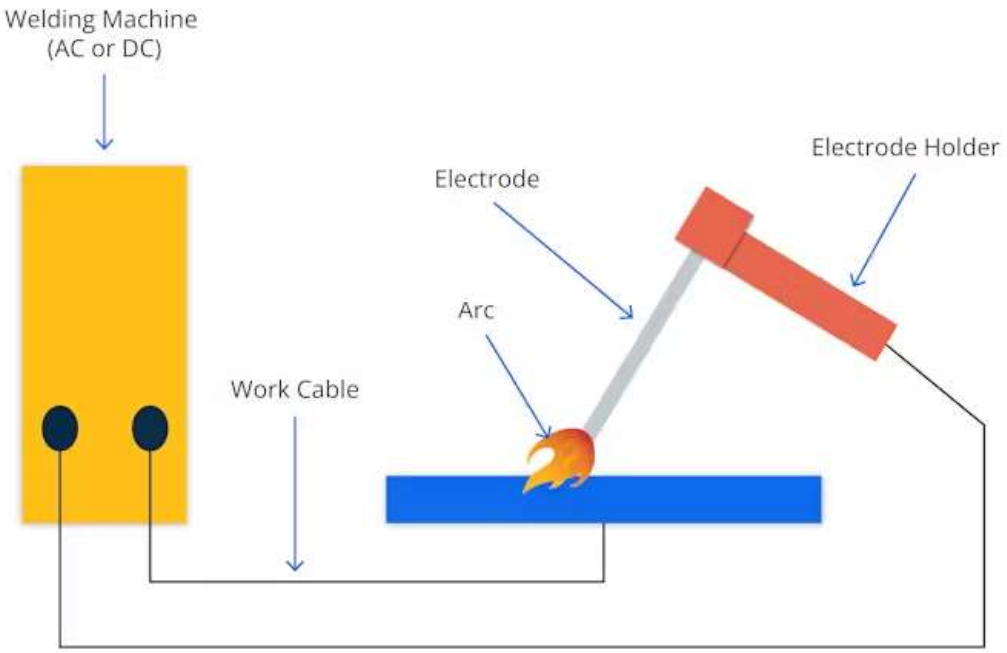
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- Portable and simple setup.
- Suitable for outdoor and field work.
- Effective for cutting and welding thin materials.

2. Electrical Energy

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- Electrical energy is one of the most widely used sources for welding processes. It is used to create an electric arc or resistive heating that melts the base material.



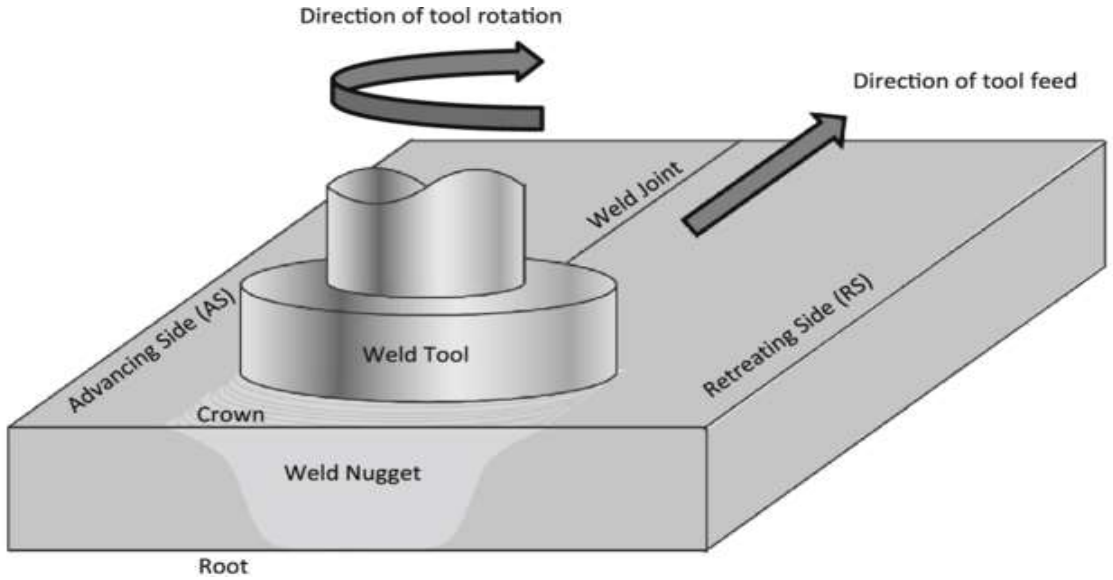
- *a. Arc Welding*
- The most common electrical welding method.
- Involves the generation of an electric arc between an electrode and the base metal.
- Arc temperature can reach up to **6000°C**.
- Common processes: SMAW (Shielded Metal Arc Welding), GMAW (MIG), GTAW (TIG), and SAW (Submerged Arc Welding).
- *b. Resistance Welding*
- Uses electrical resistance and pressure to generate localized heat at the joint.
- Common forms: Spot welding, Seam welding, Projection welding.
- No filler metal is required; heat is generated at the interface due to resistance to current flow.
- *c. Electro-Slag and Electro-Gas Welding*
- Use the resistance of a molten slag to the passage of electric current.
- Used for welding thick sections in a vertical position.

- **Advantages:**
- High heat concentration.
- Suitable for automation and robotic welding.
- High deposition rate and deep penetration.

3. Mechanical Energy

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- Mechanical energy in welding is typically converted into heat through **friction or vibration**. These processes fall under the category of **solid-state welding** where no melting occurs.



- *a. Friction Welding*
- Mechanical rubbing generates heat at the interface of two materials.
- Once the desired temperature is reached, pressure is applied to forge the materials together.
- Common types: Rotary friction welding, linear friction welding.
- *b. Ultrasonic Welding*
- Uses high-frequency vibrations (20-40 kHz) to generate heat by internal friction.
- Used for thin materials, plastics, and some metals like aluminum.

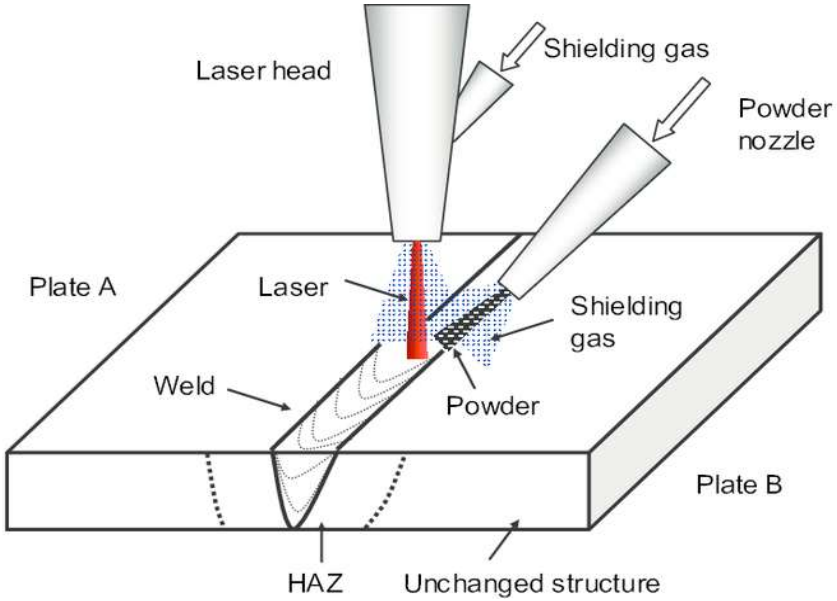
Advantages:

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- No filler material or shielding gas required.
- Strong metallurgical bond.
- Minimal distortion or heat-affected zone.

4. Radiant Energy (High-Energy Beams)

- Radiant energy includes energy from high-powered beams such as **laser** and **electron beams**. These are highly focused and provide deep, narrow welds with high precision.



- *a. Laser Beam Welding (LBW)*
- Uses a high-intensity laser beam as the heat source.
- Welds are narrow, deep, and very precise.
- Suitable for micro-welding and materials requiring minimal distortion.
- *b. Electron Beam Welding (EBW)*
- High-velocity electrons impact the workpiece inside a vacuum chamber, producing heat.
- Can weld thick sections in a single pass.
- Ideal for aerospace and nuclear applications.

Advantages:

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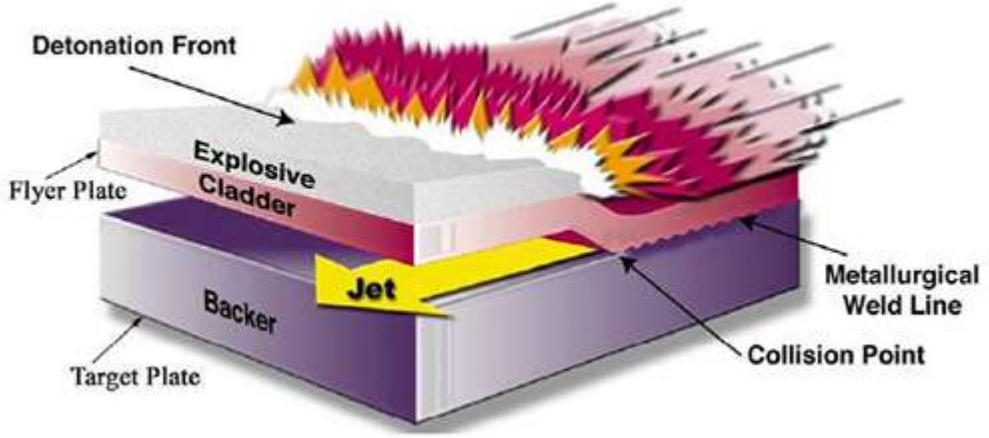
- Non-contact process.
- Very high energy density.
- Welds difficult-to-reach and miniature areas.

5. Explosive Energy

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- This is a less common but highly effective source of energy used in **explosive welding**, a type of solid-state welding.
- Uses controlled detonation to force materials together at extremely high speeds.
- Primarily used to join dissimilar metals like aluminum to steel or titanium to copper.
- Used in making bi-metallic plates for heat exchangers and cladding.

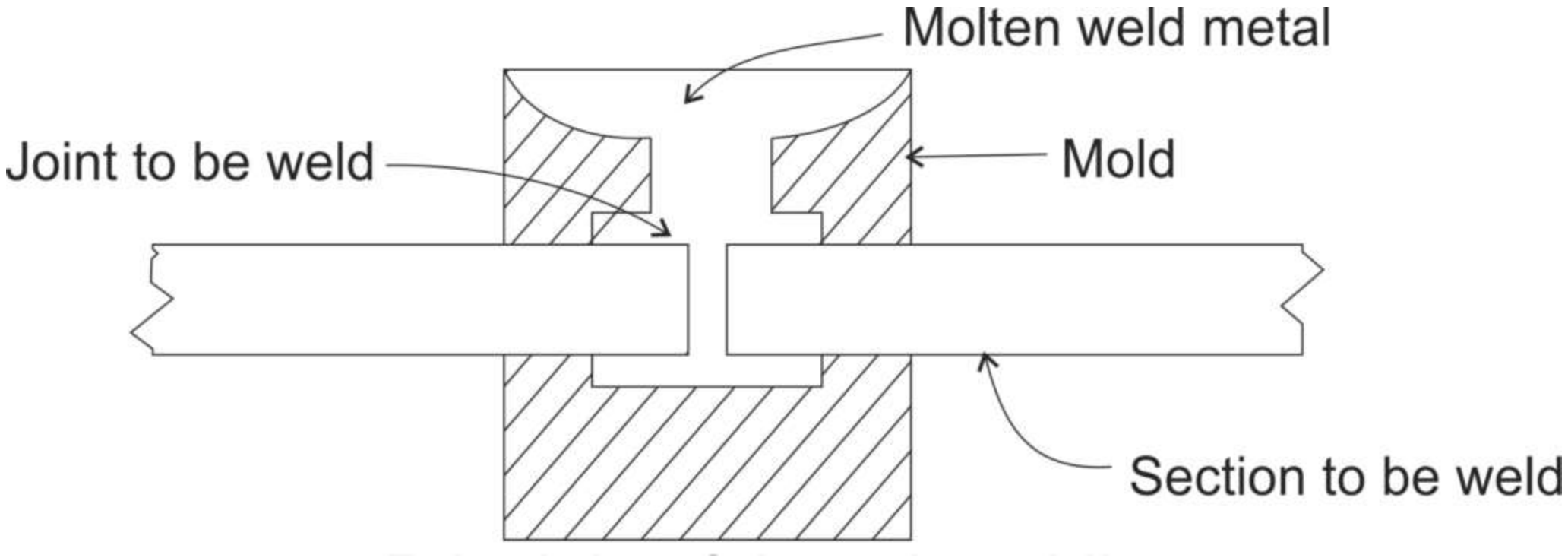
- **Advantages:**
- No melting, so avoids intermetallic formation.
- High-speed process.
- Good mechanical bonding strength.



6. Thermochemical Energy

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- This includes **thermit welding**, where heat is produced by a chemical reaction between aluminum powder and metal oxides (usually iron oxide).
- *Thermit Welding*
- Produces molten metal at ~2500°C.
- The molten steel flows into the joint to fuse the components.
- Commonly used for rail tracks, large forgings, and heavy structural components.
- **Advantages:**
- No external power required.
- High-strength joints.
- Useful for on-site welding of massive sections.


Molten weld metal
Joint to be weld
Mold
Section to be weld

Heat Input in Welding

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$$\text{Heat Input (kJ/mm)} = \frac{V \times I \times 60}{S \times 1000}$$

Where:
- **V** = Arc voltage (Volts)
- **I** = Welding current (Amperes)
- **S** = Welding speed (mm/min)

Heat input is one of the most critical parameters in the welding process. It refers to the amount of thermal energy supplied to the base material per unit length of the weld. The heat input directly influences the **microstructure**, **mechanical properties**, **residual stresses**, **distortion**, and **defects** in the welded joint. A precise control of heat input is essential to ensure a high-quality and defect-free weld.

Definition of Heat Input

Heat Input (Q) is the measure of thermal energy delivered to the workpiece per unit length of weld.
It is typically calculated using the formula:

Factors Affecting Heat Input

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- Several process variables influence the total heat input during welding:
- **Welding Current (I):**
  - A higher current increases the heat generated at the arc.
  - Excessive current can cause deeper penetration but may lead to burn-through.
- **Arc Voltage (V):**
  - Higher voltage increases the arc length, broadens the weld bead, and adds more heat.
- **Welding Speed (S):**
  - Slower speed increases heat input per unit length.
  - Faster welding reduces heat input and results in a narrow bead.
- **Arc Efficiency (η):**
  - Represents the effectiveness of energy transfer from the arc to the workpiece.
  - Depends on the process type and shielding environment.

Effects of Heat Input on Weld Quality

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- ***1.*** *Microstructure*
- High heat input results in **coarser grains** in the heat-affected zone (HAZ), reducing toughness.
- Low heat input leads to **finer grains**, which improve strength but may cause lack of fusion.
- ***2.*** *Mechanical Properties*
- Tensile strength and toughness are sensitive to cooling rates, which depend on heat input.
- Excessive heat can lead to softening of the base material or embrittlement.
- ***3.*** *Distortion and Residual Stresses*
- High heat input causes **greater thermal expansion and contraction**, leading to warping and residual stresses.
- Controlled heat input helps minimize distortion.
- ***4.*** *Weld Penetration and Fusion*
- Adequate heat input ensures proper fusion and penetration.
- Too little heat results in lack of fusion or incomplete penetration.
- ***5.*** *Porosity and Cracking*
- Improper heat input can trap gases, leading to porosity.
- High heat with rapid cooling may cause **hot cracking** or **cold cracking**.

Power Density in Welding

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Power density is a crucial concept in welding that directly influences the effectiveness and quality of the welding process. It refers to the **amount of power delivered per unit area** at the weld zone. Different welding processes deliver energy in various ways, and understanding power density helps in selecting the appropriate process for a specific application, especially when welding delicate, thick, or dissimilar materials.

Definition of Power Density

- **Power Density** is defined as the amount of **power per unit area** delivered by the heat source to the workpiece surface during welding.

Arc Polarity in Welding

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In arc welding processes that use **Direct Current (DC)**, one of the most important variables that affect the arc behavior and weld quality is **polarity**. Arc polarity determines **how the electrical current flows between the electrode and the workpiece**. It significantly influences arc characteristics such as **heat distribution**, **penetration**, **weld bead shape**, and **metal deposition rate**.

What is Polarity in Welding?

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- In welding, **polarity** refers to the direction of current flow in a **direct current (DC)** circuit—i.e., whether the electrode is positive or negative with respect to the workpiece.
- In **AC welding**, the polarity continuously alternates (changes 60 times per second in a 60 Hz system), while in **DC welding**, the polarity is fixed and can be chosen as either:
- **DCEN**: Direct Current Electrode Negative (also called **Straight Polarity**)
- **DCEP**: Direct Current Electrode Positive (also called **Reverse Polarity**)

Types of Arc Polarity

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- **1. Direct Current Electrode Negative (DCEN) (**Straight Polarity**)**
- The **electrode is connected to the negative terminal** of the power source.
- The **workpiece is connected to the positive terminal**.
- **Heat Distribution**:
- Approximately **two-thirds (66%) of the heat** is generated at the **positive terminal (workpiece)**.
- About **one-third (33%) of the heat** is generated at the **negative terminal (electrode)**.
- **Applications and Effects**:
- **Higher penetration** in the base metal due to more heat at the workpiece.
- Lower electrode melting rate.
- Suitable for **thicker materials** and deep welds.
- Commonly used in **TIG welding of steels**.

2. Direct Current Electrode Positive (DCEP) (Reverse Polarity)

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- The **electrode is connected to the positive terminal** of the power source.
- The **workpiece is connected to the negative terminal**.
- **Heat Distribution**:
- **Two-thirds (66%) of the heat** is concentrated at the **electrode**.
- **One-third (33%) of the heat** at the **workpiece**.
- **Applications and Effects**:
- **Shallower penetration**, but **higher metal deposition rate**.
- Electrode melts faster—suitable for **thin materials**.
- Helpful in **cleaning action** during welding of **aluminum and magnesium** (in TIG welding), as it removes oxide layers from the surface.
- Used in **SMAW** and **MIG** welding with certain electrodes.

3. Alternating Current (AC)

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- In **AC welding**, the polarity **reverses 50–60 times per second** (depending on the frequency of the supply).
- The electrode is **alternately positive and negative**.
- **Heat Distribution**:
- Balanced over time between the electrode and the workpiece.
- **Applications and Effects**:
- Useful for welding **magnetized materials** or in applications where **electromagnetic arc blow** is a concern.
- Often used in **TIG welding of aluminum** with **balancing cleaning and penetration**.
- Suitable for **general-purpose welding**.

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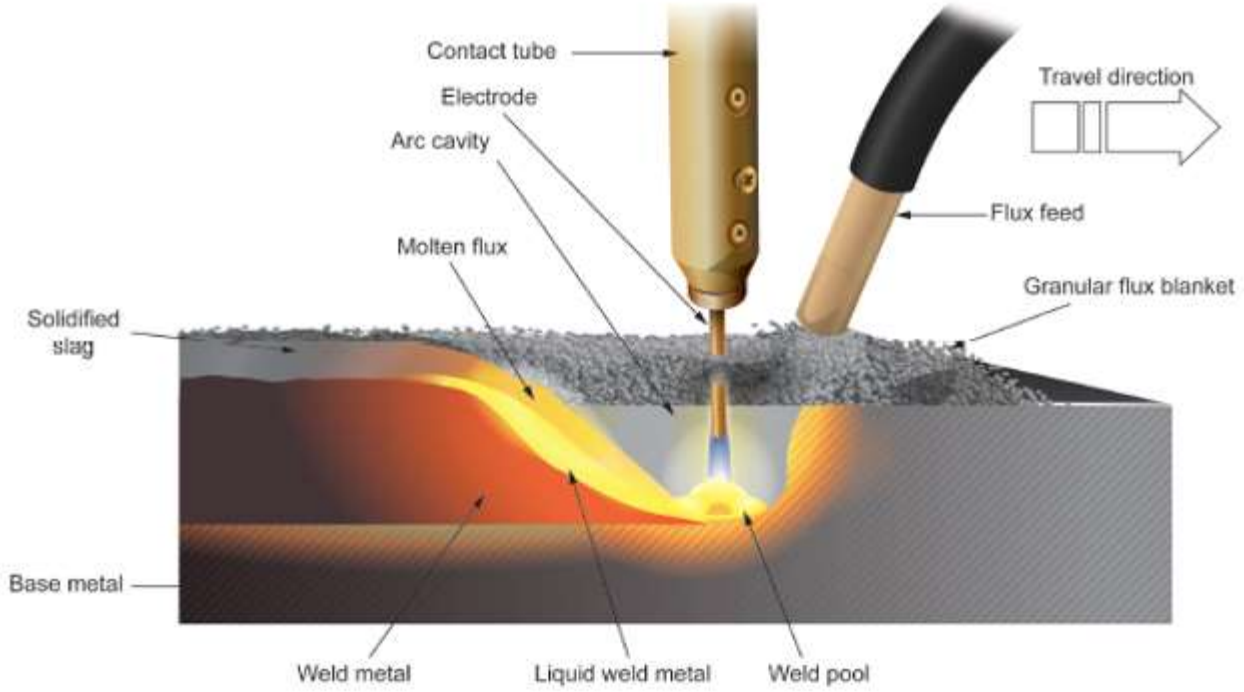
Unit 2

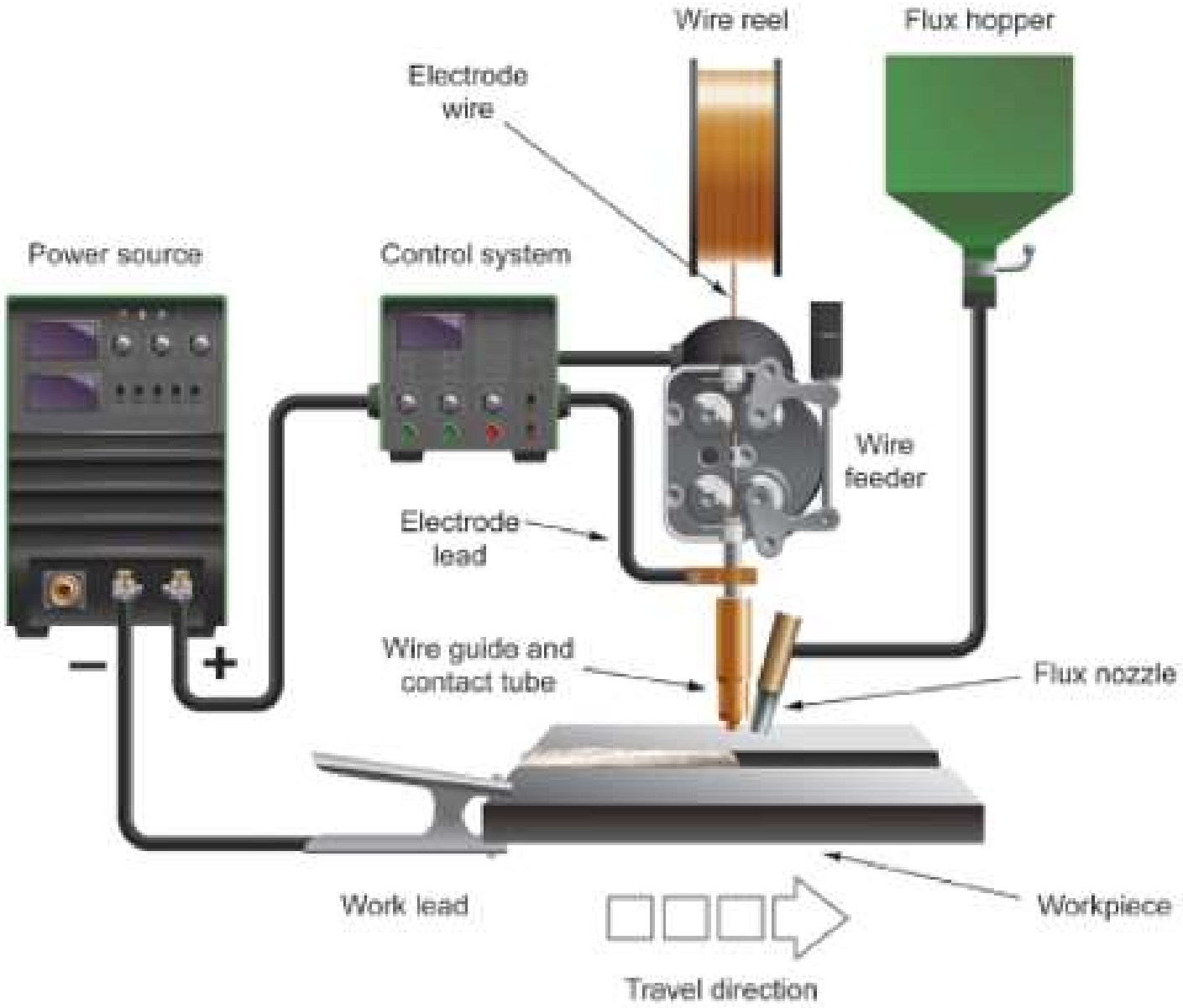
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Submerged Arc Welding Process



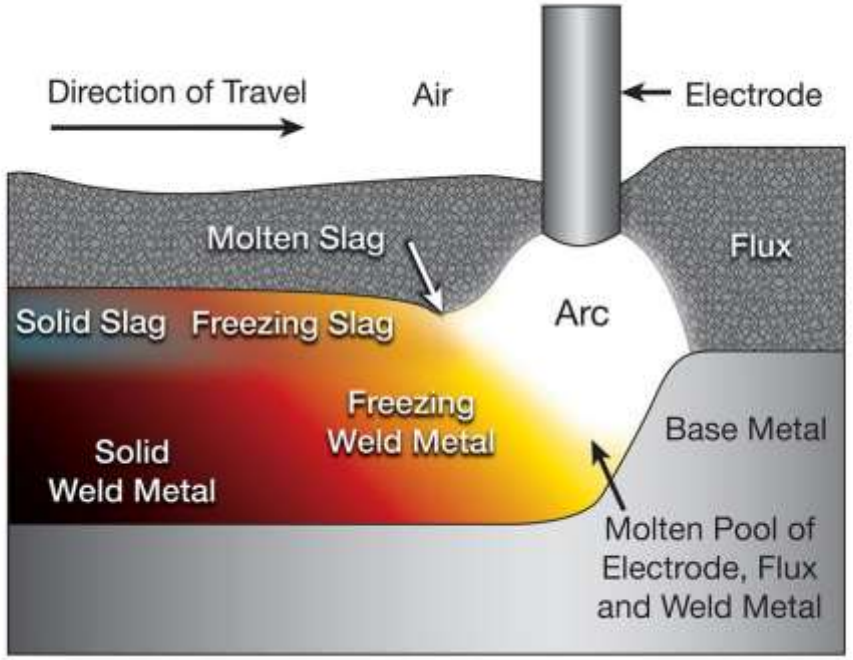
- Submerged arc welding is an arc welding process in which heat is generated by an arc which is produced between bare consumable electrode wire and the workpiece.
- The arc and the weld zone are completely covered under a blanket of granular, fusible flux which melts and provides protection to the weld pool from the atmospheric gases.




Wire reel
Flux hopper
Electrode wire
Power source
Control system
Wire feeder
Electrode lead
Wire guide and contact tube
Flux nozzle
Work lead
Workpiece
Travel direction

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- The molten flux surrounds the arc thus protecting arc from the atmospheric gases.
- The molten flux flows down continuously and fresh flux melts around the arc.
- The molten flux reacts with the molten metal forming slag and improves its properties and later floats on the molten/solidifying metal to protect it from atmospheric gas contamination and retards cooling rate.



- Extremely high welding currents can be used without the danger of spatter and atmospheric contamination giving deep penetration with high welding speeds.
- It is found that the desired composition of the weld metal can be more economically obtained through adding alloying elements in the flux and using a relatively unalloyed wire as compared with welding with alloyed wire and ordinary flux.





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- Submerged arc welding head may be mounted on self-propelled tractors carrying a flux hopper and the coiled electrode. A suction device may also be carried to recover the unused flux for reuse.



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- Since the end of the electrode and the welding zone are completely covered at all times during the actual welding operation, the weld is made without the sparks, spatter, smoke or flash commonly observed in other arc welding processes.



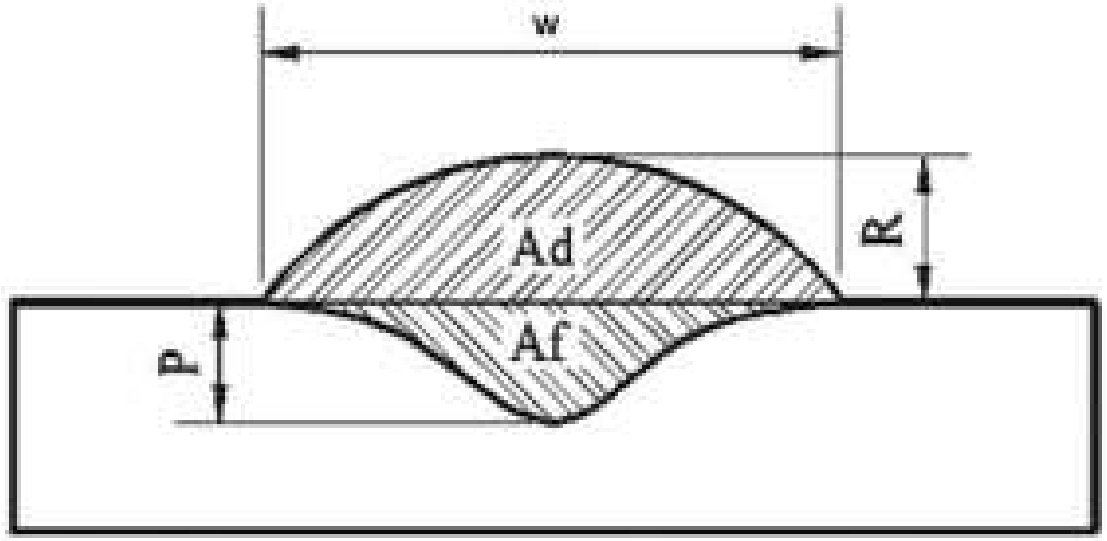
- Electrode wires and fluxes are two major consumables. Wires of structural steel are coated with copper to protect it from atmospheric corrosion and increasing its current carrying capacity while stainless steel wires are not coated with copper.



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- Flux in submerged arc welding performs more or less the similar functions as the electrode coating in the case of MMA welding, except from generation of shielding gas.
- However, these fluxes perform additional function of pickup or loss of alloying elements through gas metal and slag metal reactions as the molten flux gets sufficient time to react with molten metal and performs above reactions and then forming slag.
- Some fluxes require baking before use, to remove moisture which might have been absorbed during storage.
- Such fluxes should be baked as per manufacturer's recommendations or at 250–300 ° C for 1 - 2 hours duration before use.

- Electrode wire size, welding voltage, current and speed are four most important welding variables apart from flux.
- Welding current is the most influential variable as it controls electrode melting rate, depth of penetration and the amount of base metal fused.



P-Penetration, R-Reinforcement, W-Width

% Dilution = $[A_f/(A_f+A_d)] \times 100$

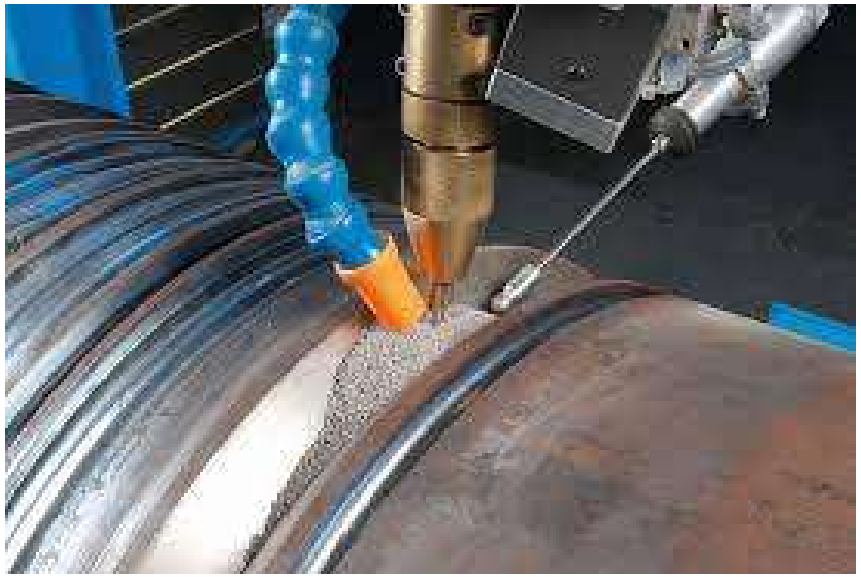
- Submerged arc welding process has high deposition rate with high depth of penetration.
- This is continuous welding process with no interruptions as electrode wire is supplied through coil on a spool.
- Welding is carried out without sparks, smoke or spatter. Weld bead is very clean and smooth.
- Welds produced are of high quality with good mechanical and metallurgical characteristics.





- As the arc is not visible, being covered with the layer of slag, so it necessitates accurate guidance of the welding head on the weld groove, failing which an improper fusion will result.

- Circumferential welds cannot be made in small diameter components because the flux falls away.



- It is widely being used in shipbuilding, offshore, structural and pressure vessel industries.
- General fabrication such as fabrication of pipes, penstocks, LPG cylinders, bridge girders and other structures are produced by SA welding.
- Surfacing for reclamation of worn out parts or for deposition of wear or corrosion resistant layers or for hardfacing layers also employ submerged arc process.





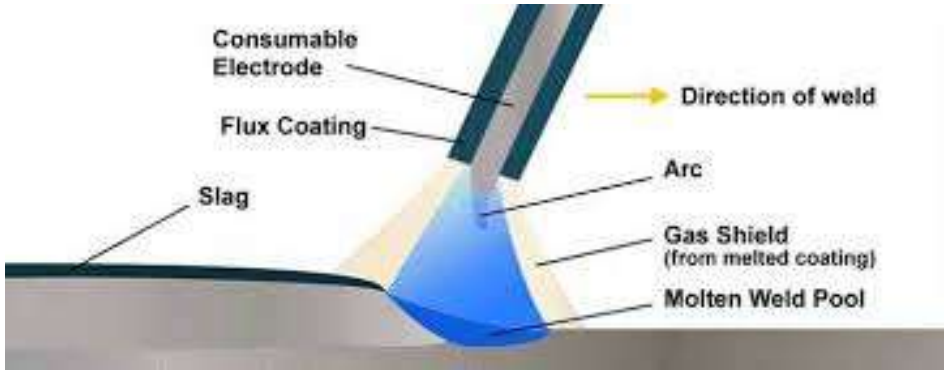
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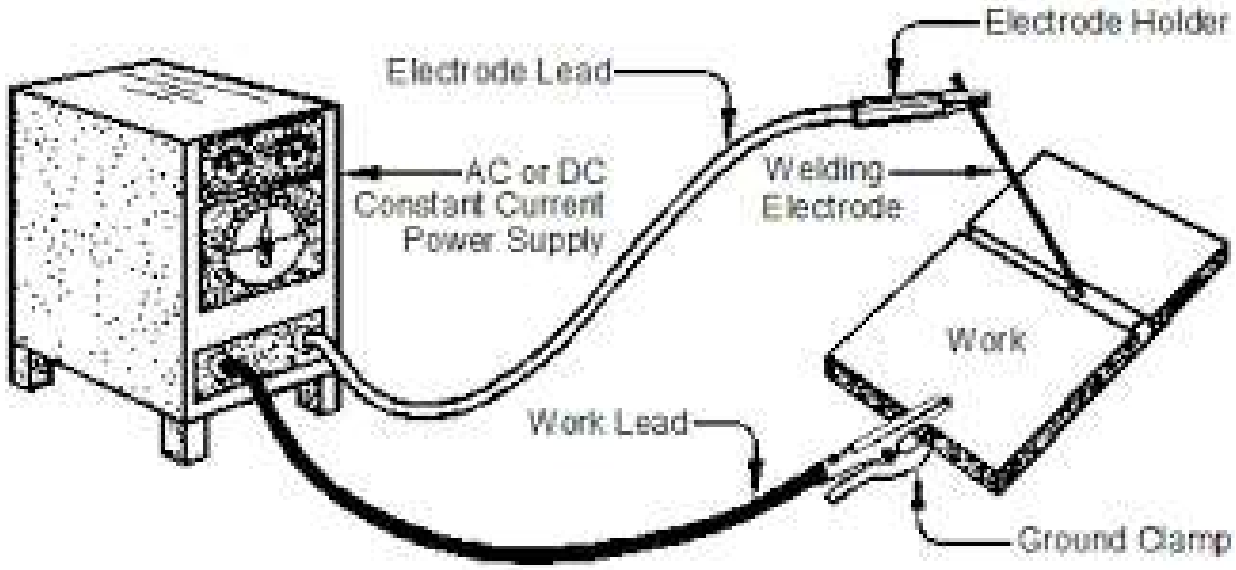
SHIELDED METAL ARC WELDING

THE PROCESS

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- Shielded metal arc welding (SMAW) is a process that melts and joins metals by heating them with an arc established between a sticklike covered electrode and the metals.
- It is often called *stick welding*.
- The electrode holder is connected through a welding cable to one terminal of the power source and the workpiece is connected through a second cable to the other terminal of the power source




Electrode Holder
Electrode Lead
AC or DC
Constant Current
Power Supply
Welding
Electrode
Work
Work Lead
Ground Clamp



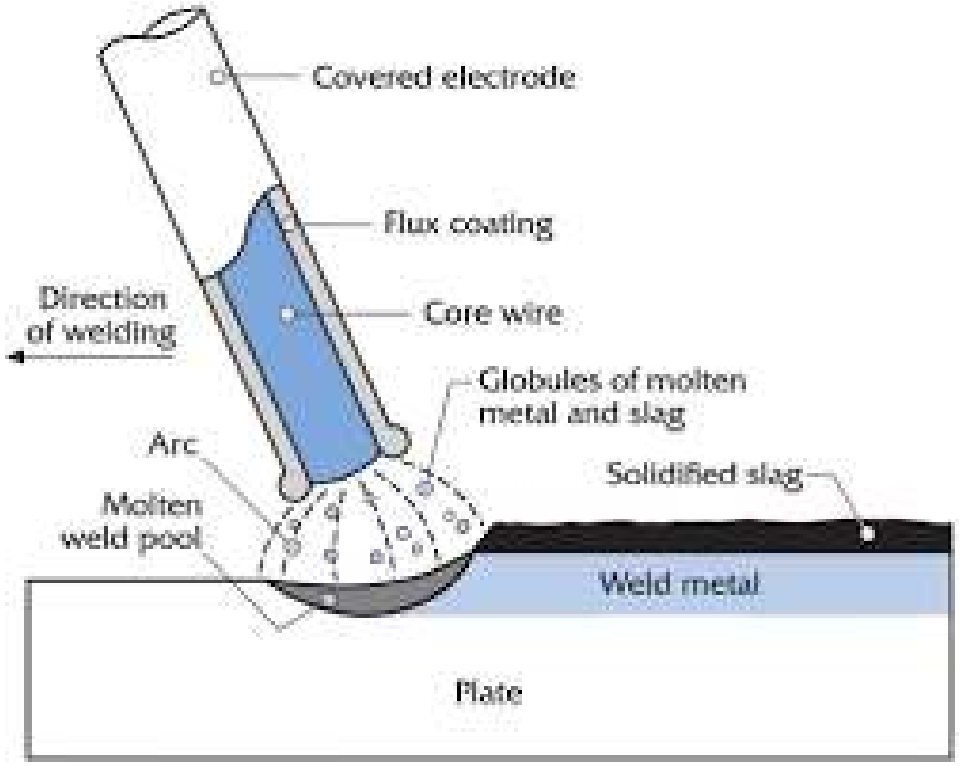

ARCRAFT



THE PROCESS

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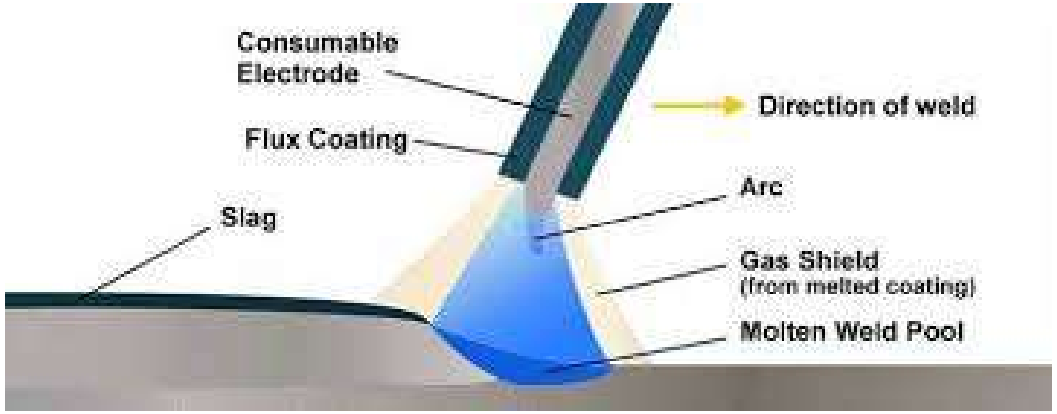
- The core of the covered electrode, the core wire, conducts the electric current to the arc and provides filler metal for the joint.
- For electrical contact, the top 1.5 cm of the core wire is bare and held by the electrode holder.
- The electrode holder is essentially a metal clamp with an electrically insulated outside shell for the welder to hold safely.



THE PROCESS

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- The heat of the arc causes both the core wire and the flux covering at the electrode tip to melt off as droplets.
- The molten metal collects in the weld pool and solidifies into the weld metal.
- The lighter molten flux, on the other hand, floats on the pool surface and solidifies into a slag layer at the top of the weld metal.

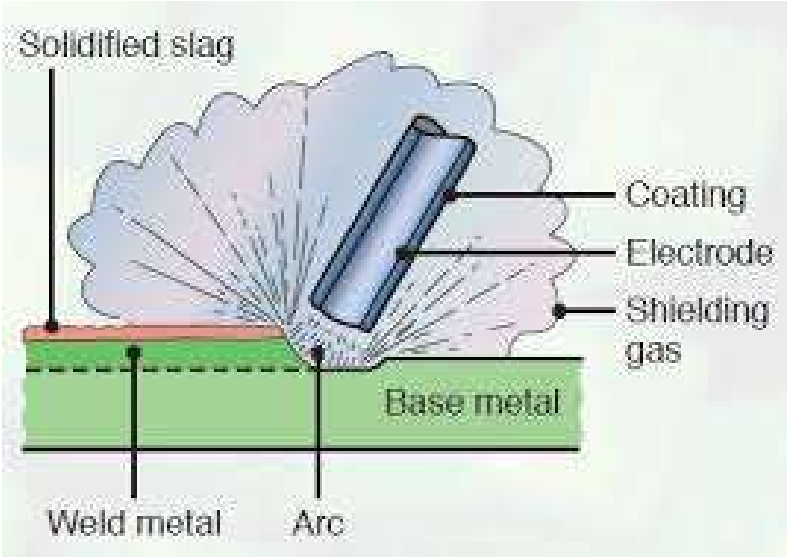


FUNCTIONS OF ELECTRODE COVERING

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A. Protection

- It provides a gaseous shield to protect the molten metal from air.
- For a *cellulose*-type electrode, the covering contains cellulose, $(C_6H_{10}O_5)x$.
- A large volume of gas mixture of H_2, CO, H_2O, and CO_2 is produced when cellulose in the electrode covering is heated and decomposes.
- For a *limestone*- ($CaCO_3$) type electrode, on the other hand,CO_2 gas and CaO slag form when the limestone decomposes.



FUNCTIONS OF ELECTRODE COVERING

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B. Deoxidation

- It provides deoxidizers and fluxing agents to deoxidize and cleanse the weld metal.
- The solid slag formed also protects the already solidified but still hot weld metal from oxidation.

FUNCTIONS OF ELECTRODE COVERING

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C. Arc Stabilization

- It provides arc stabilizers to help maintain a stable arc.
- The arc is an ionic gas (a plasma) that conducts the electric current.
- Arc stabilizers are compounds that decompose readily into ions in the arc, such as potassium oxalate and lithium carbonate.
- They increase the electrical conductivity of the arc and help the arc conduct the electric current more smoothly.

FUNCTIONS OF ELECTRODE COVERING

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D. Metal Addition

- It provides alloying elements and/or metal powder to the weld pool.
- The former helps control the composition of the weld metal while the latter helps increase the deposition rate.

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ADVANTAGES

- The welding equipment is relatively simple, portable, and inexpensive as compared to other arc welding processes.
- For this reason, SMAW is often used for maintenance, repair, and field construction





DISADVANTAGES

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- The gas shield in SMAW is not clean enough for reactive metals such as aluminum and titanium.
- The deposition rate is limited by the fact that the electrode covering tends to overheat and fall off when excessively high welding currents are used.
- The limited length of the electrode (about 35 cm) requires electrode changing, and this further reduces the overall production rate.

Reference: A text book on Welding Metallurgy by Sindo Kou

DISADVANTAGES

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Differences between Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW)

Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
A short and small diameter rod is used as electrode for Shielded Metal Arc Welding (SMAW). Electrode length is typically restricted to 60cm. (300-450 MM)	Gas Metal Arc Welding (GMAW) employs a small diameter but long consumable electrode that comes in the form of a wire. This long wire is wound in a pool.





Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
Short consumable electrode is required to replace frequently. Thus welding cannot be carried out continuously for a longer duration.	Because of very long consumable electrode, it is not required to change frequently and thus welding can be carried out continuously for a longer duration.





Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
This process is not very productive as filler deposition rate is low.	It can deposit filler metal at a very high rate, and hence it is highly productive.



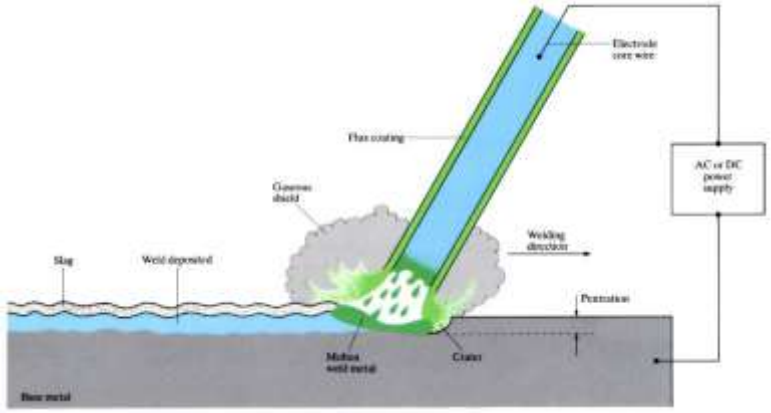


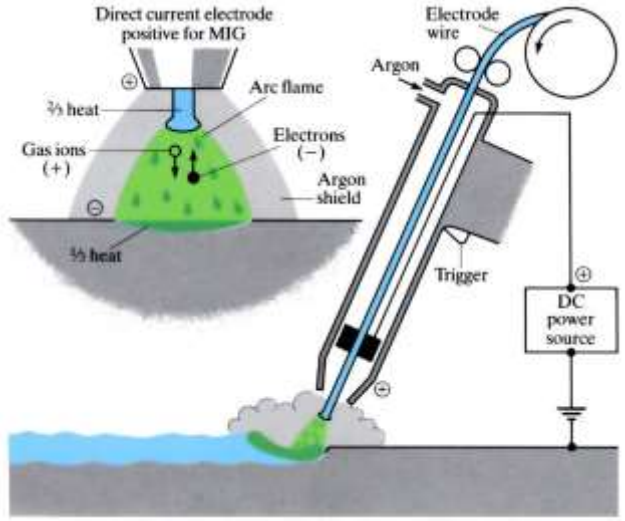
Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
A flux-coated electrode is utilized in SMAW process. The flux layer is thicker.	Bare electrode is utilized in GMAW process. Sometimes a thin anti-corrosive coating layer is deposited on the electrode.



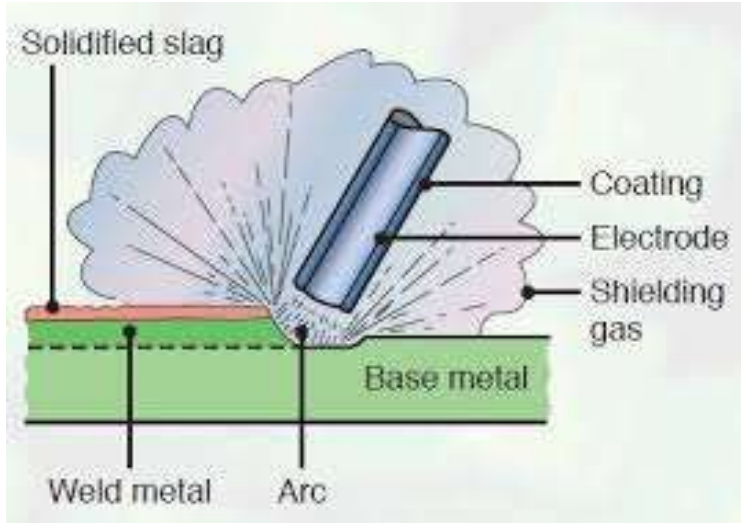


Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
The flux coating of the electrode disintegrates during welding and provides necessary shielding gas.	Here shielding gas is delivered additionally from a gas cylinder to the welding torch via suitable pipeline.





Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
The flux also produces a slag layer on the weld bead. This slag layer protects hot weld metal pool from oxidation, but can also lead to welding defects if get embedded inside the weld bead.	Due to absence of flux, no slag layer forms on the weld bead. So changes of slag inclusion defect is also nil.



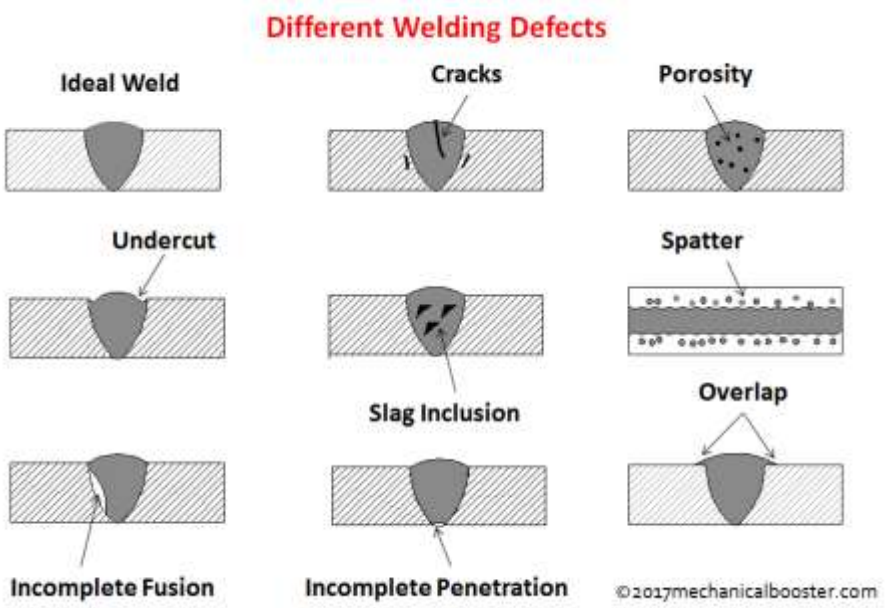


Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
It is versatile as it can be employed in different locations in several orientations (positions).	It is preferred for down-hand or inclined position only.





Shielded Metal Arc Welding (SMAW)	Gas Metal Arc Welding (GMAW)
As the name suggests, Manual Metal Arc Welding (MMAW) is mostly carried out manually. So risk of human error is associated with this process.	GMAW can be easily automated requiring minimum intervention of human operator. Accordingly, it eliminates the risk of human errors.



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Differences between
Shielded Metal Arc Welding (SMAW)
and
Tungsten Inert Gas Welding
(TIG)

SMAW	TIG
SMAW utilizes a consumable electrode.	TIG utilizes a non-consumable electrode.





SMAW	TIG
Filler material is supplied by electrode itself.	Filler metal is required to supply additionally by feeding a filer rod.





SMAW	TIG
Electrode material is usually similar to base material.	Electrode is made of tungsten having some alloying elements. It is irrespective of base material.







SMAW	TIG
It is suitable for homogeneous welding only.	It is suitable for autogenous welding. Can also be performed in homogeneous and heterogamous modes.

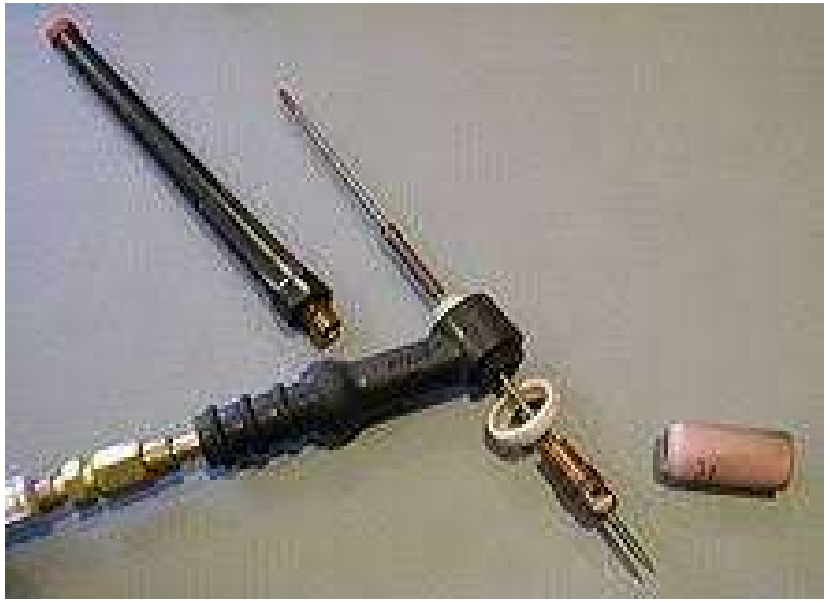




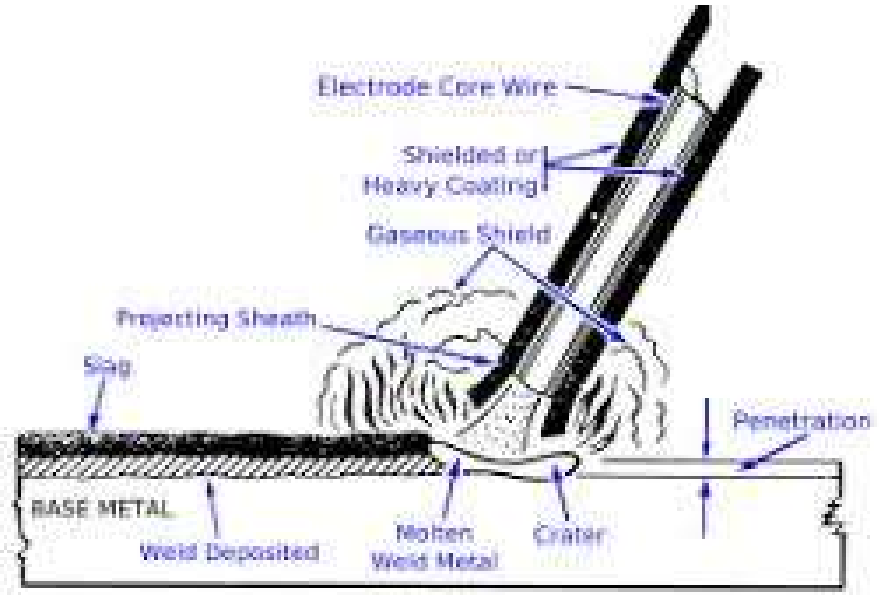
SMAW	TIG
Electrode is coated with suitable flux.	It utilizes bare electrode.

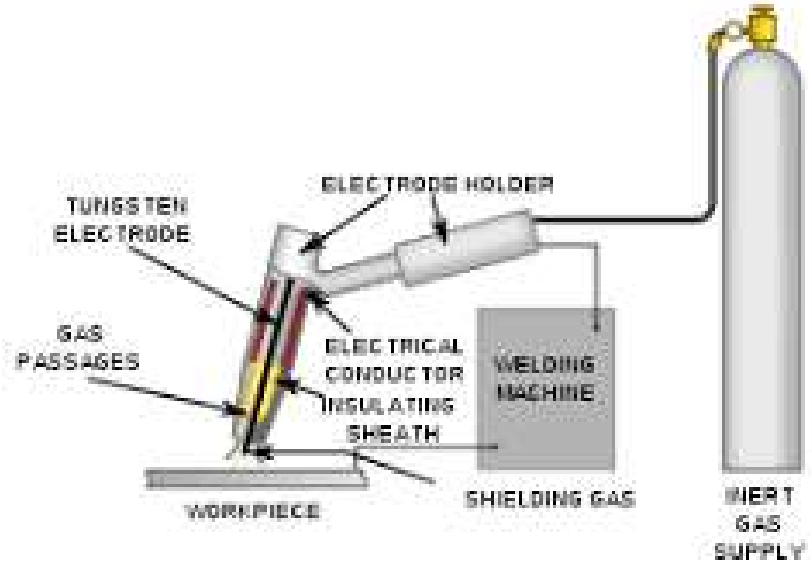






SMAW	TIG
The flux coating of electrode disintegrates during welding to produce shielding gas.	Shielding gas is supplied from external source by means of pipeline and torch/nozzle.





SMAW	TIG
SMAW produces spatter during welding, which hampers appearance.	TIG welding is free from spatter.



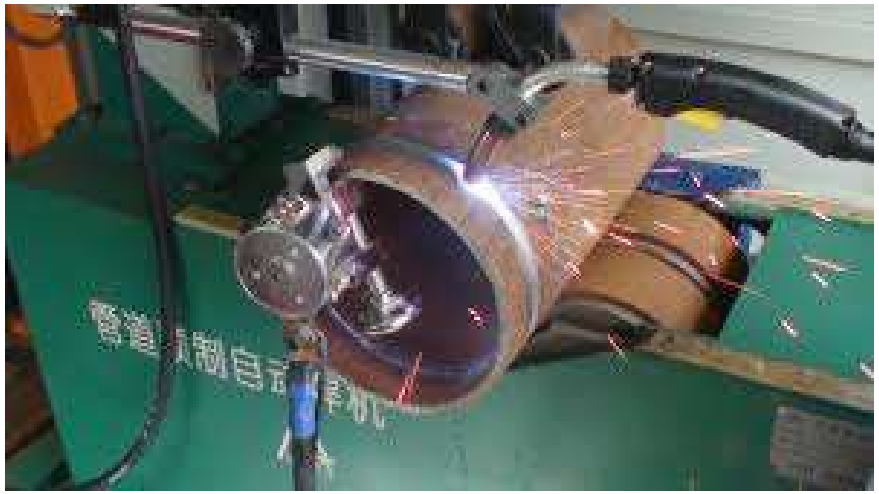






SMAW	TIG
It is performed manually and the process is quite easy.	It can be performed either manually or using some automatic arrangements. The process is not so easy to perform and requires trained welder.





SMAW	TIG
It is comparatively fast process but joint quality is not very good. It is commonly employed in household and general industrial applications.	It is not very fast process but can produce reliable, sound and good quality joint. It is mostly used in industrial sophisticated joining requirements.



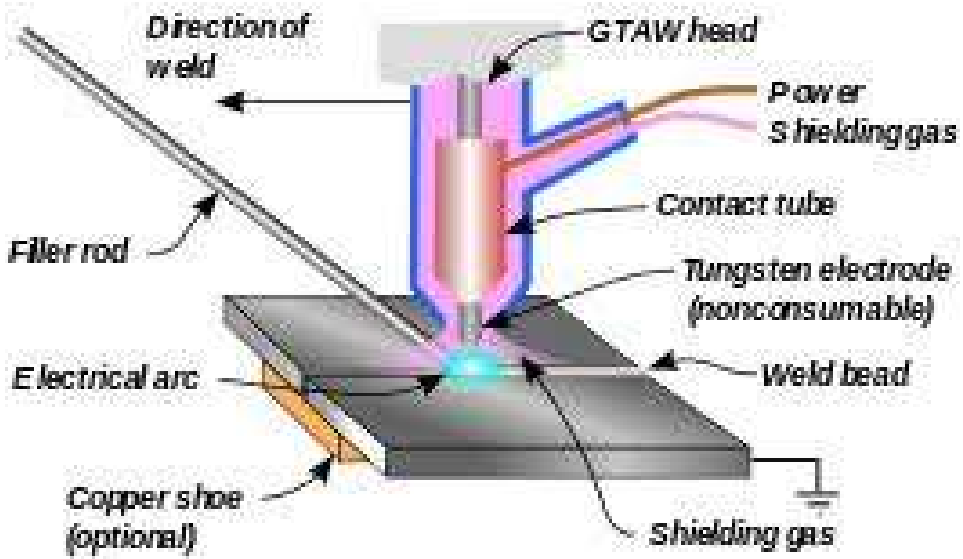


SMAW	TIG
It is flexible and can be carried out in distant location in different welding positions.	It cannot be performed in distant location unless torch can reach there.

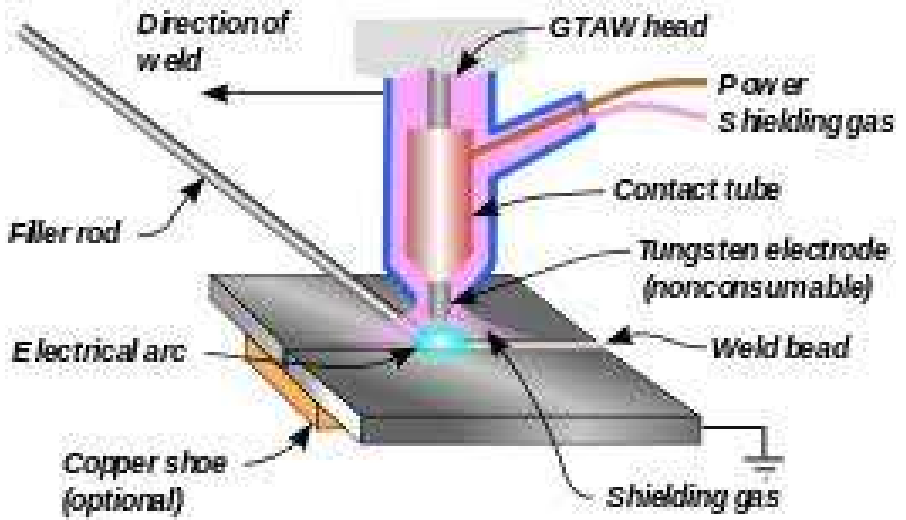
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Differences Between Homogeneous and Heterogeneous Welding

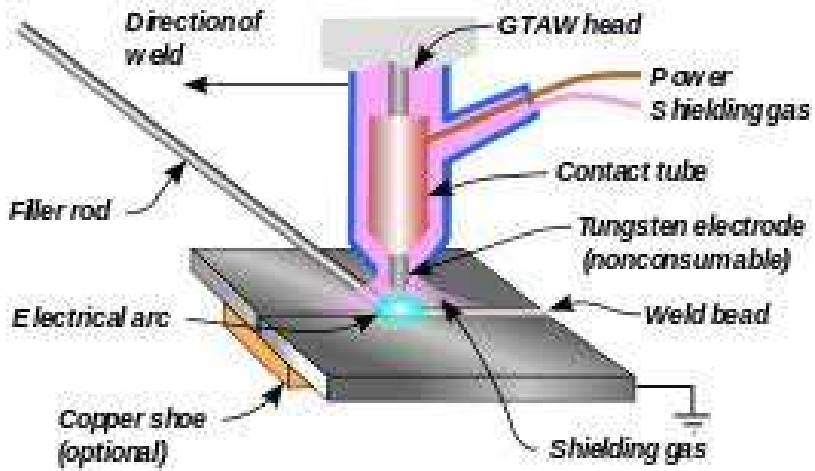
Homogeneous Welding	Heterogeneous Welding
In homogeneous welding, chemical composition of filler material is identical with that of the parent materials.	In heterogeneous welding, chemical composition of filler material is substantially different from that of the parent materials.



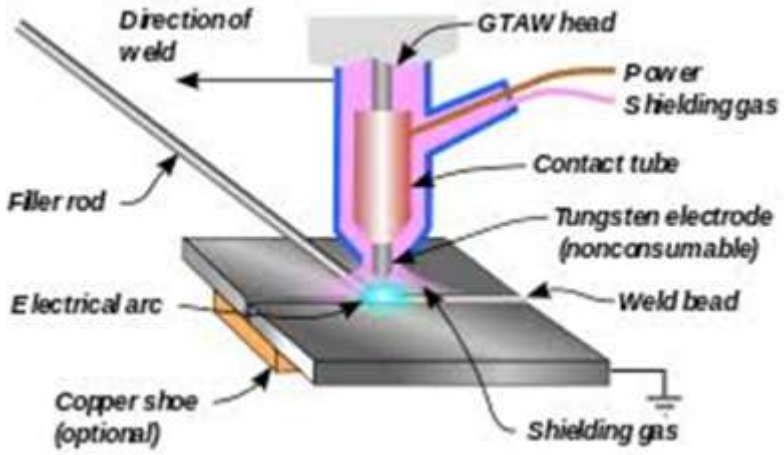
Homogeneous Welding	Heterogeneous Welding
It is not possible while joining dissimilar materials.	Dissimilar metal joining is inherently a heterogeneous welding process.



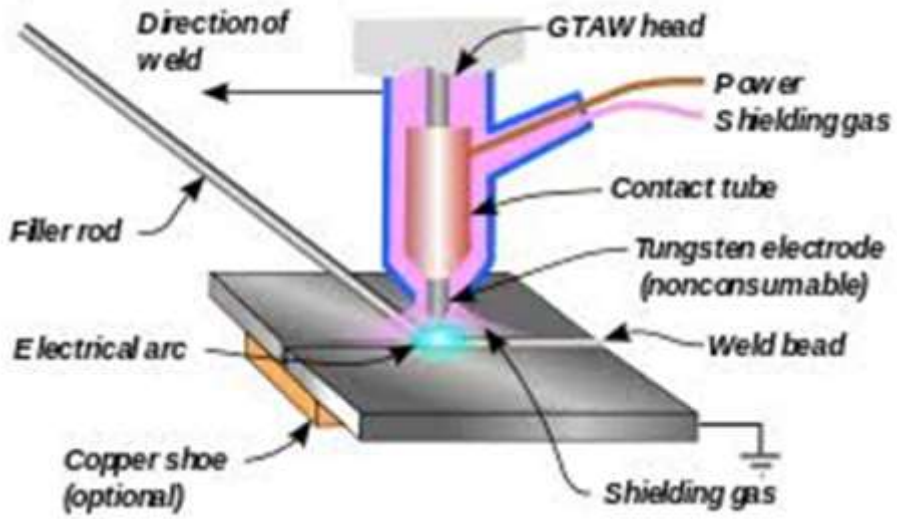
Homogeneous Welding	Heterogeneous Welding
Because of same chemical composition between filler and parent metals, compatibilities in terms of chemical, physical and metallurgical are inherent and obvious.	Here the filler metal should be chosen considering the compatibility issues to obtain a defect-free joint.



Homogeneous Welding	Heterogeneous Welding
Melting point of filler is same with that of the base plates.	Melting points of filler and base plates can be substantially different and this factor should be carefully considered prior to welding.



Homogeneous Welding	Heterogeneous Welding
Physical, chemical and mechanical properties of weld bead are roughly same with that of base metals.	Properties of weld bead can be improved to desired level by suitably selecting a compatible filler.



Homogeneous Welding	Heterogeneous Welding
Joints might be susceptible to corrosion. Corrosion resistance of the joint cannot be improved by homogeneous welding.	Corrosion resistance of the joint can be enhanced by heterogeneous welding by employing a corrosion resistive filler. This is advantageous for marine applications.



Homogeneous Welding	Heterogeneous Welding
No such dilution effect (changes in composition in filler metal due to its mixing with the base metal on weld bead) exists here.	During heterogeneous welding, dilution effect needs to be carefully controlled (otherwise it can lead to inhomogeneity on weld bead).

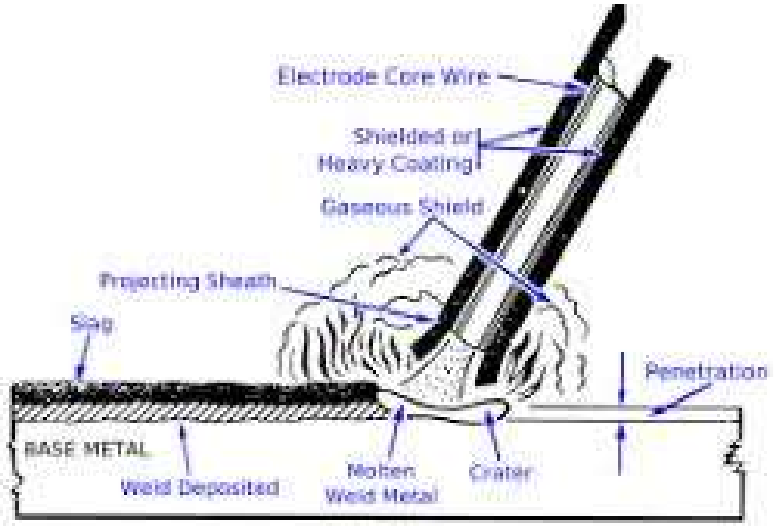
Homogeneous Welding	Heterogeneous Welding
Rate of expansion or contraction is approximately same for molten filler and base metals. So chance of crack formation on the weld bead is also less.	Unequal rate of contraction between molten filler and base metals during solidification can lead to residual stress generation and crack formation on the weld bead.



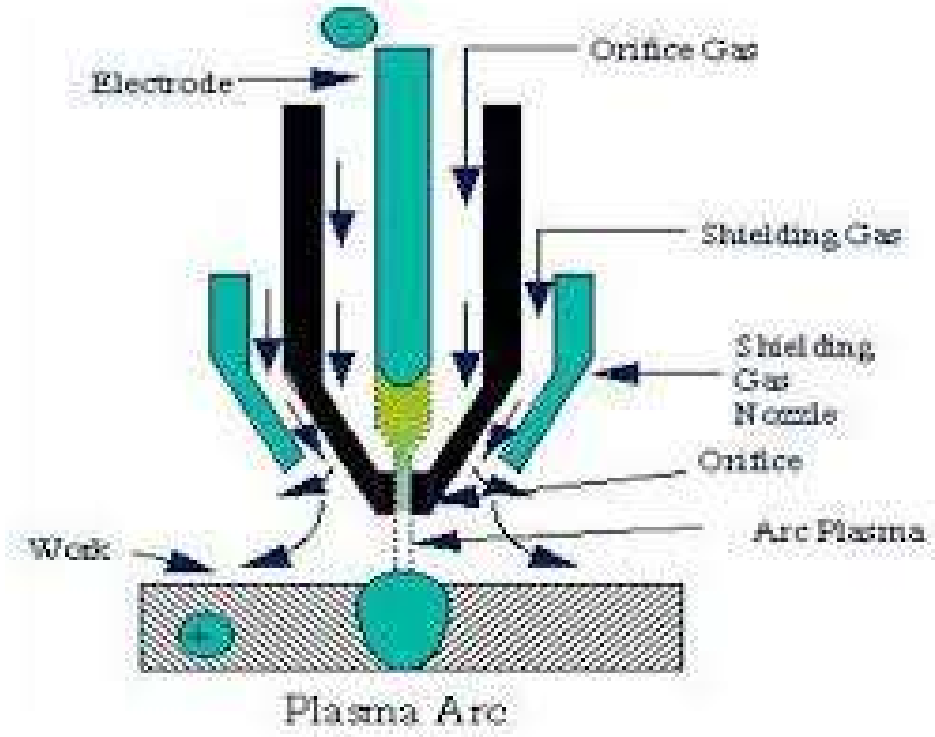
Homogeneous Welding	Heterogeneous Welding
Certain welding processes are suitable for homogeneous welding (for example: SMAW, GMAW, SAW).	Similarly, certain welding processes are suitable for heterogeneous welding (for example: PAW, FSW, LBW).

Homogeneous Welding	Heterogeneous Welding

Shielded Metal Arc Welding (SMAW)

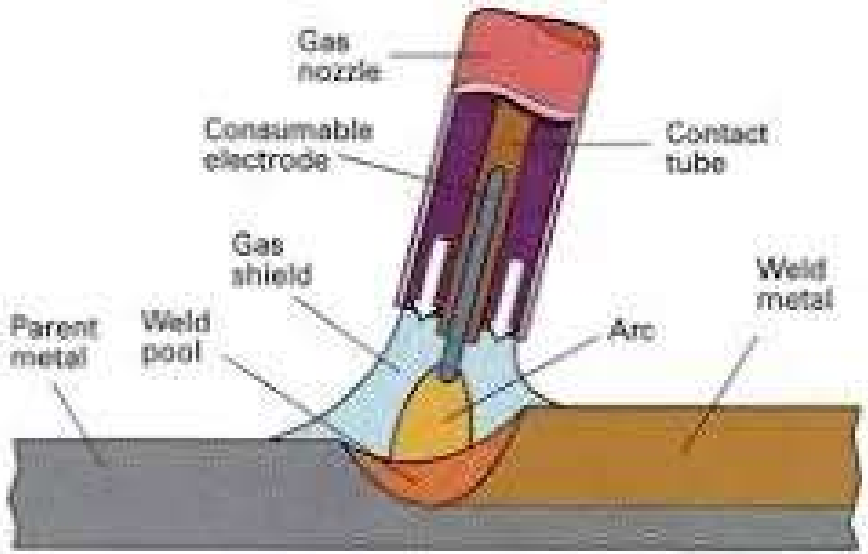


Plasma Arc Welding (PAW)

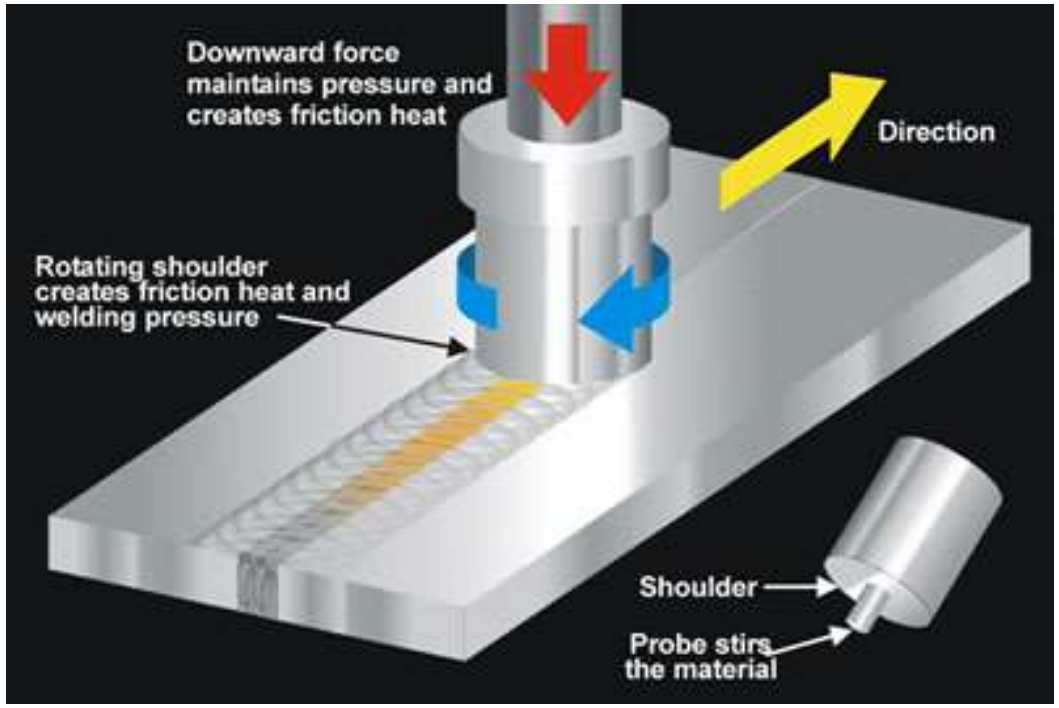


Homogeneous Welding	Heterogeneous Welding

Gas Metal Arc Welding (GMAW)



Friction Stir Welding (FSW)

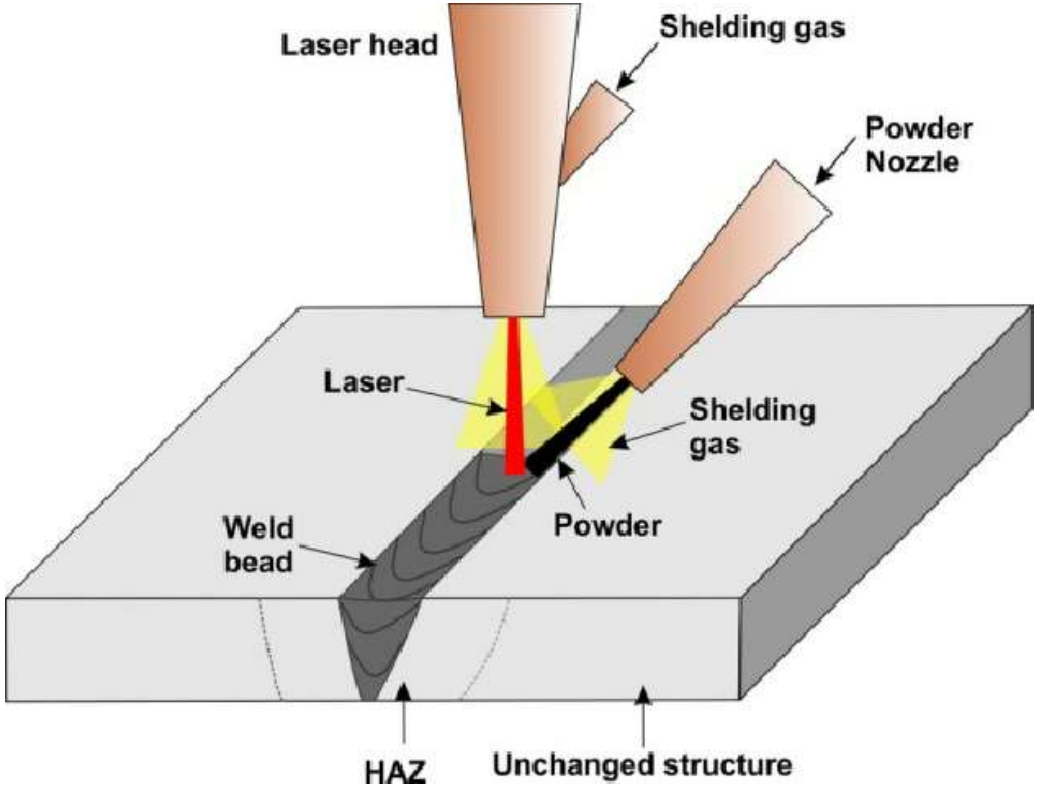


Homogeneous Welding	Heterogeneous Welding

Submerged Arc Welding (SAW)



Laser Beam Welding (LBW)



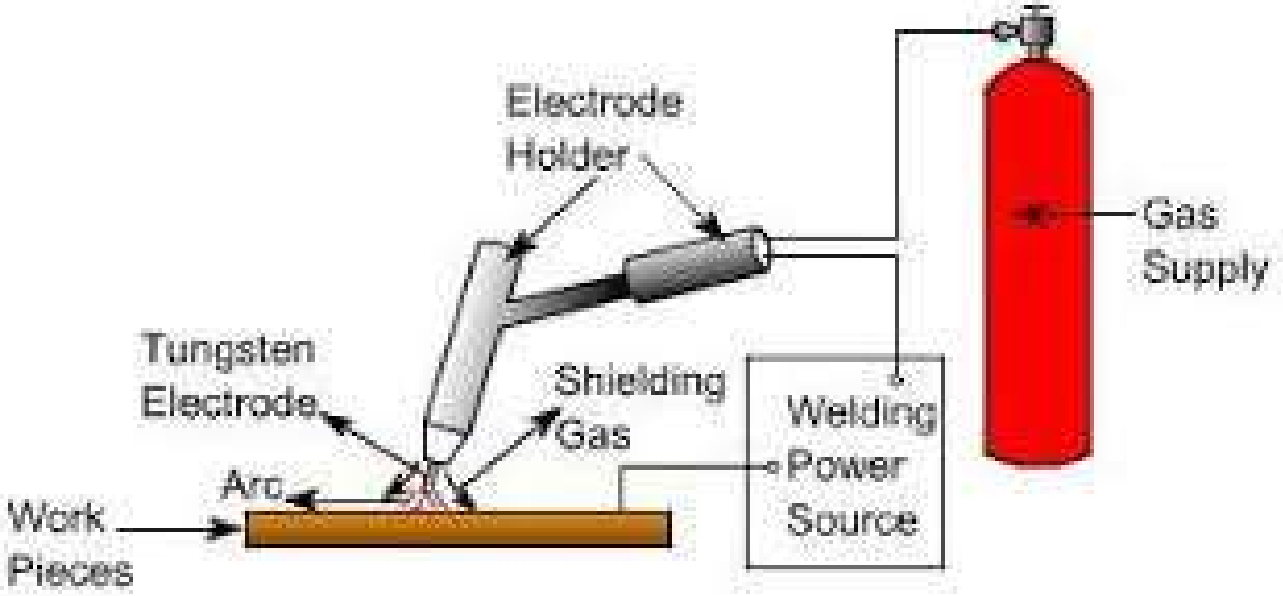
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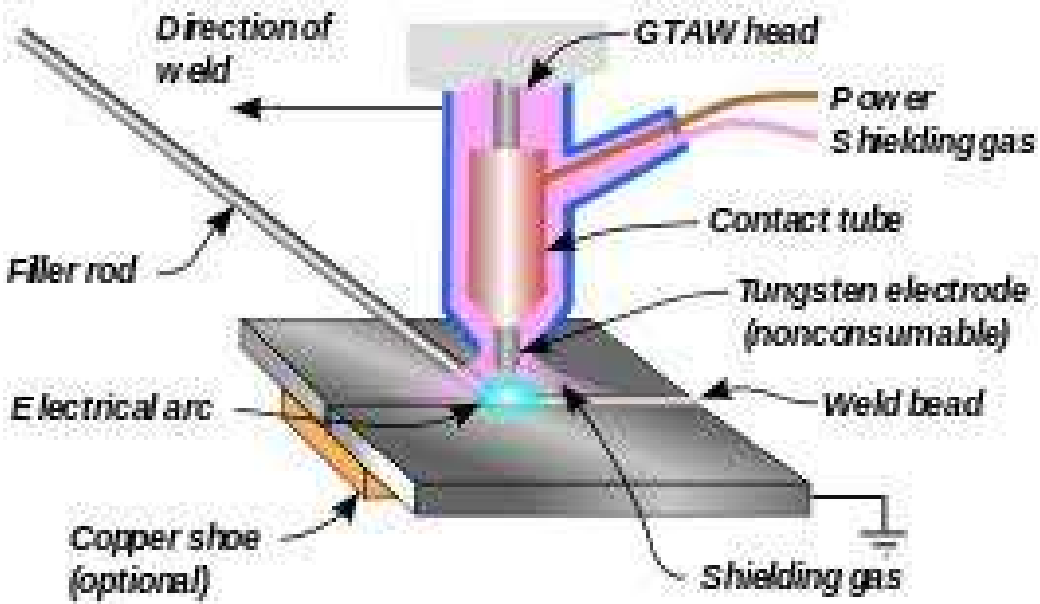
GAS-TUNGSTEN ARC WELDING

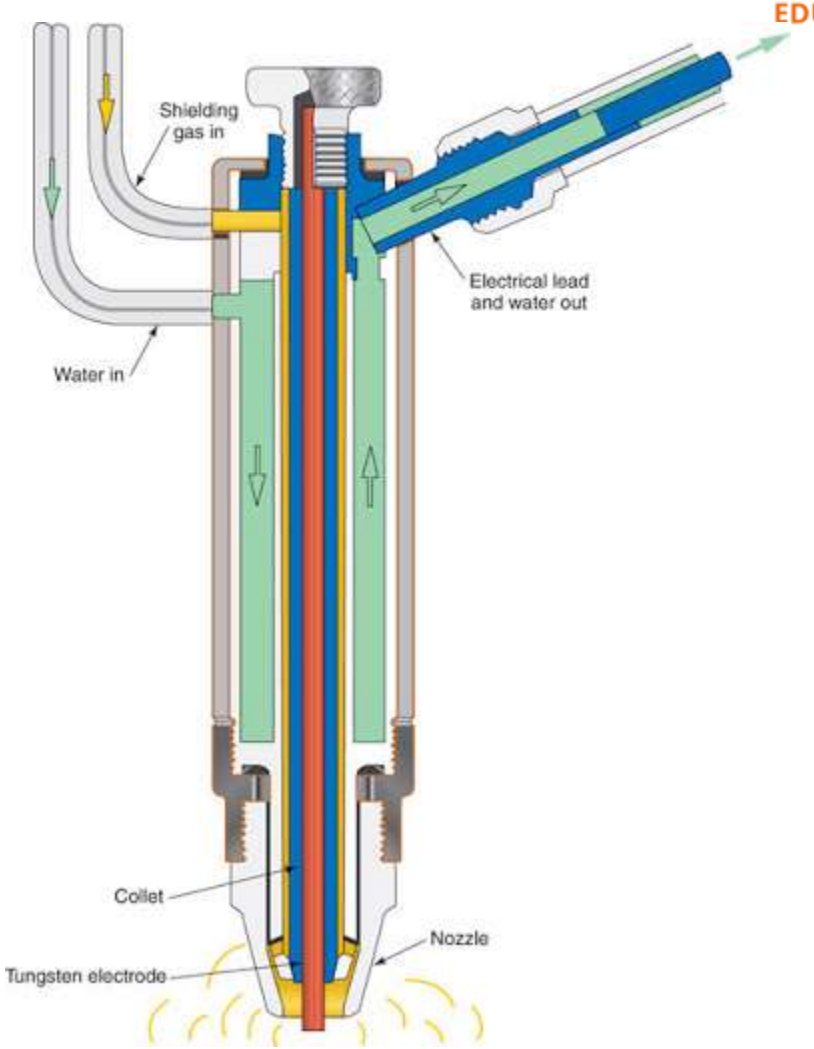
THE PROCESS

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- Gas–tungsten arc welding (GTAW) is a process that melts and joins metals by heating them with an arc established between a non consumable tungsten electrode and the metals.
- The torch holding the tungsten electrode is connected to a shielding gas cylinder as well as one terminal of the power source.
- The tungsten electrode is usually in contact with a water-cooled copper tube, called the contact tube which is connected to the welding cable from the terminal.


Electrode
Holder
Gas
Supply
Tungsten
Electrode
Shielding
Gas
Welding
Power
Source
Arc
Work
Pieces


Direction of
weld
GTAW head
Power
Shielding gas
Contact tube
Filler rod
Tungsten electrode
(nonconsumable)
Electrical arc
Weld bead
Copper shoe
(optional)
Shielding gas


Shielding
gas in
Electrical lead
and water out
Water in
Collet
Nozzle
Tungsten electrode

THE PROCESS

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- The workpiece is connected to the other terminal of the power source through a different cable.
- The shielding gas goes through the torch body and is directed by a nozzle toward the weld pool to protect it from the air.
- Protection from the air is much better in GTAW than in SMAW because an inert gas such as argon or helium is usually used as the shielding gas and because the shielding gas is directed toward the weld pool.

THE PROCESS

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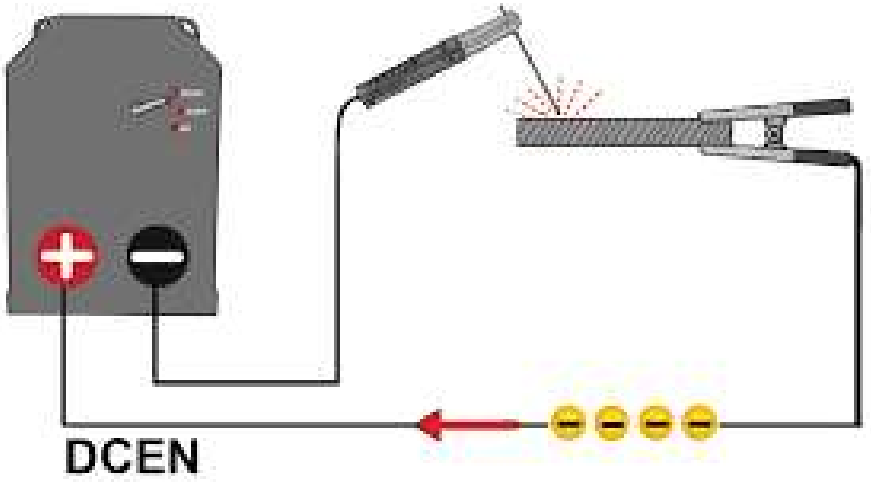
- For this reason, GTAW is also called *tungsten–inert gas* (TIG) welding. However, in special occasions a noninert gas can be added in a small quantity to the shielding gas.
- Therefore, GTAW seems a more appropriate name for this welding process.
- When a filler rod is needed, for instance, for joining thicker materials, it can be fed either manually or automatically into the arc.

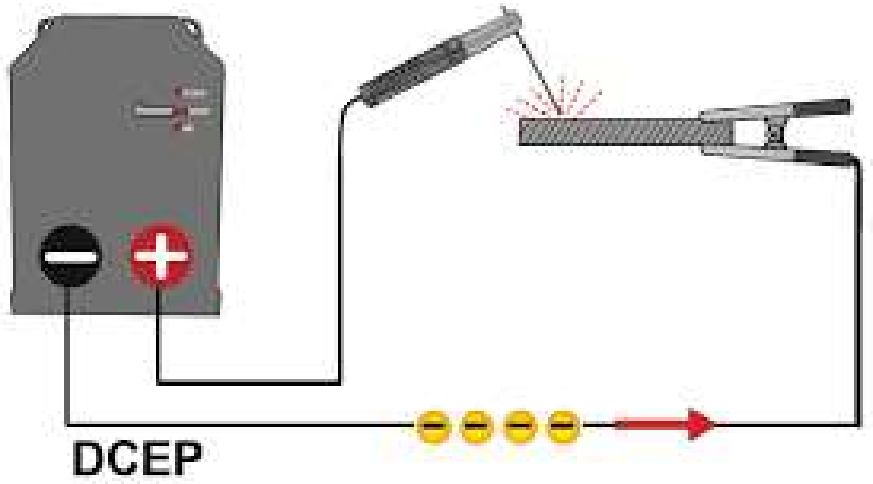
POLARITY

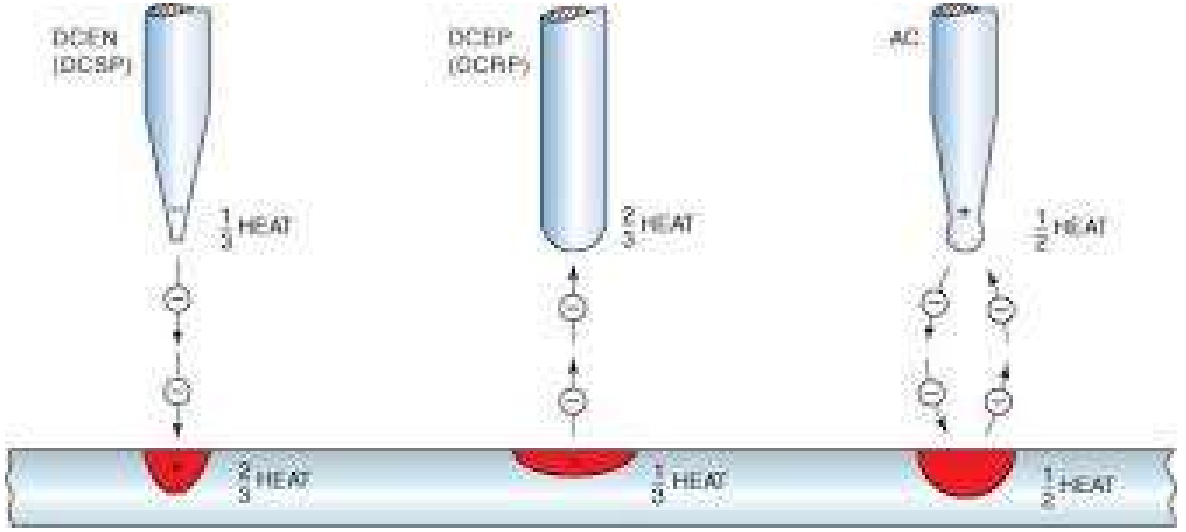
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A. Direct-Current Electrode Negative (DCEN)

- This, also called the *straight polarity*, is the most common polarity in GTAW.
- The electrode is connected to the negative terminal of the power supply.
- Electrons are emitted from the tungsten electrode and accelerated while traveling through the arc.
- When the electron enters the workpiece, an amount of energy equivalent to the work function is released.
- This is why in GTAW with DCEN more power (about two-thirds) is located at the work end of the arc and less (about one-third) at the electrode end.
- Consequently, a relatively narrow and deep weld is produced.


DCEN


DCEP


DCEN
(DCSP)
1/3 HEAT
2/3 HEAT
DCEP
(DCRP)
2/3 HEAT
1/3 HEAT
AC
1/2 HEAT
1/2 HEAT

POLARITY

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B. Direct-Current Electrode Positive (DCEP)

- This is also called the *reverse polarity*. The electrode is connected to the positive terminal of the power source.
- The heating effect of electrons is now at the tungsten electrode rather than at the workpiece.
- Consequently, a shallow weld is produced.
- The positive ions of the shielding gas bombard the workpiece,, knocking off oxide films and producing a clean weld surface.
- Therefore, DCEP can be used for welding thin sheets of strong oxide-forming materials such as aluminum and magnesium, where deep penetration is not required.

ELECTRODES

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- Tungsten electrodes with 2% cerium or thorium have better electron emissivity, current-carrying capacity, and resistance to contamination than pure tungsten electrodes.
- As a result, arc starting is easier and the arc is more stable.
- The electron emissivity refers to the ability of the electrode tip to emit electrons.
- A lower electron emissivity implies a higher electrode tip temperature required to emit electrons and hence a greater risk of melting the tip.



SHIELDING GASES

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- Both argon and helium can be used.
- Since it is easier to ionize argon than helium, arc initiation is easier and the voltage drop across the arc is lower with argon.
- Also, since argon is heavier than helium, it offers more effective shielding and greater resistance to cross draft than helium.
- With DCEP or AC, argon also has a greater oxide cleaning action than helium.
- These advantages plus the lower cost of argon make it more attractive for GTAW than helium.

ADVANTAGES

- Gas–tungsten arc welding is suitable for joining thin sections because of its limited heat inputs.
- It can also be used to weld butt joints of thin sheets by fusion alone, that is, without the addition of filler metals or *autogenous* welding.
- Since the GTAW process is a very clean welding process, it can be used to weld reactive metals, such as titanium and zirconium, aluminum, and magnesium.

DISADVANTAGES

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- The deposition rate in GTAW is low.
- Excessive welding currents can cause melting of the tungsten electrode and results in brittle tungsten inclusions in the weld metal. However, by using preheated filler metals, the deposition rate can be improved.

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Unit 3

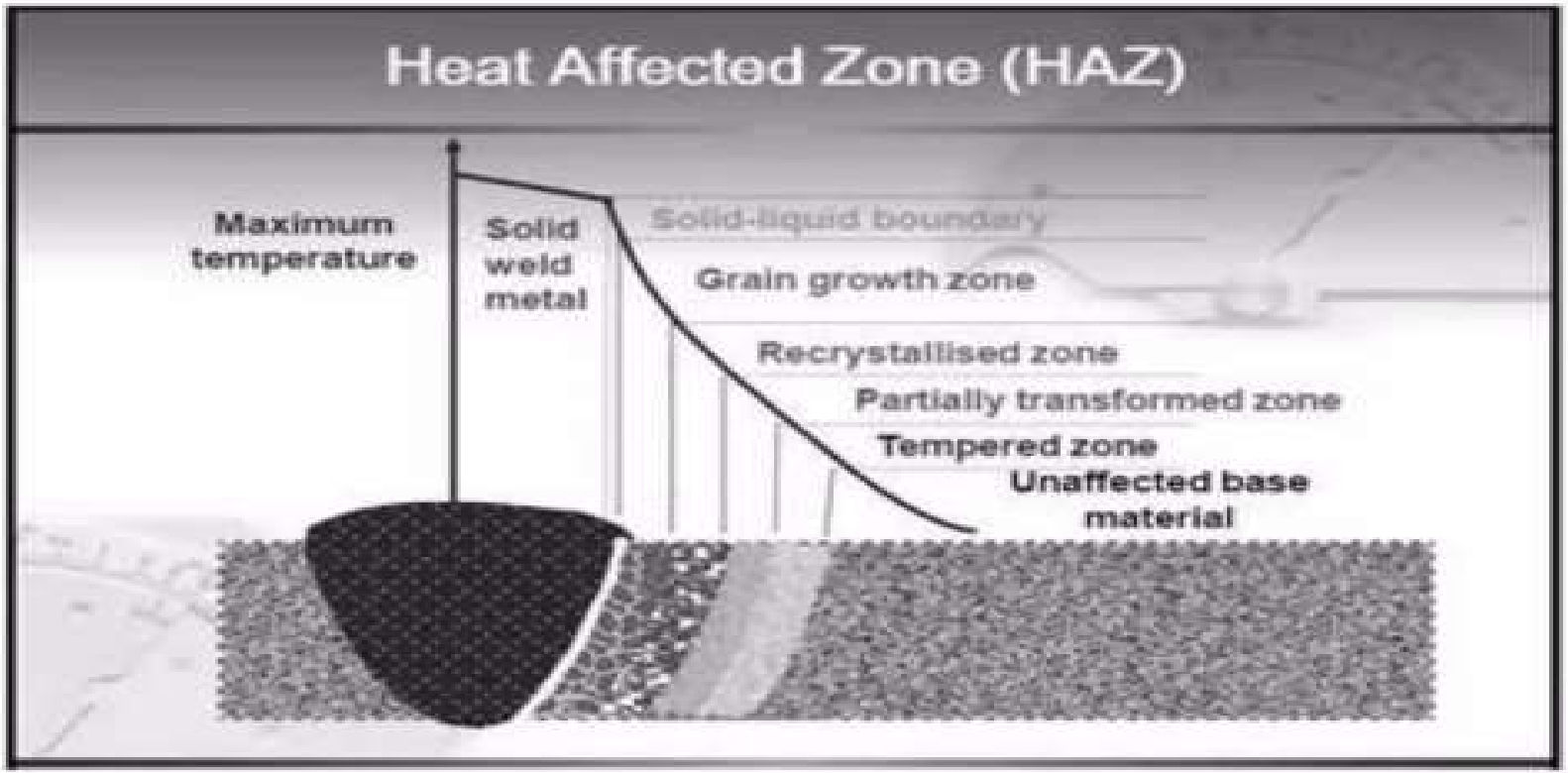
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HEAT AFFECTED ZONES

The heat affected zone (HAZ) is a non-melted area of metal that has undergone changes in material properties as a result of being exposed to high temperatures. These changes in material property are usually as a result of welding or high-heat cutting. The HAZ is the area between the weld or cut and the base (unaffected), parent metal.

The HAZ area can vary in severity and size depending on the properties of the materials, the concentration and intensity of the heat, and the welding or cutting process used.

Heat Affected Zone



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Heat Affected Zone

What are the Causes of Heat-Affected Zones?

1. The heating associated with welding and/or cutting generally uses temperatures up to and often exceeding the temperature of melting of the material in question, depending on the welding process used.

2. However, the heating and cooling thermal cycle associated with these processes is different to whatever processing has occurred with the parent material previously. This leads to a change in microstructure associated with the heating and cooling process.

Heat Affected Zone

3. The size of a heat affected zone is influenced by the level of thermal diffusivity, which is dependent on the thermal conductivity, density and specific heat of a substance as well as the amount of heat going in to the material.
4. Those materials with a high level of thermal diffusivity are able to transfer variations of heat faster, meaning they cool quicker and, as a result, the HAZ width is reduced.
5. On the other hand, those materials with a lower coefficient retain the heat, meaning that that the HAZ is wider.
6. Generally speaking, the extension of the HAZ is dependent on the amount of heat applied, the duration of exposure to heat and the properties of the material itself. When a material is exposed to greater amounts of energy for longer periods the HAZ is larger.

Heat Affected Zone

7. With regard to welding procedures, those processes with low heat input will cool faster, leading to a smaller HAZ, whereas high heat input will have a slower rate of cooling, leading to a larger HAZ in the same material.

8. In addition, the size of the HAZ also grows as the speed of the welding process decreases. Weld geometry is another factor that plays a role in the HAZ size, as it affects the heat sink, and a larger heat sink generally leads to faster cooling.

9. High temperature cutting operations can also cause a HAZ and, similarly to welding procedures, those processes that operate at higher temperatures and slow speeds tend to create a larger HAZ, while lower temperature or higher speed cutting processes tend to reduce the HAZ size.

Heat Affected Zone

10. Different cutting processes have differing effects on the HAZ, regardless of the material being cut.

11. For example, shearing and water jet cutting do not create a HAZ, as they do not heat the material, while laser cutting creates a small HAZ due to the heat only being applied to a small area.

12. Meanwhile, plasma cutting leads to an intermediate HAZ, with the higher currents allowing for an increased cutting speed and thereby a narrower HAZ, while oxyacetylene cutting creates the widest HAZ due to the high heat, slow speed and flame width.

13. Arc welding falls between the two extremes, with individual processes varying in heat input.

Weldability

- The capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure, and to perform satisfactorily in the intended service.
  - » AWS Welding Handbook, Vol. 4, 7th Edition

What is weldabilty

- Weldabilty is the ease with which a material or materials can be welded to give an acceptable joint.
- Ability of a material to be welded by most of the common welding processes,
- retain the properties for which it has been designed

- A steel which can be welded without any real dangerous consequences is said to possess ***Good Weldability.***

- A steel which can not be welded without any dangerous consequences occurring is said to possess ***Poor Weldability.***

- Poor weldability normally generally results in the occurrence of some sort of cracking problem

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Factors which affect weldabilty

- Material type,
- welding parameters amps, volts
- travel speed,
- heat input.

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Other factors affecting weldabilty

- arc welding position
- welding techniques.

When considering any type of cracking mechanism, three elements must be present

1. Stress
2. Restraint
3. Susceptible microstructure

- Residual stress is always present in a weldment, through loacal expansion and contraction
- Restraint may be a local restriction, or through plates being welded to other
- The microstructure is often made susceptible to cracking by the process of welding

- Hydrogen induced HAZ cracking. (C/Mn steels)
- Hydrogen induced weld metal cracking. (HSLA steels).
- Solidification cracking. (All steels)
- Lamellar tearing. (All steels)
- Re heat cracking. (All steels, very susceptible Cr/Mo steels)
- Inter-crystalline corrosion. (stainless steels)

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Weldability is a function of many inter-related factors but these may be summarised as:

- Composition of parent material
- Joint design and size
- Process and technique
- Access

Steels are classified into groups as follows

Plain Carbon Steels

1. Low Carbon Steel 0.01 – 0.3% Carbon

2. Medium Carbon Steel 0.3 – 0.6% Carbon

3. High Carbon Steel 0.6 – 1.4% Carbon

Plain carbon steels contain only iron & carbon as main alloying elements, traces of Mn, Si, Al, S & P may also be present

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An Alloy steel is one that contains more than Iron & Carbon as a main alloying elements

Alloy steels are divided into 2 groups

1. Low Alloy Steels < 7% extra alloying elements

2. High Alloy Steels > 7% extra alloying elements

Carbon: Major element in steels, influences strength,toughness and ductility

Manganese: Secondary only to carbon for strength toughness and ductility, secondary deoxidiser and also acts as a desulphuriser.

Silicon: Primary deoxidiser

Molybdenum: Effects hardenability, and has high creep strength at high temperatures. Steels containing molybdenum are less susceptible to temper brittleness than other alloy steels.

Chromium: Widely used in stainless steels for corrosion resistance, increases hardness and strength but reduces ductility.

Nickel: Used in stainless steels, high resistance to corrosion from acids, increases strength and toughness

The amounts of alloying elements present will also affect the weldability of the material. The *CE* of a given material also depends on its alloying elements

- Higher the *CE*, lower the weldability
- Higher the *CE*, higher the susceptibility to brittleness
- The *CE* is calculated using the following formula

$$CE = C + \frac{Mn+Si}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

$$CE = C + \frac{Mn}{6}$$

FACTORS EFFECTING WELDABILITY

For making a good joint that performs satisfactorily in service, there are so many factors. Some of them are: -

1. Parent metal composition
2. Parent metal thickness
3. Weld metal composition
4. Welding process
5. Welding procedure

FACTORS EFFECTING WELDABILITY Parent metal composition

CE- < 0.35, The steel is weldable using rutile electrode without any pre-heat

CE- 0.35-0.45, Either preheat or low hydrogen electrode is required

CE- 0.45-0.55, Both preheat & low hydrogen electrode is required

CE- > 0.55, The steel is theoretically not weldable unless special care such as preheat, low hydrogen electrode ,post weld heat treatment etc.is taken care of.

FACTORS EFFECTING WELDABILITY

WELDING PROCEDURE

The effects can be summarized as below:-

1. Penetration increases with increased current and reduced travel speed.

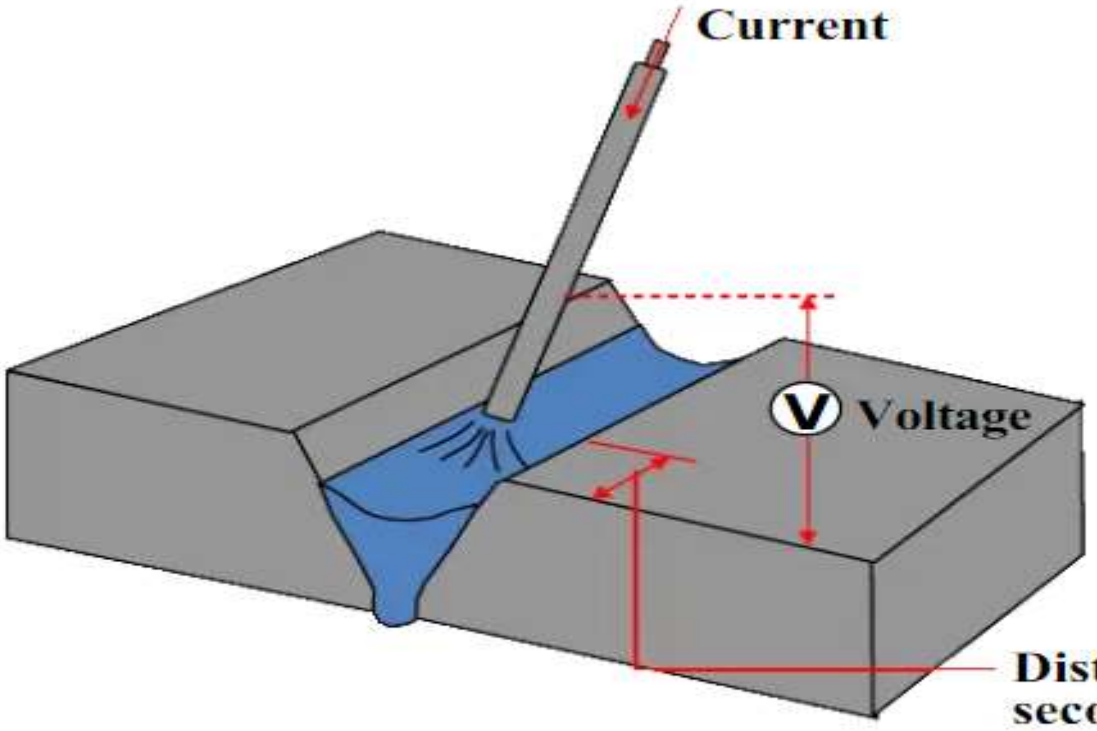
2. Use if lower size electrode i.e. more no. of parts increase the extent of HAZ & more grain coarsening.

3. In some cases, weaving is helpful & in other stringer bead is desired.

4. Change in polarity effects penetrations & melting rate.

5. Pre-heating and post-heating reduces HAZ hardness & chance of cracking.

6. 6. Back step welding, skip welding reduces it input.



Amps = 200 Volts = 32

Travel speed = 240 mm/min

$$\text{Heat input} = \frac{200 \times 32 \times 60}{240 \times 1000}$$

Heat input = 1.6 kJ/mm

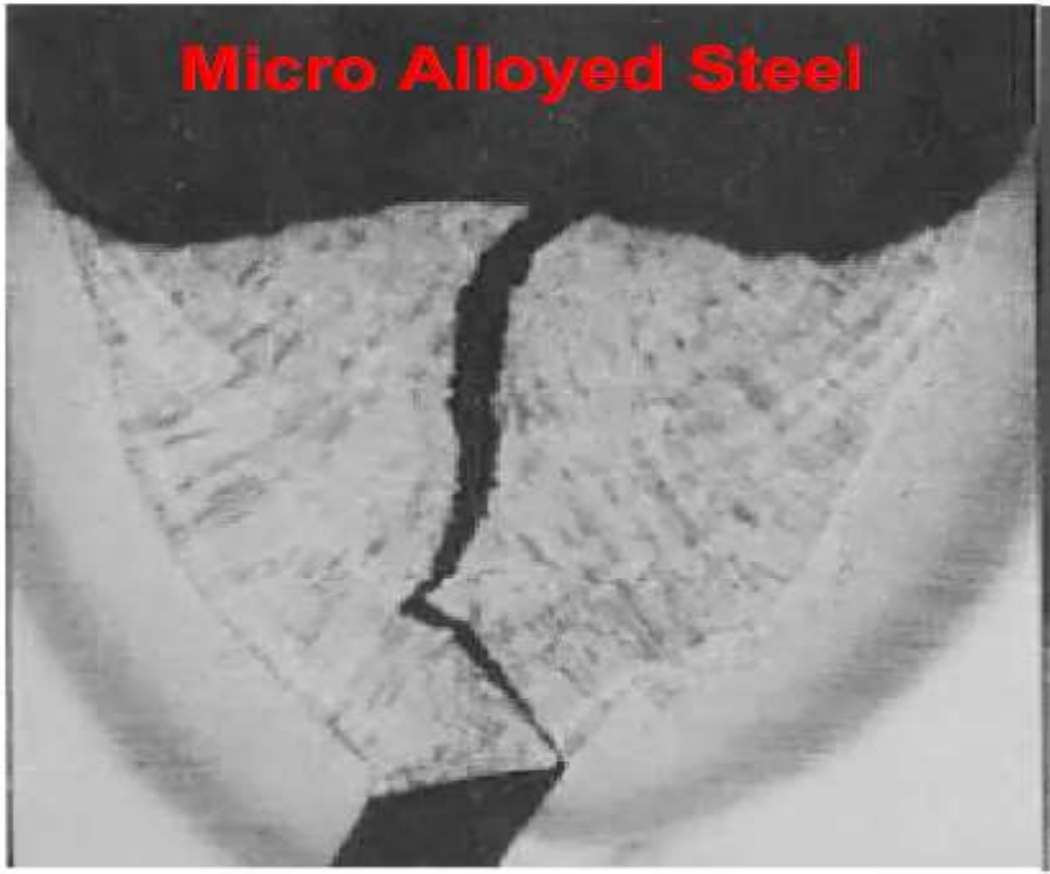
$$\text{Heat input} = \frac{\text{Amps x volts}}{\text{Travel speed mm/sec} \times 1000}$$

High heat input - slow cooling

- Low toughness
- Reduction in yield strength

Low heat input - fast cooling

- Increased hardness
- Hydrogen entrapment
- Lack of fusion



Hydrogen induced
weld metal cracking

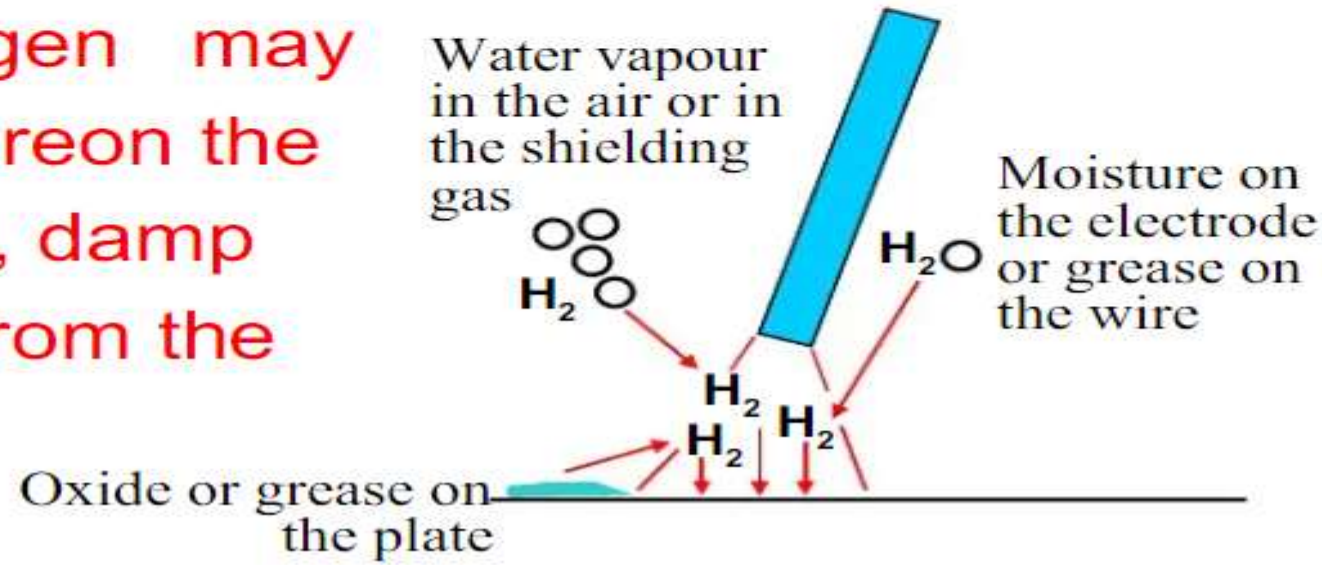


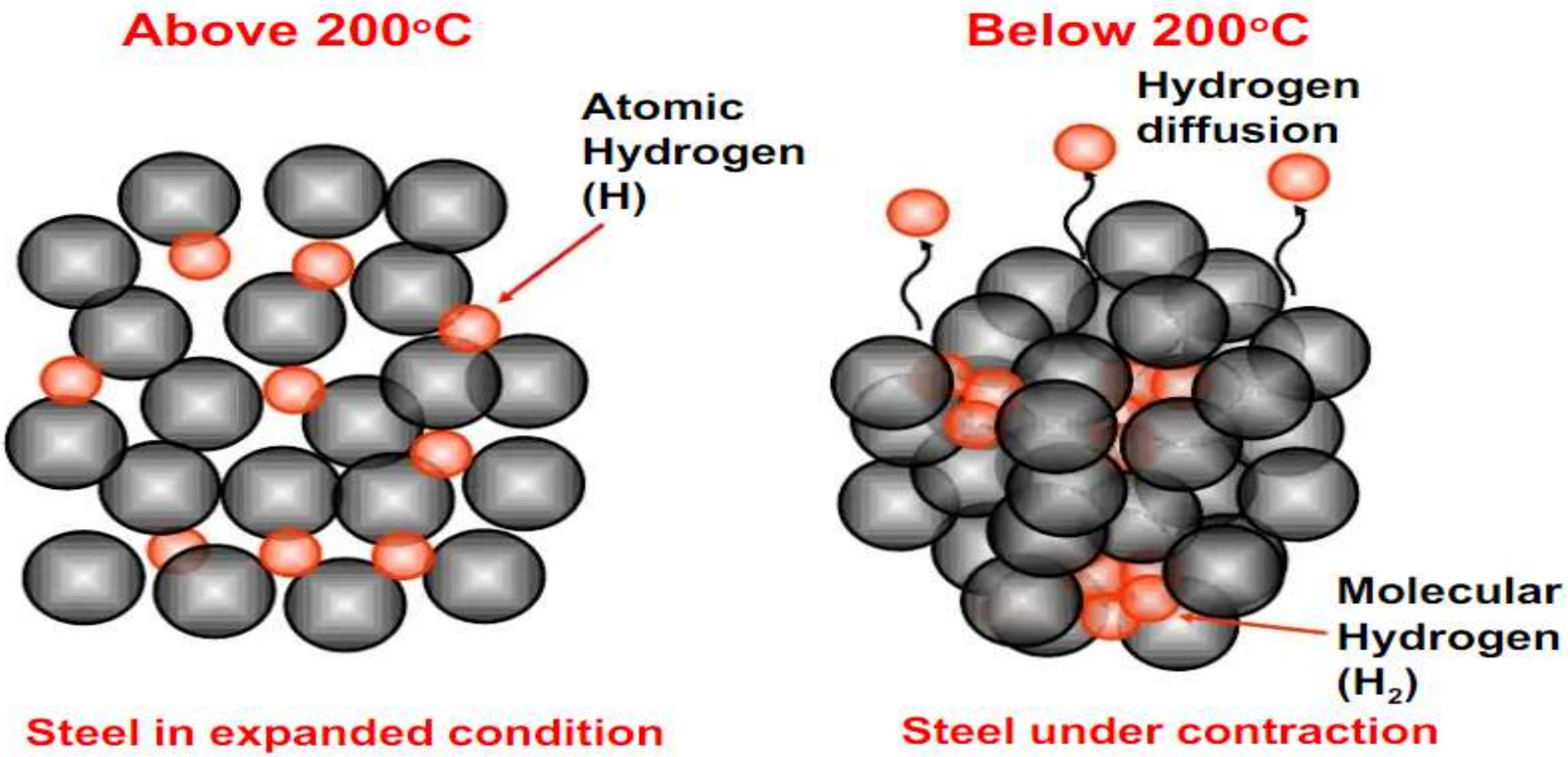
Hydrogen induced
HAZ cracking

Hydrogen causes general embrittlment and in welds may lead directly to cracking,



- Hydrogen smallest atom known atomic number 1
- Hydrogen enters the weld via the arc
- Diatomic element (H+H = H_2) at room temperature
- Source of hydrogen may be from moistureon the parent material, damp welding fluxes or from the parent material




Above 200°C
Atomic Hydrogen (H)
Steel in expanded condition
Below 200°C
Hydrogen diffusion
Molecular Hydrogen (H_2)
Steel under contraction

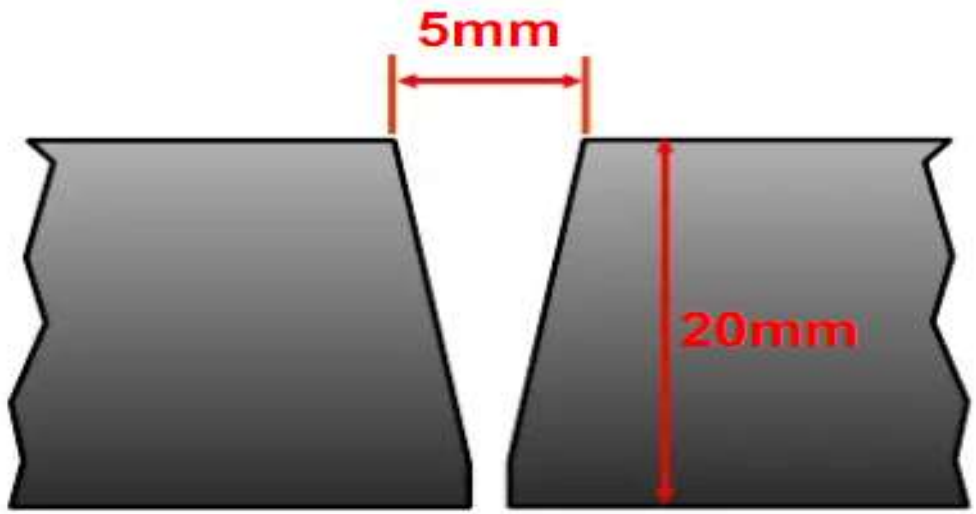
Precautions for controlling hydrogen cracking

- Pre heat, removes moisture from the joint preparations, and slows down the cooling rate
- Ensure joint preparations are clean and free from contamination
- The use of a low hydrogen welding process and correct arc length
- Ensure all welding is carried out is carried out under controlled environmental conditions
- Ensure good fit-up as to reduced stress
- The use of a PWHT
- Avoid poor weld profiles

EFFECT OF SULPUR IN THE WELD METAL

- During welding, sulphur in or on the parent material may be re-melted.
- The sulphur will join with iron to form iron sulphides, they will seek the last place of solidification, weld centreline
- It is here that they form a liquid film around the solidifying grains, which are themselves under great stress.
- The bonding between the grains may now be very poor to maintain cohesion and a crack will result, weld centreline

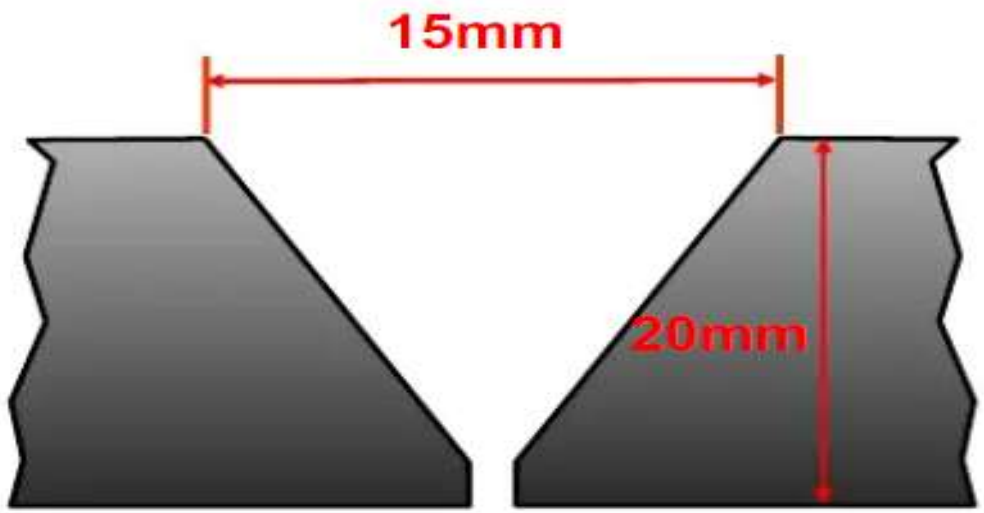
L-21



Width / Depth = < 0.7 (5 / 20 = 0.25)

Cracking likely

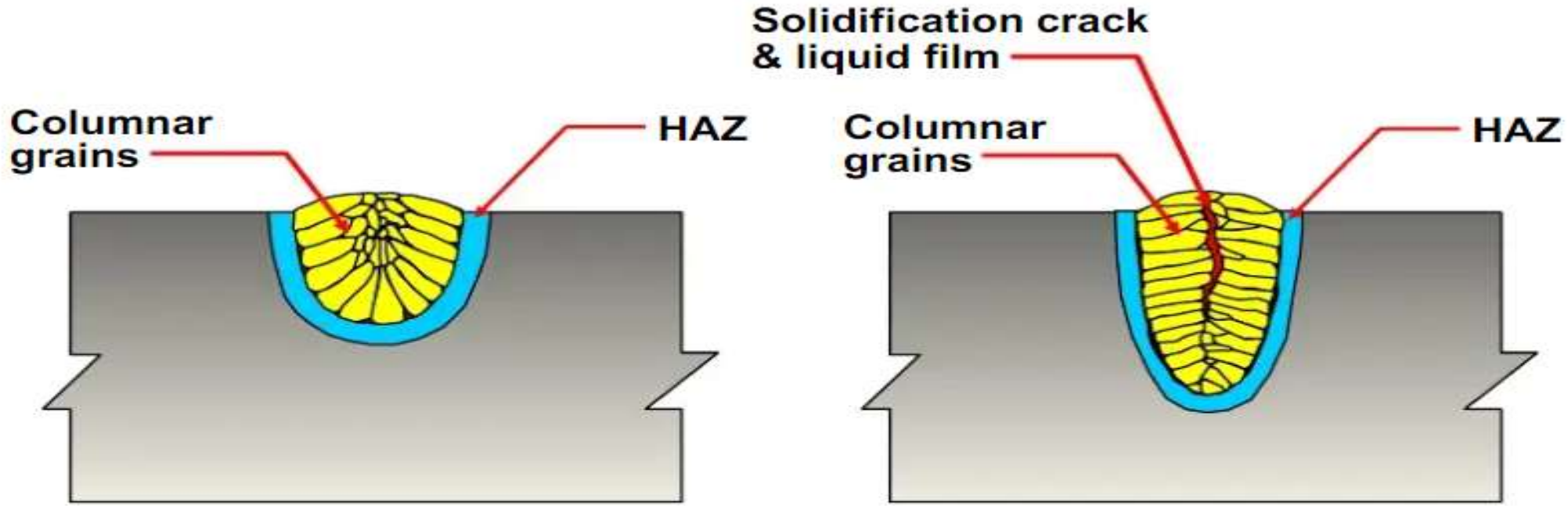
Higher dilution levels
faster cooling



Width / Depth = > 0.7 (15 / 20 = 0.75)

Cracking unlikely

Lower dilution levels
slower cooling



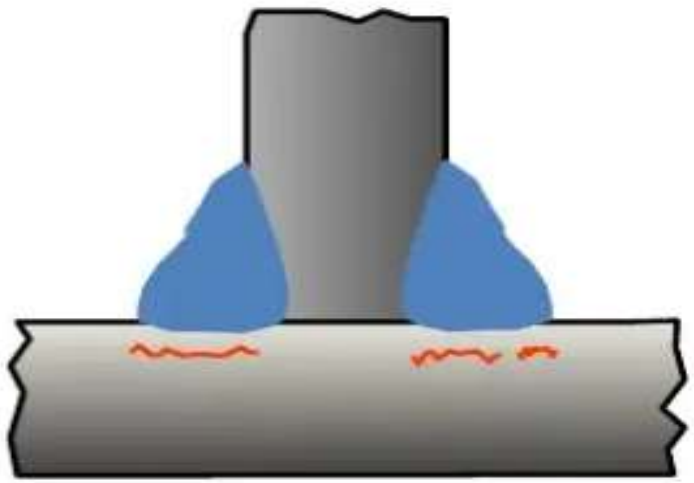
Shallow, wider weld bead

On solidification the bonding between the grains may be adequate to maintain cohesion and a crack is unlikely to occur

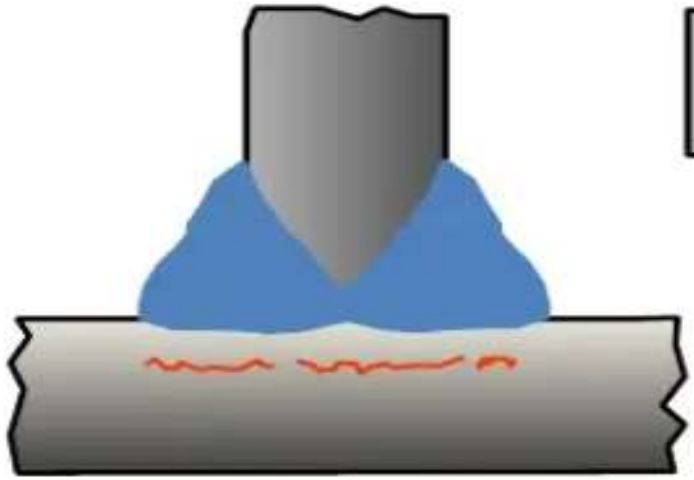
Deeper, narrower weld bead

On solidification the bonding between the grains may now be very poor to maintain cohesion and a crack may result

Susceptible joint types

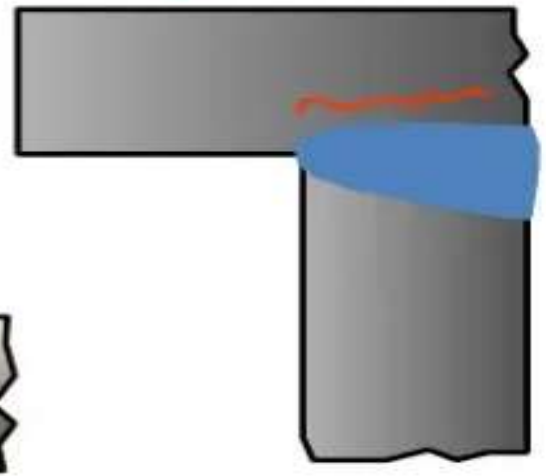


Tee fillet weld

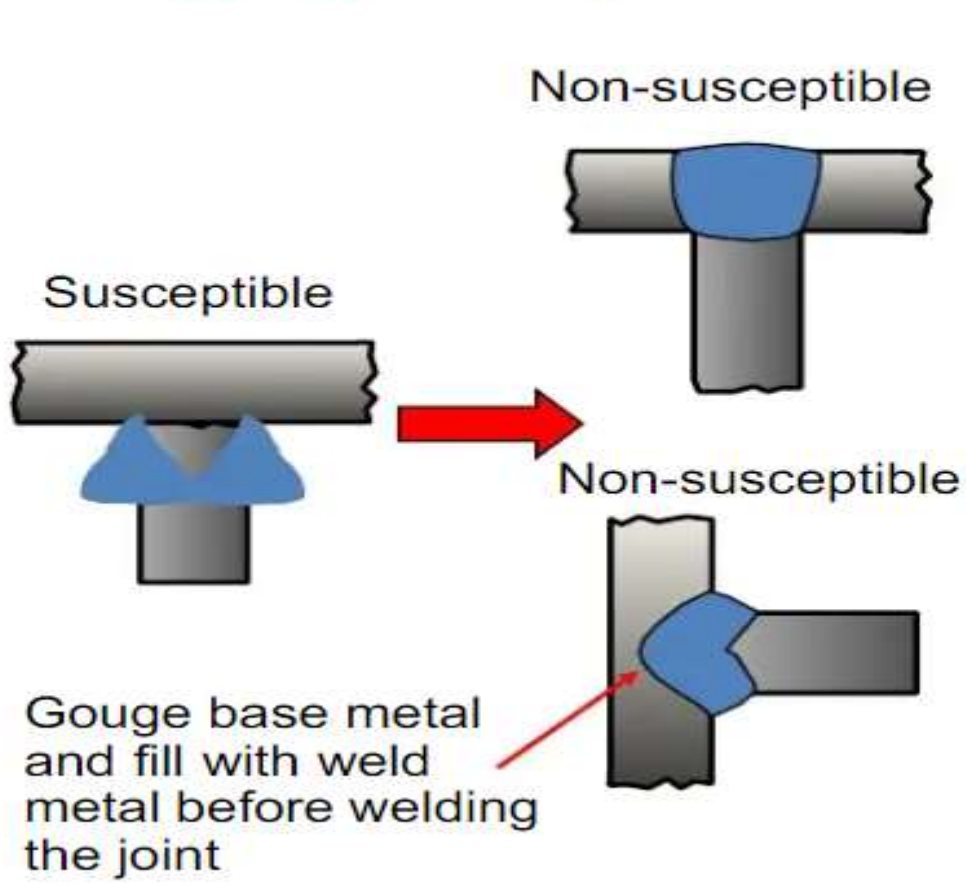


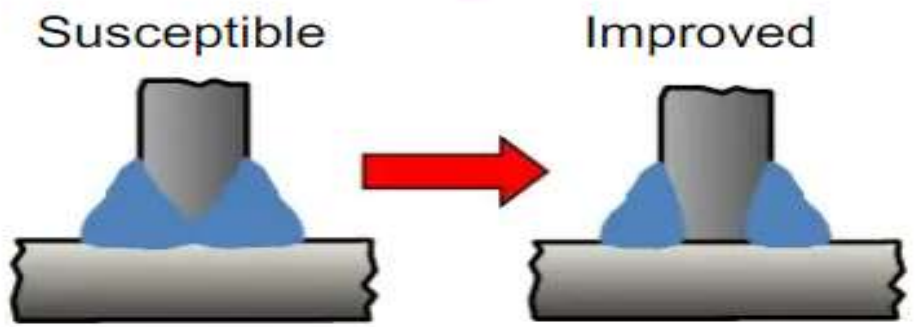
Tee butt weld
(double-bevel)

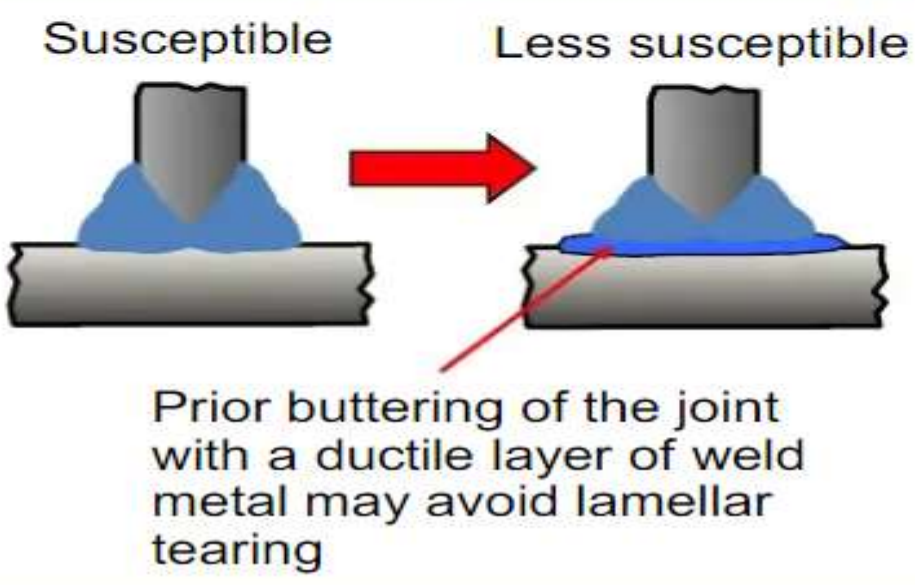
Corner butt weld
(single-bevel)



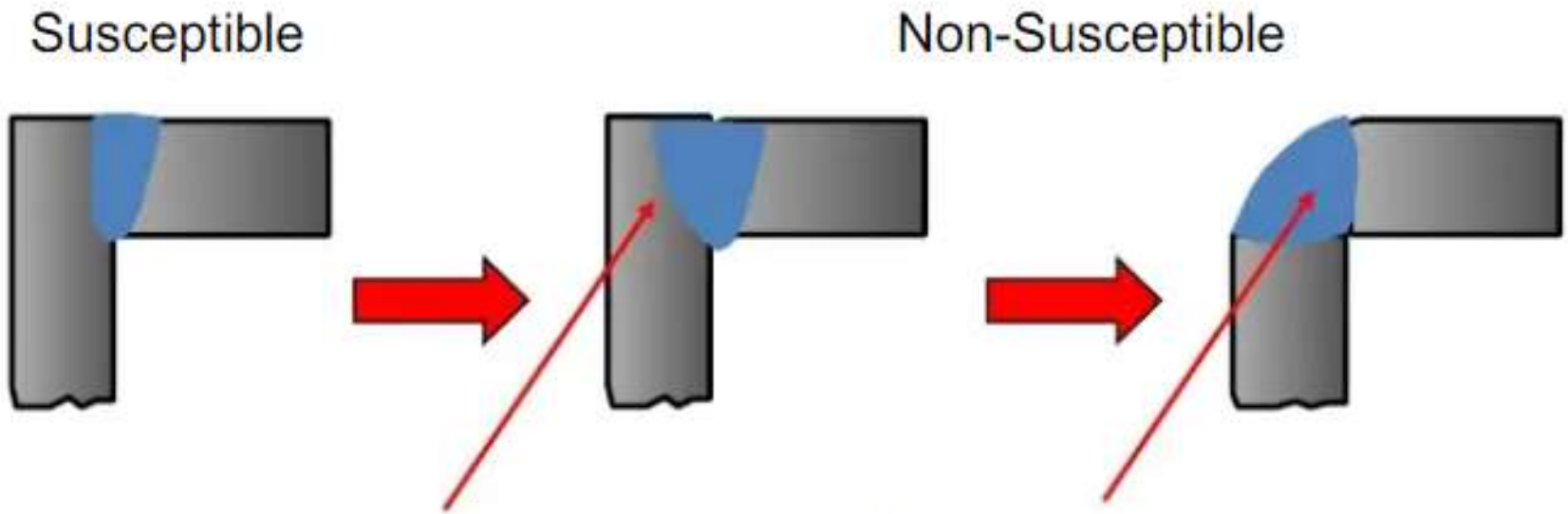
Modifying a Tee joint to avoid lamellar tearing

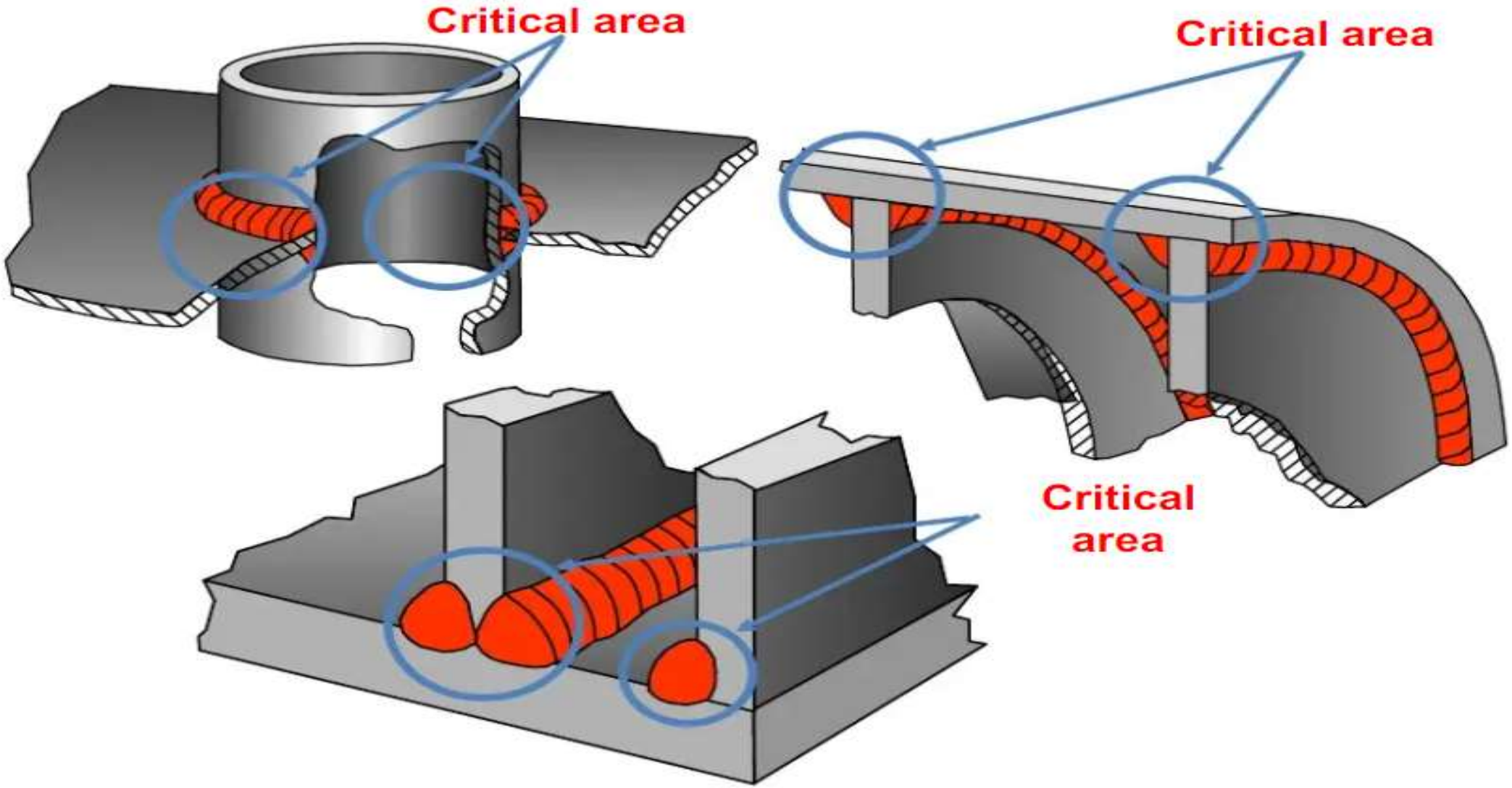






Modifying a corner joint to avoid lamellar tearing




Critical area
Critical area
Critical
area

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Unit 4

Welding Metallurgy

- Study of Welding Metallurgy is important because the overall-mechanical properties of a weldments are determined by the properties of individual microstructure present in the weld deposit and the weld heat affected zone. Major problem associated with welding fabrication is the inability to obtain uniform mechanical properties through out the weldments. Welding Metallurgy is concerned with

1. Melting of electrode and base metal
2. Solidification of weld metal
3. Gas absorption
4. Slag metal reactions

Metallurgical Effects of Welding

1. Weld Metal

Weld Metal behaves like a casting with defects and characteristics of a casting. Solidification of metals is usually considered to be a Nucleation and Growth process. Nucleation involves creation of critical sized particles (nuclei) and from which Growth will proceed.

Metallurgical Effects of Welding

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2. Absorption of Gases by Weld

Gases such as Hydrogen gets dissolved in the molten metal and may get trapped in the solid metal if the cooling is rapid. These gases may get retained in the microstructure or may form bubbles to form porosity in the meld metal. The gases may also react with the liquid metal or with one another. The gases which often cause trouble are Hydrogen, Nitrogen, Oxygen.

Metallurgical Effects of Welding

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3. **Slag Inclusions** : Slag inclusions are frequently trapped in fusion welds and there is difficulty of removing it.

4. **Hot Cracking of Welds** : Hot Cracking of welds occurs at high temperatures. This may be due to the low ductility of the base metal.

5. **Heat Affected Zone (HAZ):**

6. **Corrosion of Welds** : Depends on the composition of base metal, process employed etc.

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Welding Zones

If welded joint closely examined, the joint consists of three distinct zones namely

1. Weld Metal Zone
2. Heat Affected Zone
3. Unaffected base metal or parent metal.

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Weld Metal Zone

- Weld Metal is formed as well as the weld metal solidifies from molten state. This is a mixture of parent metal and electrode (or filler metal). The ratio depends on welding process used, type of joint and plate thickness.
- Weld Zone resembles a cast metal.

Heat Affected Zone (HAZ)

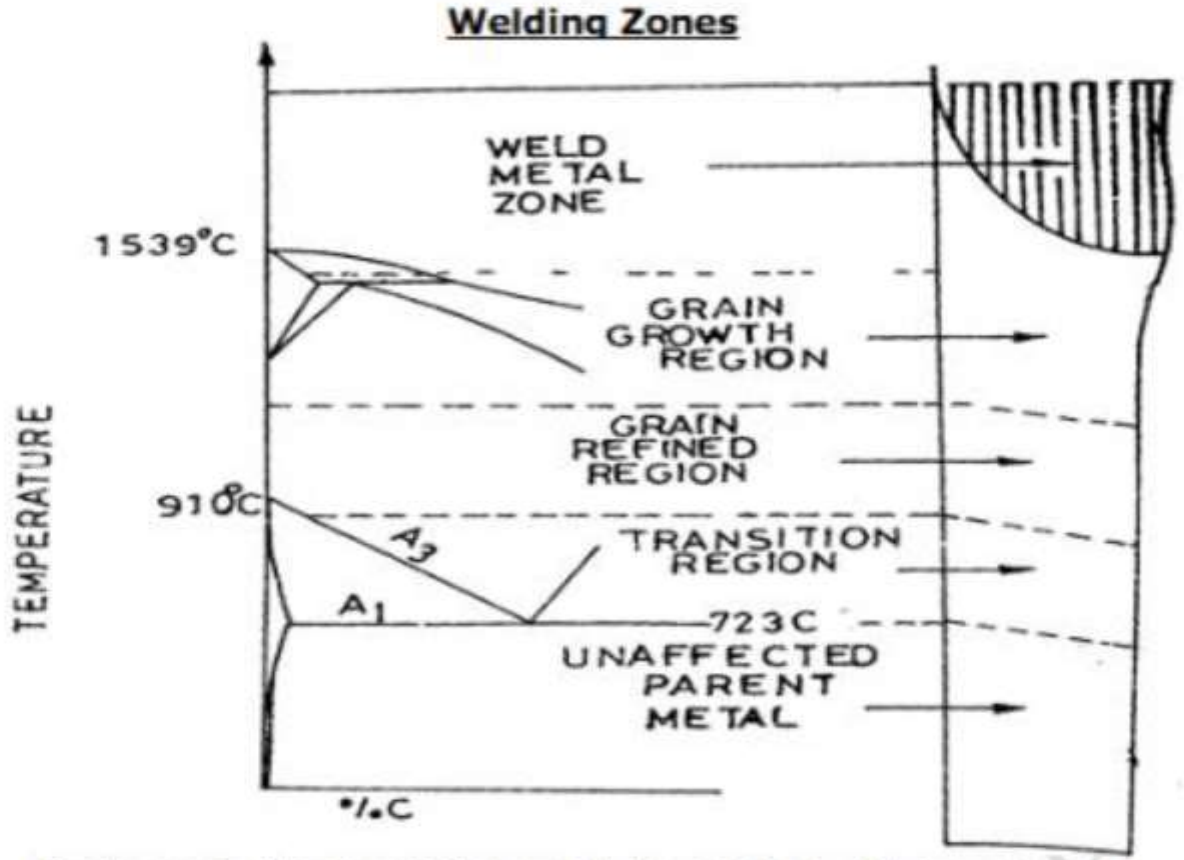
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- Adjacent to the Weld Metal Zone is the HAZ. HAZ is composed of the parent metal that did not melt but was heated to a high temperature for a sufficient period so that grain growth occurred.
- Heat Affected Zone is that portion of base metal whose mechanical properties and microstructure have been altered by the heat of welding.
- The width of HAZ varies according the welding process and technique.
- HAZ consists of three metallurgically distinguished regions.



Welding Zones

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Regions of a Welded Joint and their relations with temperature.

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1. The Grain Growth Region :

- Grain Growth Region is immediately adjacent to Weld Metal Zone.
- In this zone, the metal his heated to a temperature well above the Upper Critical Temperature(A3).
- This result in grain growth.

2. The Grain Refined Region :

- Adjacent to the Grain Growth Region is the Grain Refined Region.
- In this zone, the metal his heated to a temperature just above the Upper Critical Temperature(A3).
- In this region finest grain structure exists.

3. The Transition Region :

- Adjacent to the Grain Refined Region is the Transition Region.
- In this zone, the metal his heated to a temperature between Upper Critical Temperature(A3) and A1.

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Unaffected base metal or parent metal.

- Outside the HAZ is the parent metal is the parent metal that was not heated sufficiently to change its microstructure.

Welding Stresses

- Residual stresses are stresses existing within the weldment in the absence of external forces.
- They are in static equilibrium within the body and are internally balanced.

Residual Stresses may be classified into two categories.

1. **Macro stresses** : They are large scale internal stresses and may be developed by inhomogeneous plastic deformation from external loading, by non-uniform heating or by varied chemical diffusion.
2. **Micro stresses** : They are small scale internal stresses and may be developed by heterogeneities due to difference in elastic modulus, co-efficient of expansion etc.

Causes of Internal Stresses

1. **Mechanical Residual Stresses** Expansion and contraction of heated metal due to the piece being welded itself
2. **Metallurgical Residual Stresses.** Phase transformation which takes place while cooling
3. **Reaction Stresses.** Expansion and contraction of heated metal due to the other parts of structure to which the piece being welded is attached

Effects of Thermal Stresses

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- Residual Stresses can cause
  1. Distortion of work-piece when welded.
  2. Distortion of welded objects while machining.
  3. Result in weld cracking.
  4. Result in brittle fracture.
  5. Result in lowered ductility.
  6. Affect fatigue strength adversely.
  7. Lower creep strength.

Methods for controlling Welding Stresses

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- Welding stresses may be reduced (before the weld is made) by the following methods.

1. Structure should be designed so that joints will have slowest residual stresses. For example a double V groove butt joint instead of single V.

2. Since residual stresses are caused by thermal strains due to welding, a reduction in amount of weld metal usually results in reduction of residual stresses. For example use of a U-groove instead of V-grove should result in reduction of amount of weld metal.

3. Peening will reduce residual stresses.

4. Cracks are great stress raisers. Crack tack welds should be chipped or melted out before welding work.

Stress Relief Heat Treatment of Weldments

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1. **Peening :**

In Peening, outer fibres of the weld are elongated with the help of hammer blows. When properly applied Peening reduces residual stresses to a great extent. But Peening reduces internal stresses of a low intensity. Peening also reduces distortion. Peening should not be employed to the first and last layers of weld. Excessive Peening will result in cracking of weld.

2. **Vibratory Stress Relief :**

In this method, weld structures are subjected to vibrations to relive residual stresses. The weld structure is placed on a platform that vibrates. Up to 25%of residual stresses may be relived by Vibratory Stresses Relief Treatment.

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3. Thermal Heat Treatment :

Thermal treatment of weld consists of heating the weld structure uniformly to a suitable temperature for a predetermined period of time followed by uniform cooling. Thermal Treatment is a better substitute than Vibratory Stress relief.

4. Thermo-mechanical Treatment :

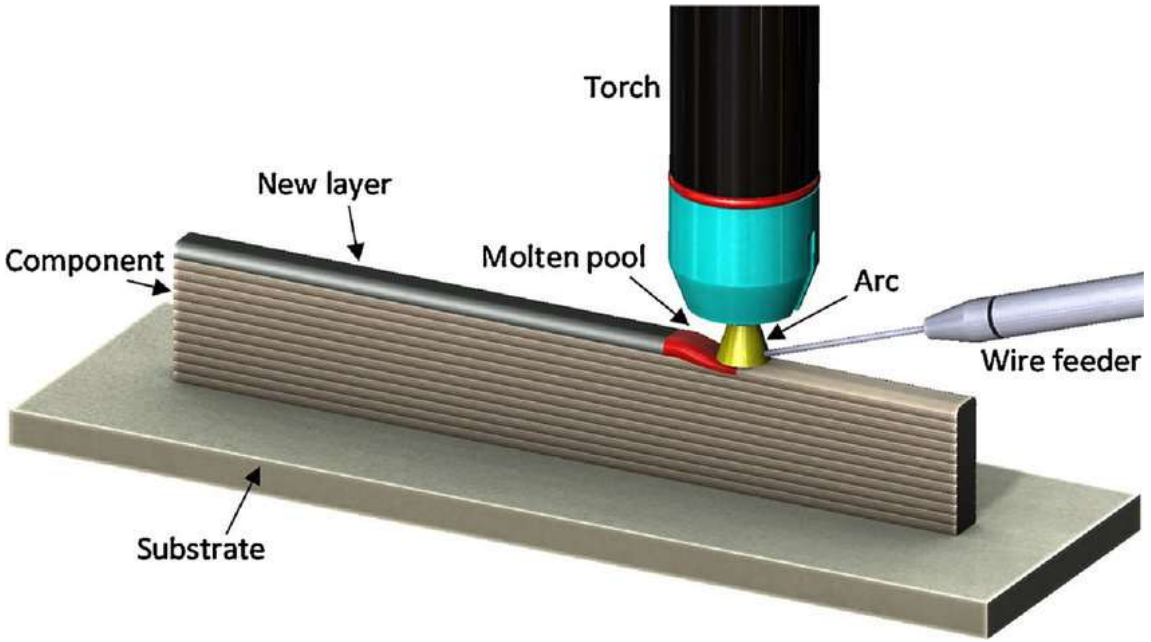
In this method, the weld is heated to set up another residual stresses so as to counteract and thereby cancel the original residual stresses due to welding. This is a low temperature treatment when compared to Thermal Heat Treatment. Reductions up to 60% of residual stresses have been reported by this method.

5. Overstressing Treatment :

In this method, the weld is loaded above the yield stress of the metal. When such pressure are removed, the residual stresses are found to be largely disappeared.

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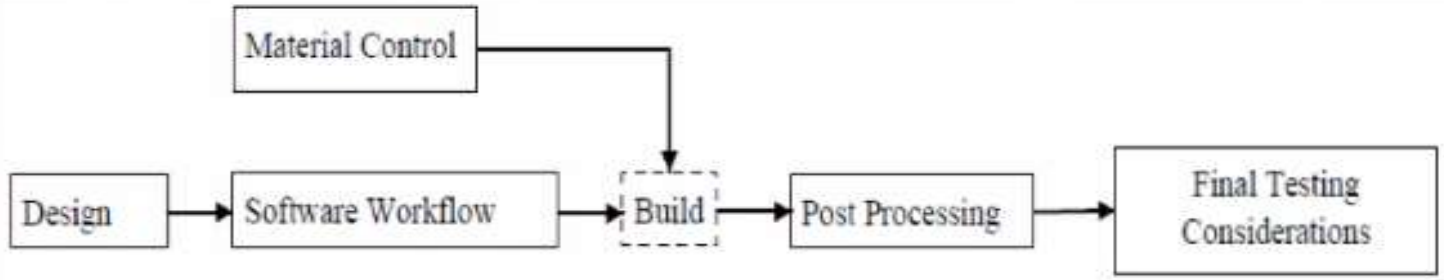
Wire Arc Additive Manufacturing (WAAM)



Additive Manufacturing(AM)

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- Additive Manufacturing (AM) is a technique where structures are produced by ading and depositing material in a layer upon layer manner. Rather than removing materials, AM processes make three-dimensional parts directly from CAD models by adding materials layer by layer, offering the beneficial ability to build parts with geometric and material complexities.

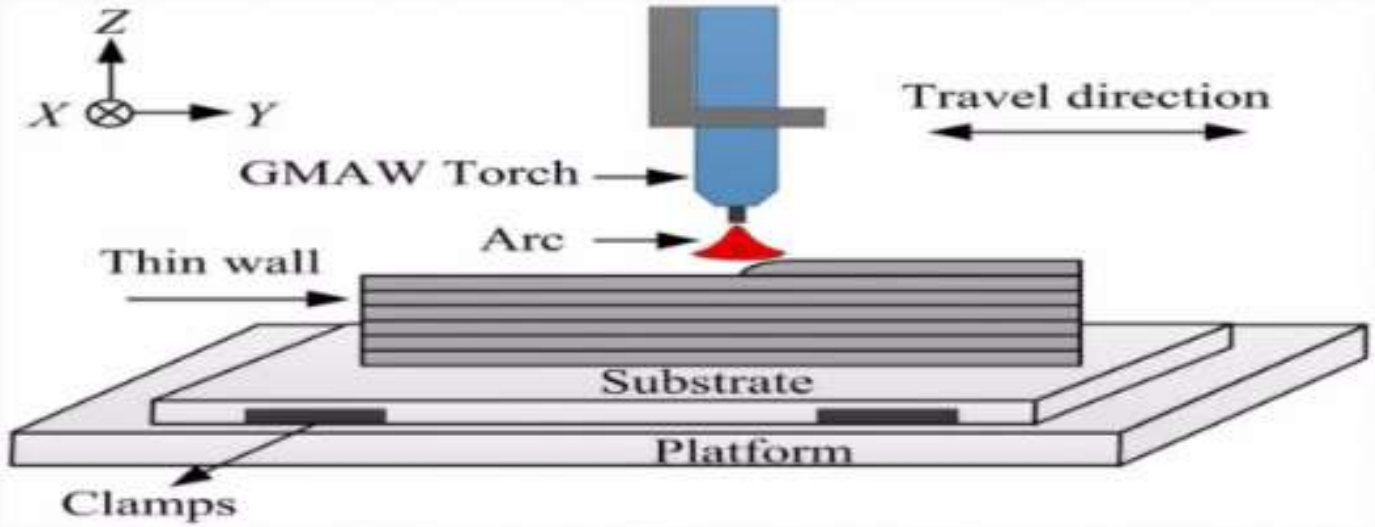


- Flow Chart of the Additive Manufacturing Process



Wire Arc Additive Manufacturing(WAAM)

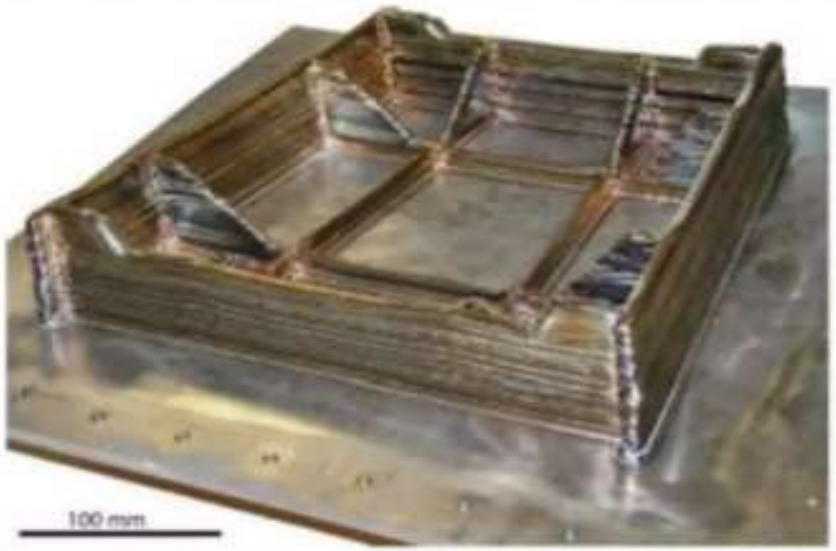
- WAAM is mostly used in modern industries, like aerospace industry. It uses existing welding equipment, electric arc as energy source and welding wire as feedstock. Because of this, it is cheaper than other AM technologies, which usually need specific equipment and materials.



Waam sample schema

Wire Arc Additive Manufacturing(WAAM)

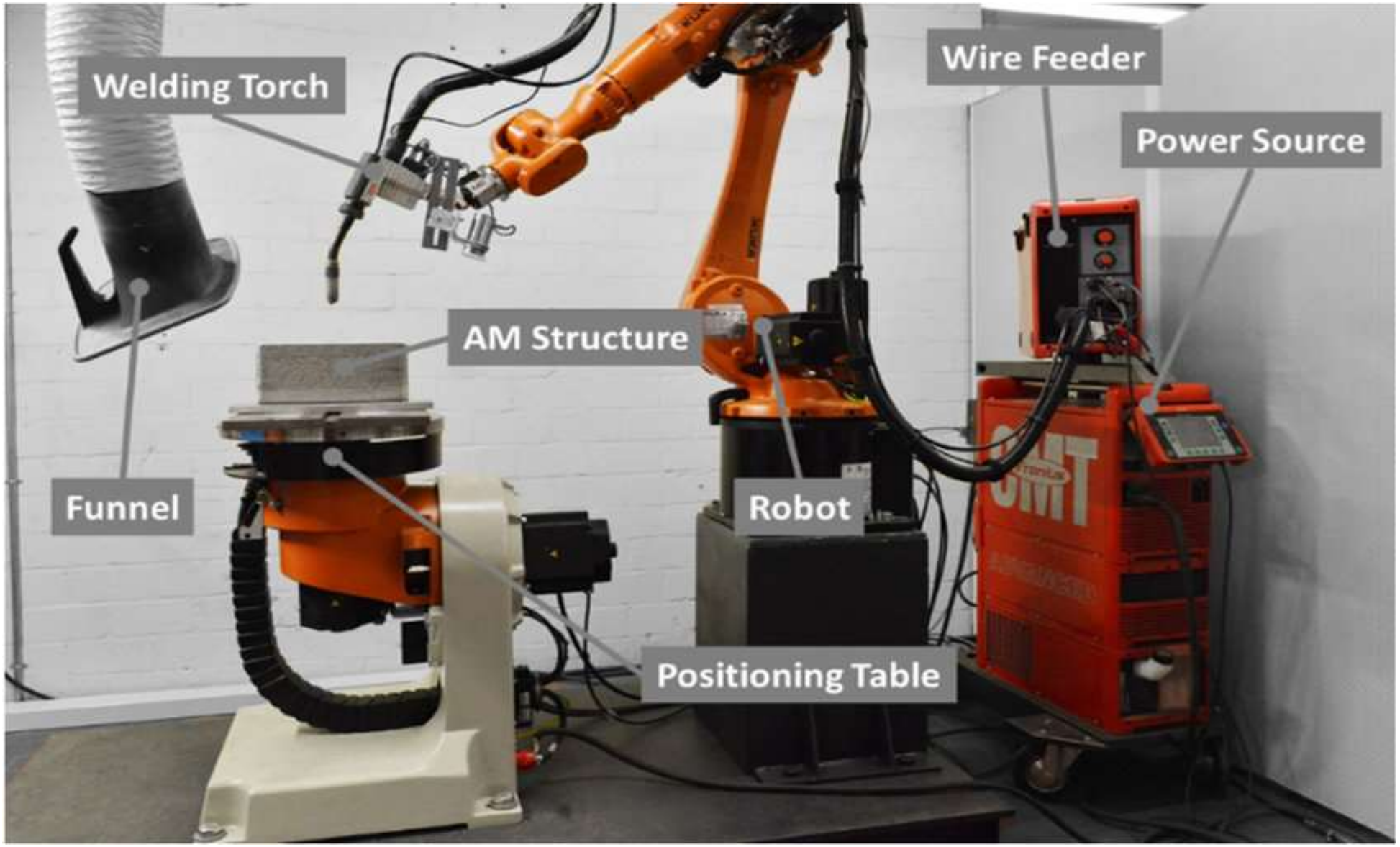
- While the material deposition rate is 2-10 g/min in laser-based methods, the material deposition rate reaches 50-130 g/min in the WAAM method. In addition, WAAM is less costly. Material handling efficiency reaches 100% in terms of wire material deposited on the part.



Landing gear component

PROCESS

- Wire as feedstock
- Electric Arc as heat source
- Adds material layer by layer
- Motion can be provided either by
    1. Robotic System
    2. Computer Numerical Controlled Gantries



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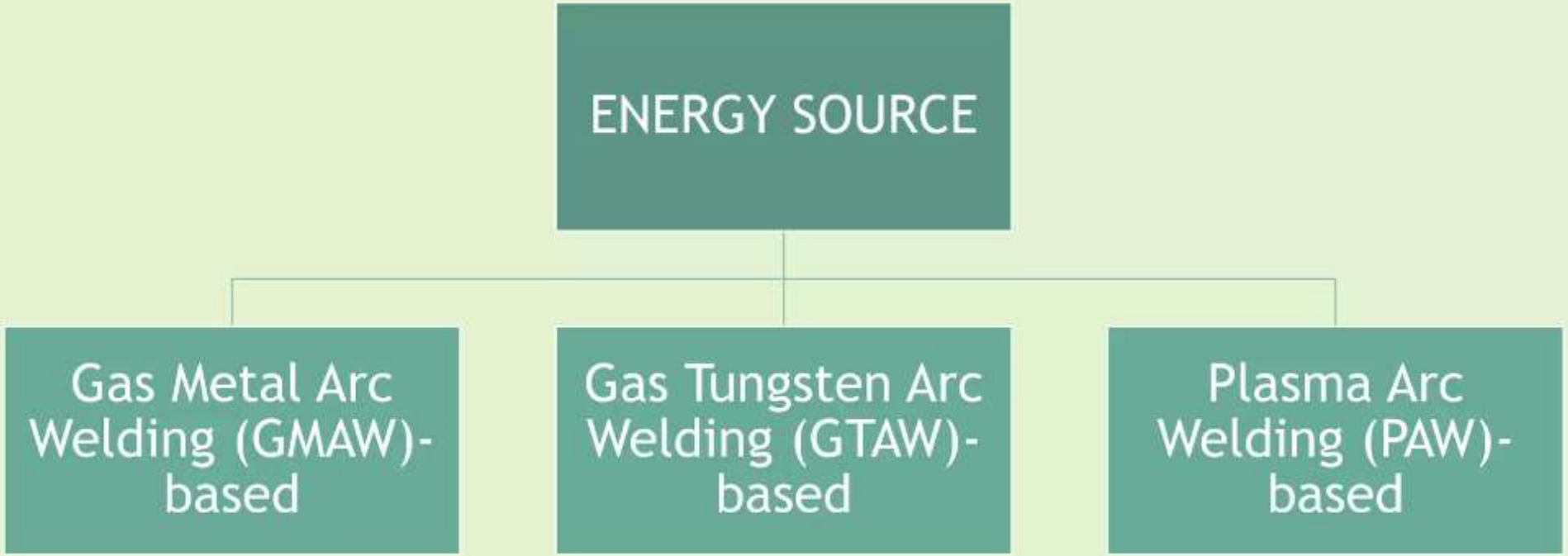
PROCESS PARAMETERS

- Wire feed speed(WFS)
  Rate at which wire is fed through the torch

- Travel speed(TS)
  Speed of the bead relative to the surface and typically it is controlled by the speed of the torch

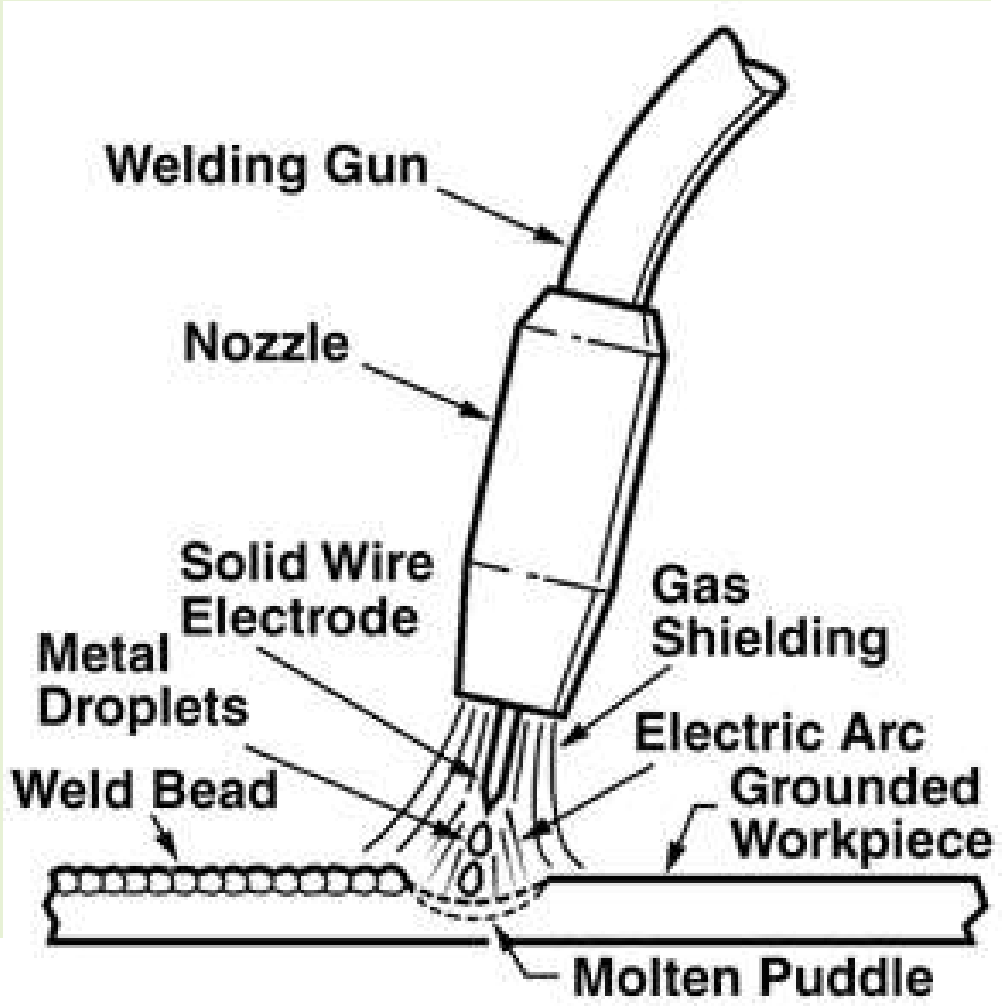
- Current, Voltage
  Automatically adjusted depending on the WFS to produce a suitable arc of the correct energy and length for welding

CLASSIFICATION



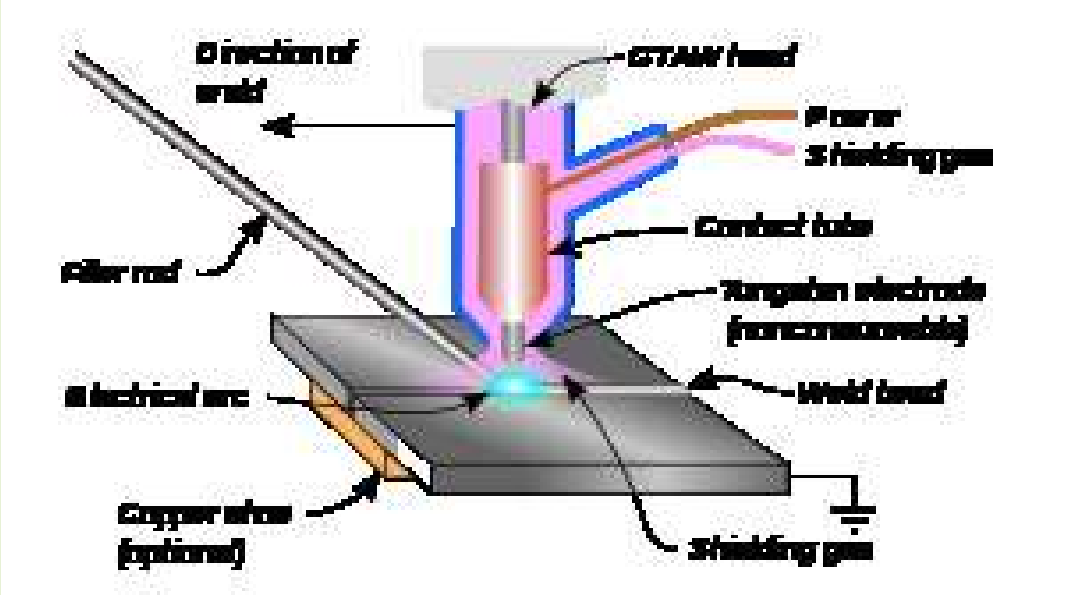
GMAW-based

- Commonly used process
- Consumable wire electrode
- Typical deposition rate: 3-4kg/hour
- Poor arc stability
- Spatter
- Aluminium and steel
- Arc wandering when Titanium is used



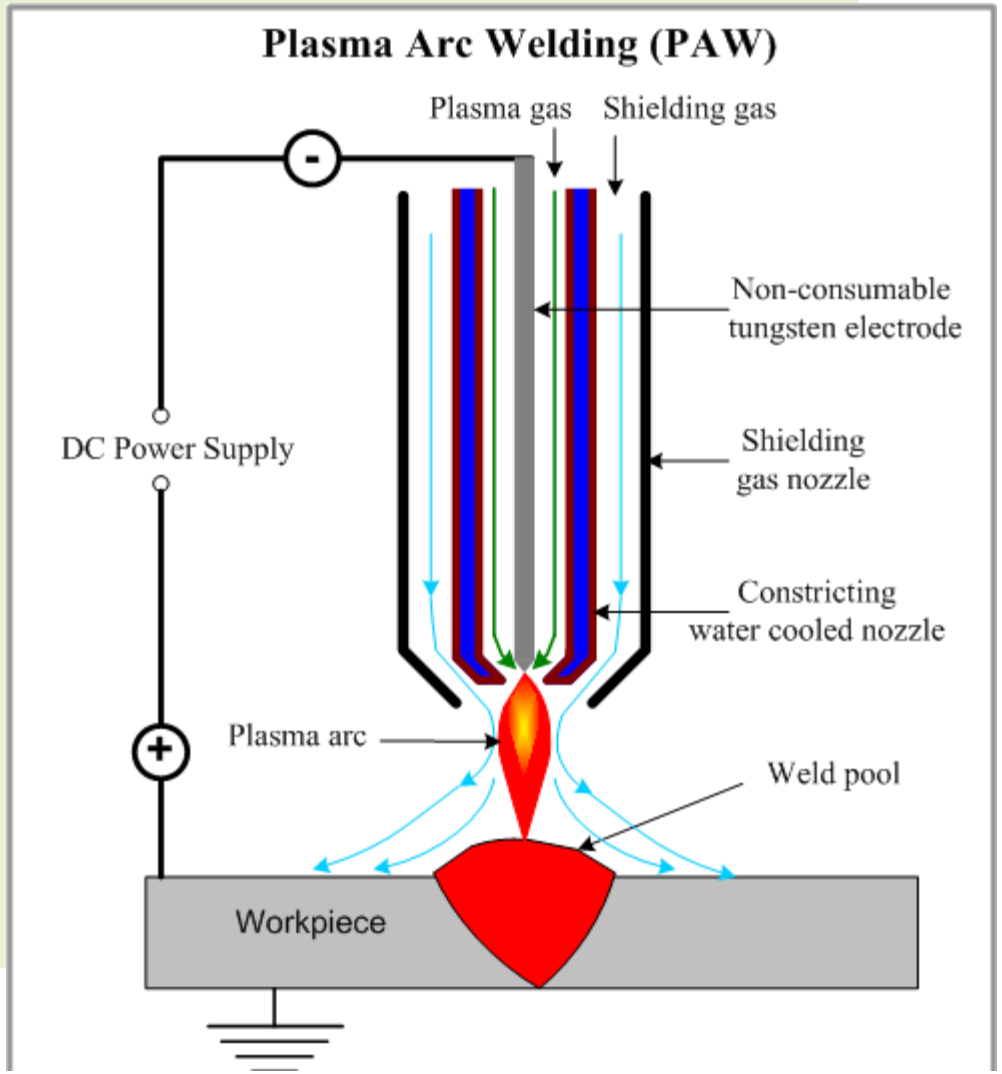
GTAW-based

- Non-consumable electrode
- Separate wire feed process
- Typical deposition rate: 1-2kg/hour
- Wire and torch rotation are needed
- Complicated Robot Programming
- Titanium



PAW-based

- Non-consumable electrode
- Separate wire feed process
- Typical deposition rate: 2-4kg/hour
- Wire and torch rotation are needed
- Complicated Robot Programming
- Titanium



METALS USED

- Titanium Alloys
- Aluminium Alloys and Steel
- Nickel-based super alloys
- Magnesium Alloys
- Bimetals

BENEFITS

- Capital Cost
- Open Architecture
- Part Size
- Deposition Rate
- Reduced post-machining time
- Complex geometries

COMMON DEFECTS

- Deformation and Residual Stress
- Porosity
- Crack
- Delamination
- Oxidation
- Surface finish

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APPLICATIONS

- Aerospace
- Automotive
- Marine
- Architecture
- Tools

Welding Defects – Types, Causes and Remedies

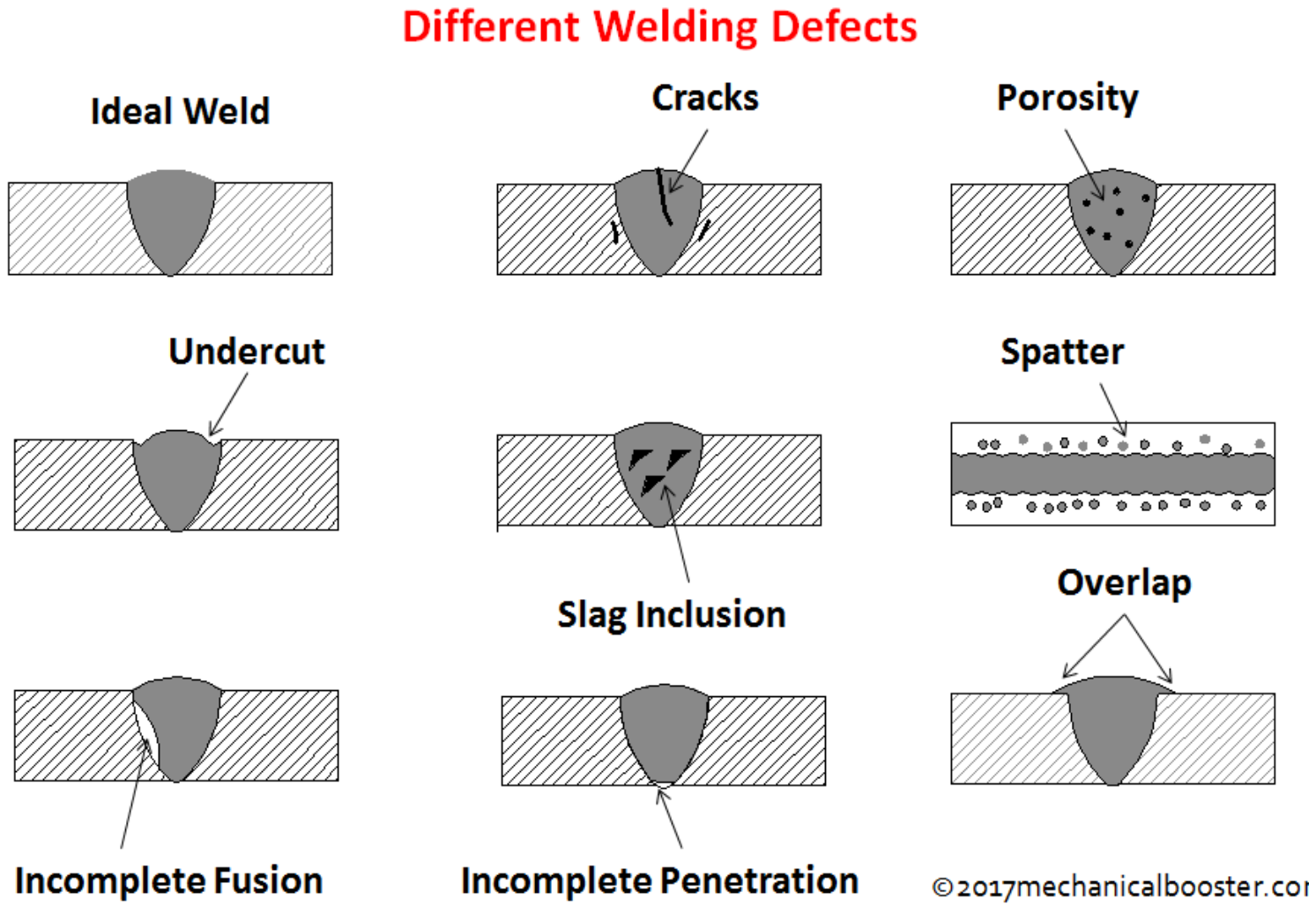
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Welding Defects

- Irregularities formed in the given weld metal due to wrong welding process or incorrect welding patterns, etc.
- The defect may differ from the desired weld bead shape, size, and intended quality.
- Welding defects may occur either outside or inside the weld metal.
- Some of the defects may be allowed if the defects are under permissible limits but other defects such as cracks are never accepted.

Welding Defects -Types

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Welding defects can be classified as:

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External Welding Defects:

- Weld Crack
- Undercut
- Spatter
- Porosity
- Overlap
- Crate

Internal Welding Defects:

- Slag Inclusion
- Incomplete Fusion
- Incompletely filled groove or incomplete penetration

While welding, it is very important to remove all the defects of welding present in the work piece, otherwise the components of the material would fail in severe conditions which may lead to loss of property and sometimes also life.

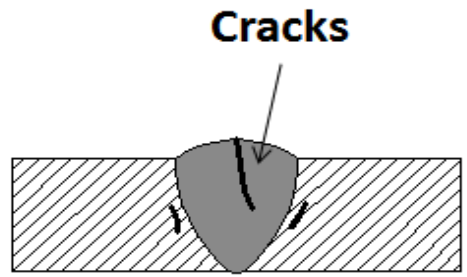
External Welding Defects

1. Weld Crack

Most unwanted defect of all the other welding defects.

Welding cracks can be present at the surface, inside of the weld material or at the heat affected zones.

Crack can also appear at different temperatures:



Hot Crack – It is more prominent during crystall weld joints.

Cold Crack – This type of crack occurs at the end of the welding process where the temperature is quite low.

Sometimes cold crack is visible several hours after welding or even after few days.

Causes of Weld Crack:

- Poor ductility of the given base metal.
- The presence of residual stress.
- The rigidity of the joint.
- If there is high content of sulfur and carbon then also the cracks may appear.
- Using hydrogen as a shielding gas while welding ferrous materials.

Remedies for Weld crack:

- Use of appropriate materials may decrease the chances of crack.
- Preheating the weld and reducing the cooling rate.
- Reduce the gap between the weld joints.

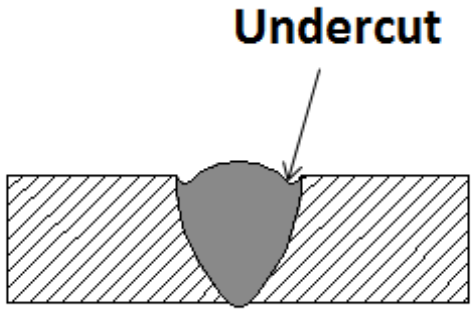
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2. Undercut

When the base of metal melts away from the weld zone, then a groove is formed in the shape of a notch, known as Undercut. It reduces the fatigue strength of the joint.

Causes of Undercut:

- Very high arc voltage.
- Use the wrong electrode or wrong angle of electrode.
- Using a large electrode.
- High electrode speed.



Remedies for Undercut:

- Reduce the arc length or lower the arc voltage.
- Keep the electrode angle from 30 to 45 degree.
- Use of small diameter electrode.
- Reduce the travel speed of the electrode.

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3. Spatter

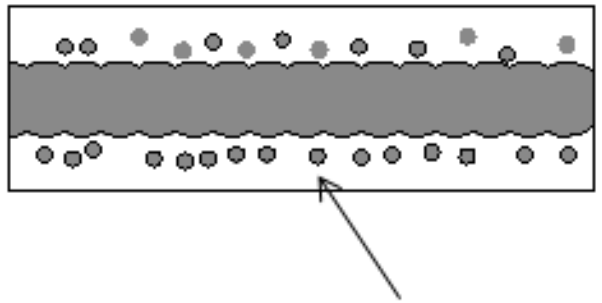
When some metal drops are expelled from the weld and remain stuck to the surface, then this defect is known as Spatter

Causes Of Spatter:

- High Welding current.
- Longer arc.
- Incorrect polarity.
- Improper gas shielded.

Remedies for Spatter:

- Reducing the arc length and welding current
- Using the right polarity.
- Increasing the plate angle and using proper gas shielding.

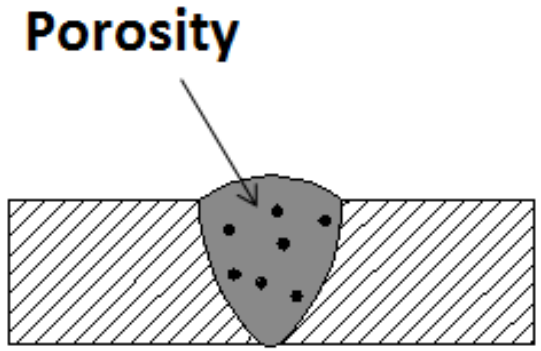


4. Porosity

Porosity is the condition in which the gas or small bubbles gets trapped in the welded zone.

Causes of Porosity:

- Improper electrode coating.
- Using a longer arc may also increase its chances.
- Increased welding currents.
- Rust or oil on the welding surface.



Remedies for porosity:

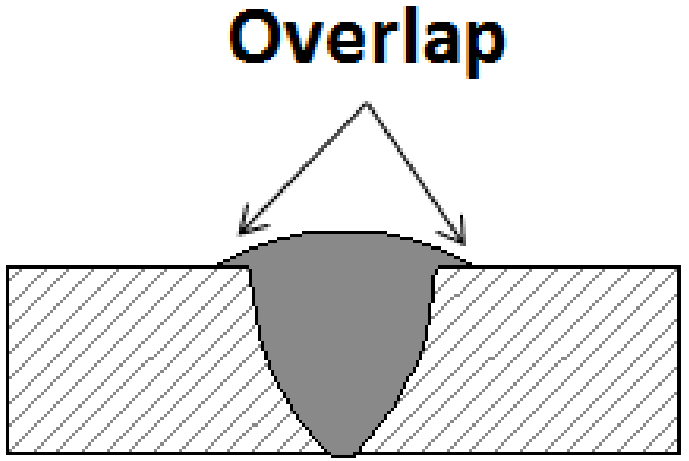
- Proper selection of the electrode.
- Decreasing the welding current.
- Using smaller arc and slowing the process to allow the gases to escape.
- Remove rust or oil from the surface and use a proper technique.

5. Overlap

When the weld face extends beyond the weld toe, then this defect occurs. In this condition the weld metal rolls and forms an angle less than 90 degrees.

Causes of Overlap:

- Improper welding technique.
- By using large electrode.
- High welding current



Remedies for Overlap:

- Using a proper technique for welding.
- Use small electrode.
- Less welding current.

6. Crater

It occurs when the crater is not filled before the arc is broken, which causes the outer edges to cool faster than the crater. This causes a stress and then crack is formed.

Causes of the crater:

- Incorrect torch angle.
- Use of large electrode:
- Improper welding technique

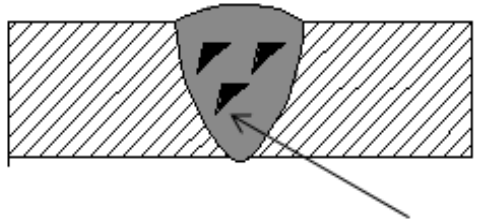
Remedies for crater:

- Using a proper torch angle may reduce the stress on the metal
- Using a small electrode.
- Use a proper technique.

Internal Welding Defects

1. Slag Inclusion

Slag is formed on the surface of the weld or between the welding turns.



Slag inclusion

Causes of Slag:

- Slag is formed if the welding current density is very small, as it does not provide the required amount of heat for melting the metal surface.
- High welding speed.
- Improper cleaning of the weld surface.
- Improper welding angle and travel rate of welding rod.

Remedies for Slag Inclusion:

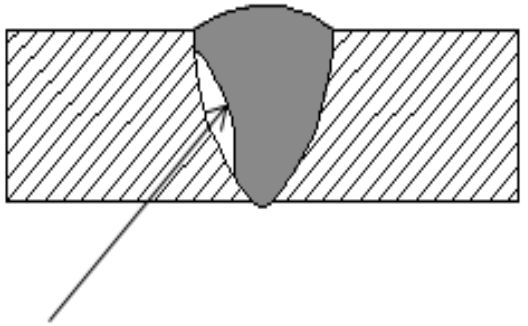
- Increase the current density
- Adjusting the welding speed.
- Clean the weld edges and remove the slag of previous weld.
- Have a proper electrode angle and travel rate.

2. Incomplete Fusion

Incomplete fusion occurs when the welder does not accurately weld the material and the metal pre solidifies which leads to a gap which is not filled with the molten metal.

Causes of Incomplete fusion:

- It occurs because of the low heat input.
- When the weld pool is very large and runs ahead of the arc.
- When the angle of the joint is too low.
- Incorrect electrode and torch angle.
- Improper bead position.



Remedies for Incomplete Fusion:

- Increasing the welding current and decreasing the travel speed.
- Reducing the deposition rate.
- Increasing the joint angle.
- Position the electrode and torch angle properly.
- Positioning the bead properly so that the sharp edges with other beads can be avoided.

3. Incompletely Filled Groove or Incomplete Penetration

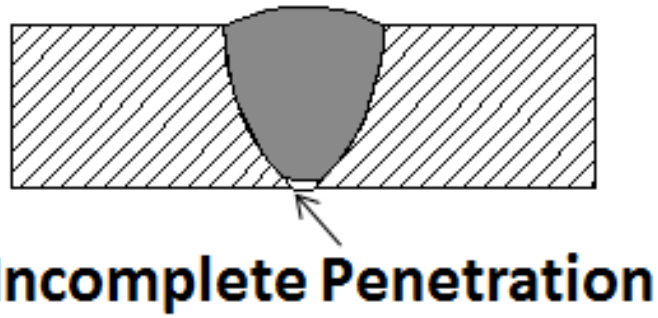
These defects occur only in the butt welds where the groove of the metal is not filled completely. It is also called as incomplete penetration defect.

Causes of an Incomplete filled groove are:

- Less deposition of the weld metal
- Use of improper size of the electrode
- Improper welding technique

Remedies for Incomplete filled groove are:

- More deposition of the weld metal.
- Use a proper size of the electrode.
- By using a proper welding technique.



Weldability

- The ease with which welding of a given material can be done without producing any defect is called **Weldability**.
- Weldability can also be defined as the capability of metal to be welded under the fabrication conditions imposed satisfactorily on the intended surface.
- The metal should not require expensive or complicated or extracting procedures to produce a sound joint.
- The American Welding Society defines weldability as, "the capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service."

Weldability …..

When nearly any process can be used on a metal and minimal effort is necessary to produce a sound weld, the metal is said to have "good weldability."

In cases where a welder can choose from only a limited number of processes and must carefully prepare the joint and execute the welding procedure to create a strong weld, the metal is considered to have "poor weldability."

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Factors affecting Weldability:

- **Melting point of metal**: Materials with a medium melting point can be welded very easily.
- **Thermal conductivity**: Material with high thermal conductivity (K) are treated as difficult to weld materials.
- **Reactivity**: If the material reacts with air, water or surroundings it becomes difficult to weld.
- **The coefficient of thermal expansion of metals**: Material with high thermal expansion coefficient, it becomes difficult to weld.
- **Electrical resistance**: Higher the electrical resistance of the material, it becomes difficult because it requires a lot of heat energy.
- **Surface condition**: The material with the dirty surface it becomes difficult to weld.

How to Improve Weldability

- The heating and cooling cycles inherent to most forms of welding can create strains and stresses in the weld.
- They also affect physical, chemical, and metallurgical changes in the metal.
- When such changes make a metal prone to poor weldability, adjustments can be made to improve the quality of the weld.

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Friction stir welding



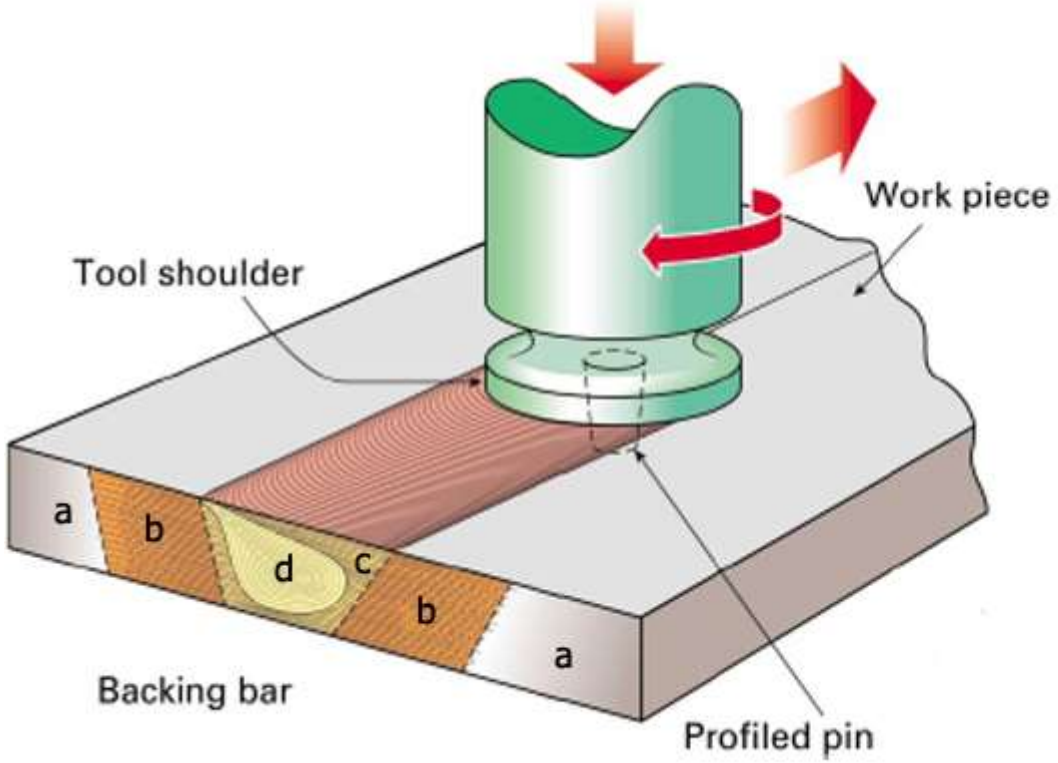
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- **Friction stir welding** (**FSW**) is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material.



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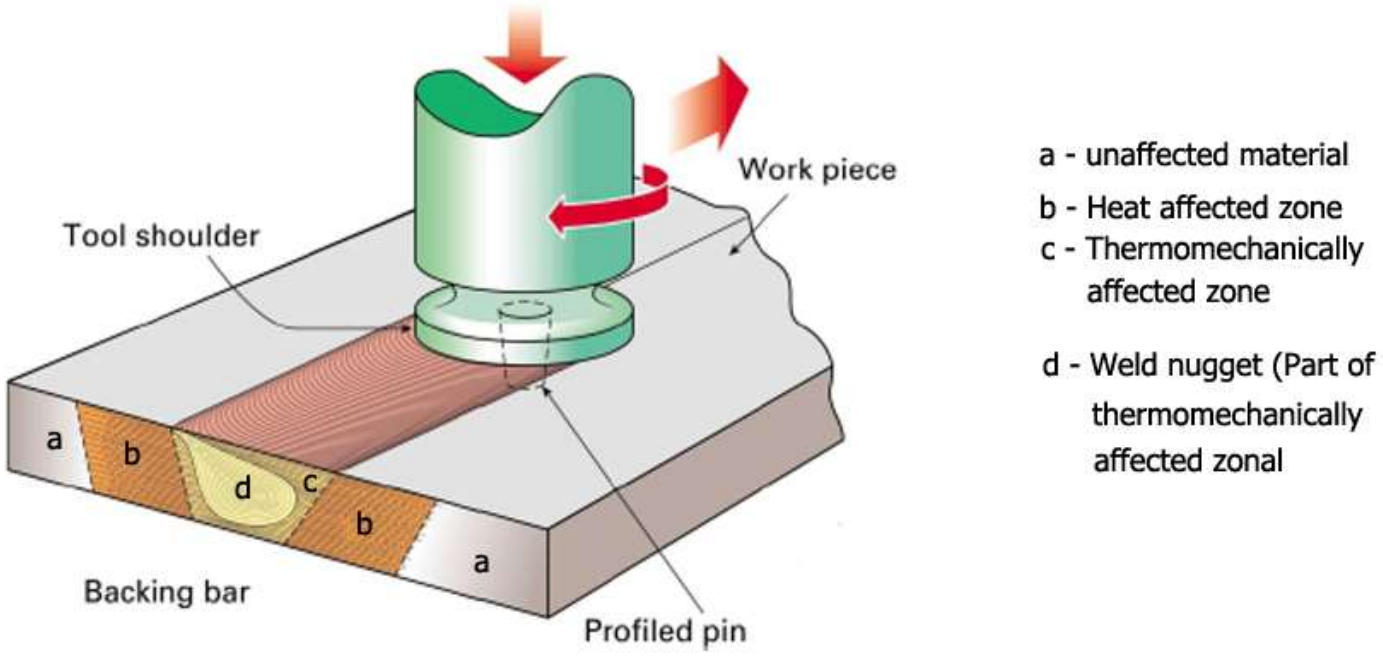
- Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool.



a - unaffected material
b - Heat affected zone
c - Thermomechanically affected zone
d - Weld nugget (Part of thermomechanically affected zonal

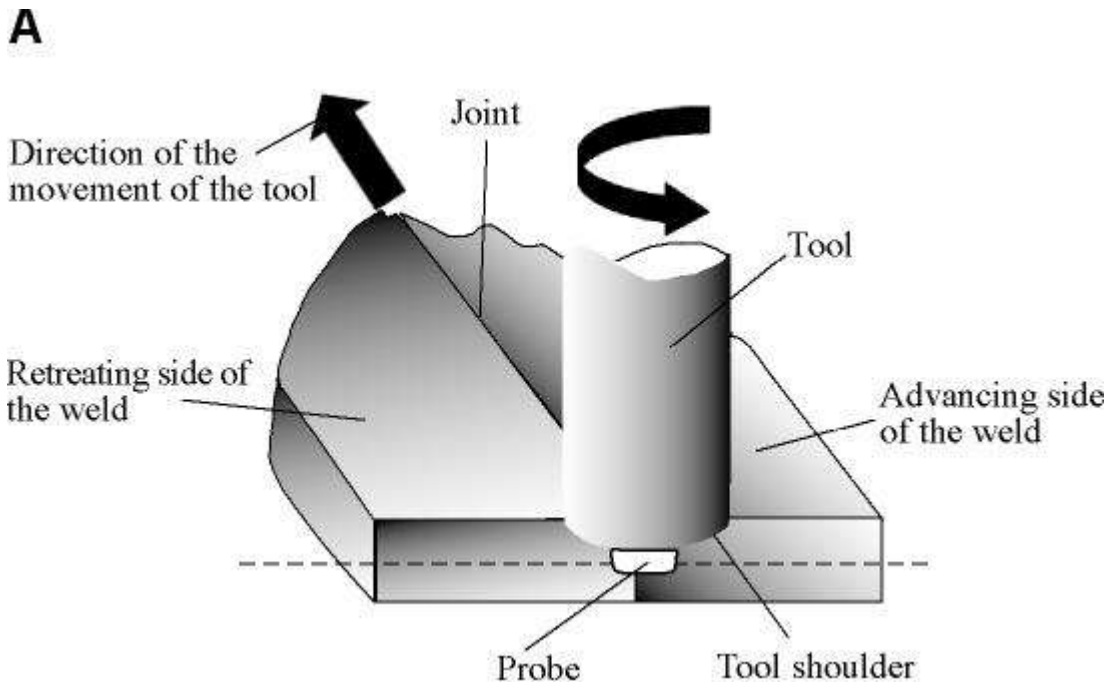
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- While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough.

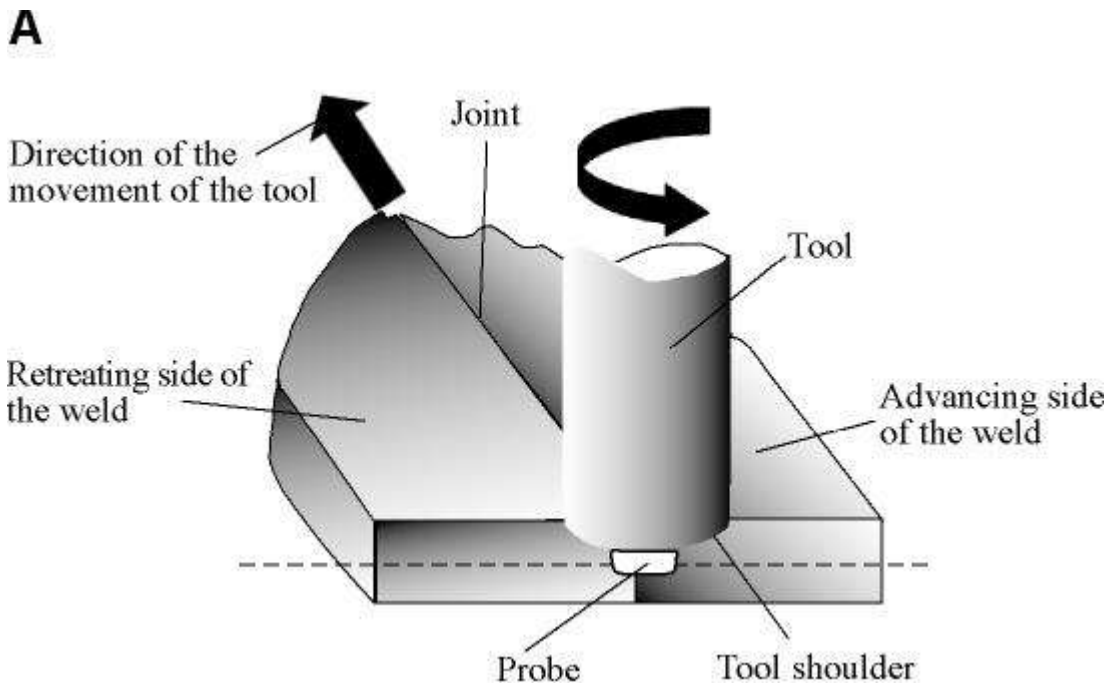


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- The FSW is performed with a rotating cylindrical tool which has profiled pin (also known a probe) having diameter smaller than the diameter of shoulder.

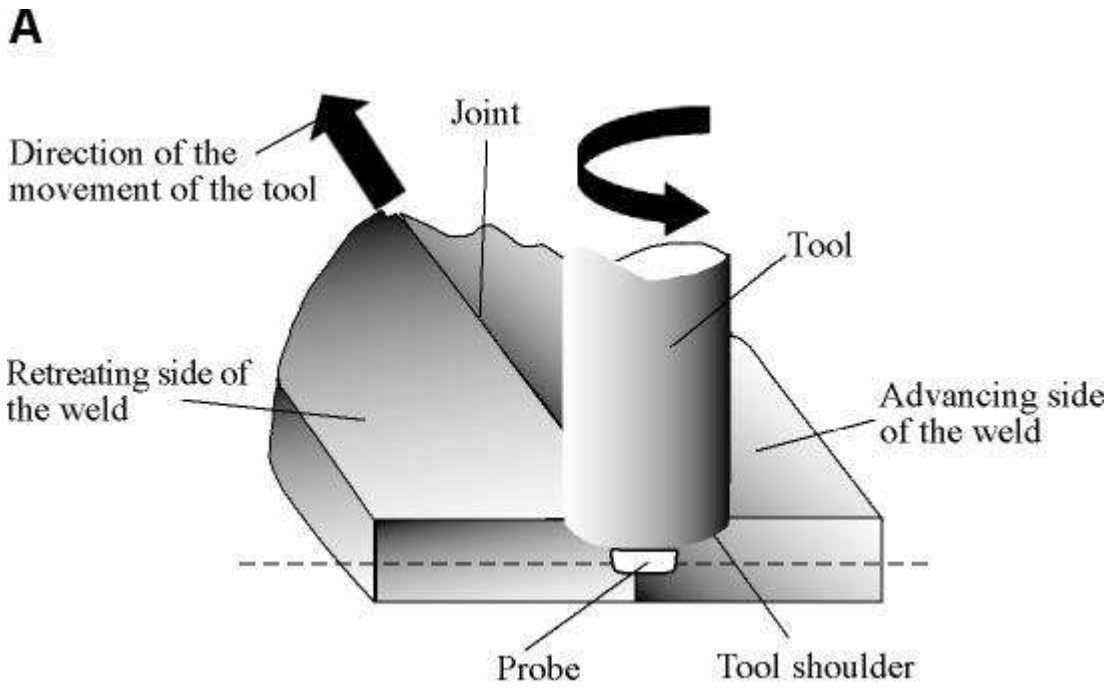


- During welding the tool is fed into a butt joint between two clamped workpieces, until the probe pierces into the workpiece and shoulder touches the surface of the workpieces.



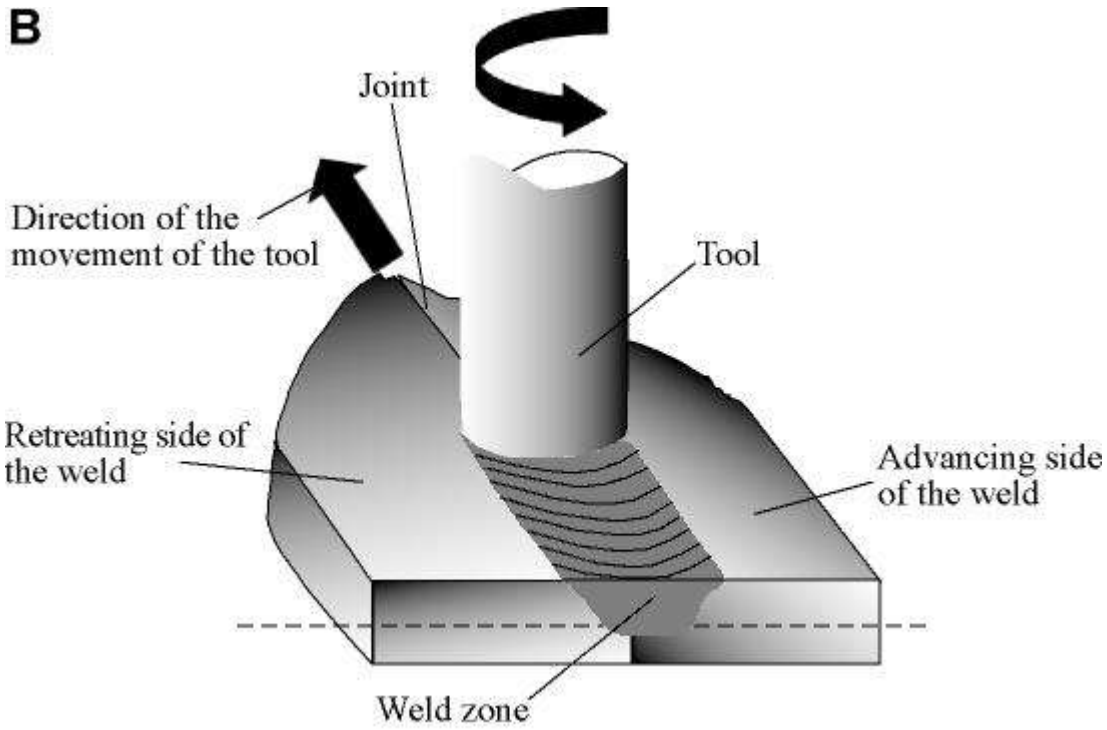
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- The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. After a short dwell time, the tool is moved forward along the joint line at the pre-set welding speed.



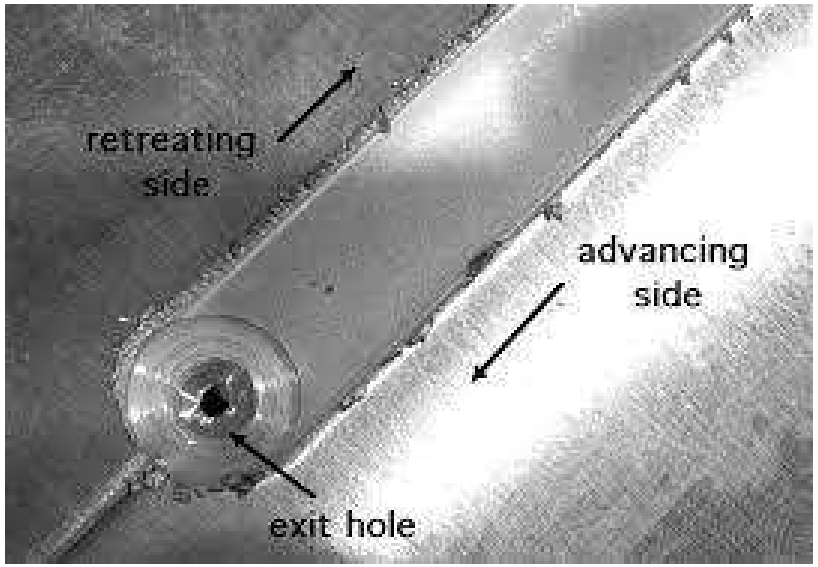
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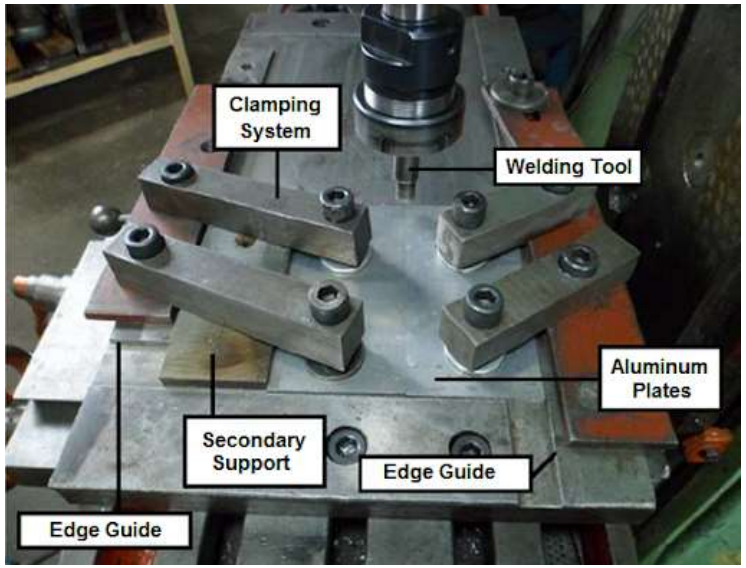
- Frictional heat is generated between the wear-resistant tool and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting.



- Good mechanical properties in the as-welded condition.
- Improved safety due to the absence of toxic fumes or the spatter of molten material.
- No consumables
- Easily automated on simple milling machines — lower setup costs and less training.
- Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
- Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
- Can use thinner materials with same joint strength.
- Low environmental impact.
- General performance and cost benefits from switching from fusion to friction.

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.





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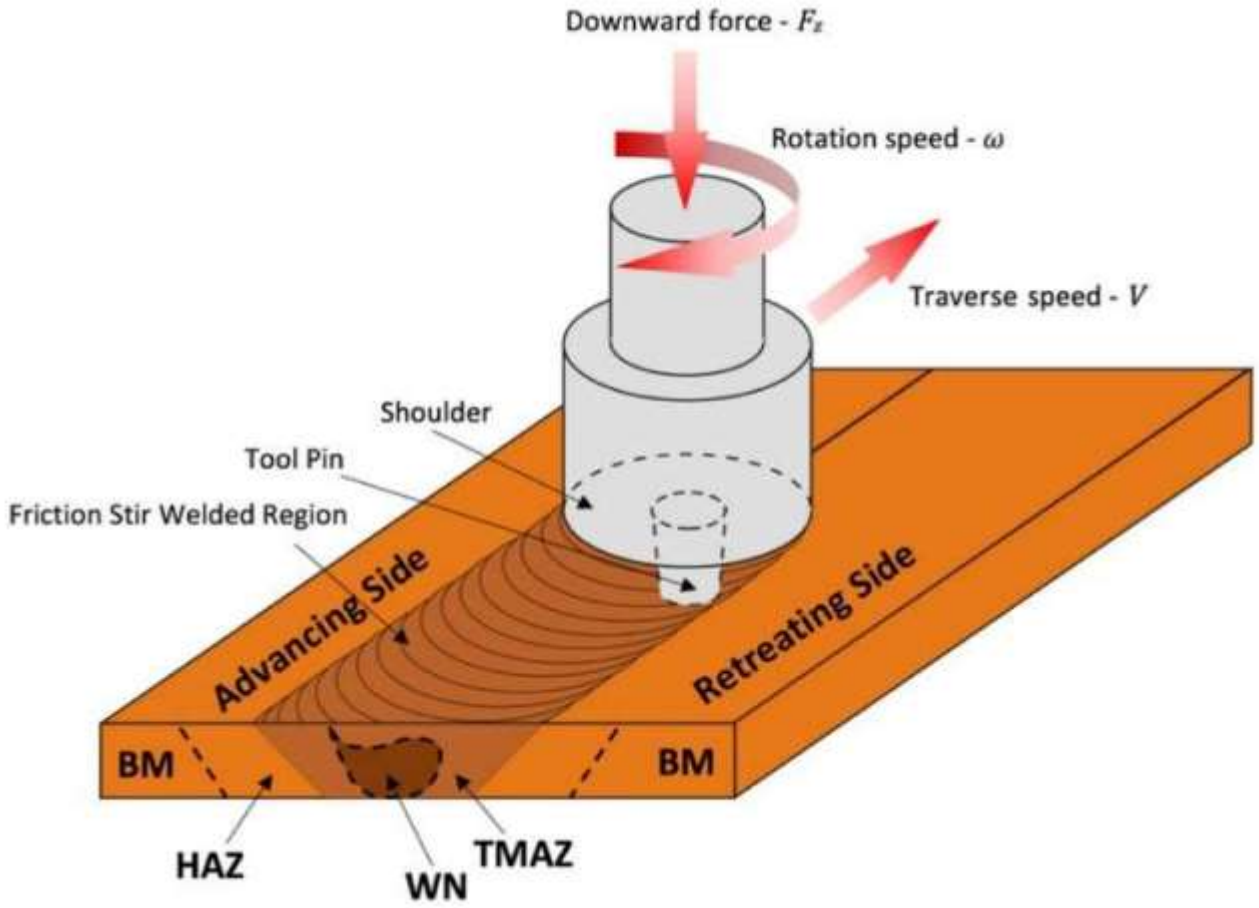
- **Tool Design:** The design of the tool is a critical factor, as a good tool can improve both the quality of the weld and the maximal possible welding speed.



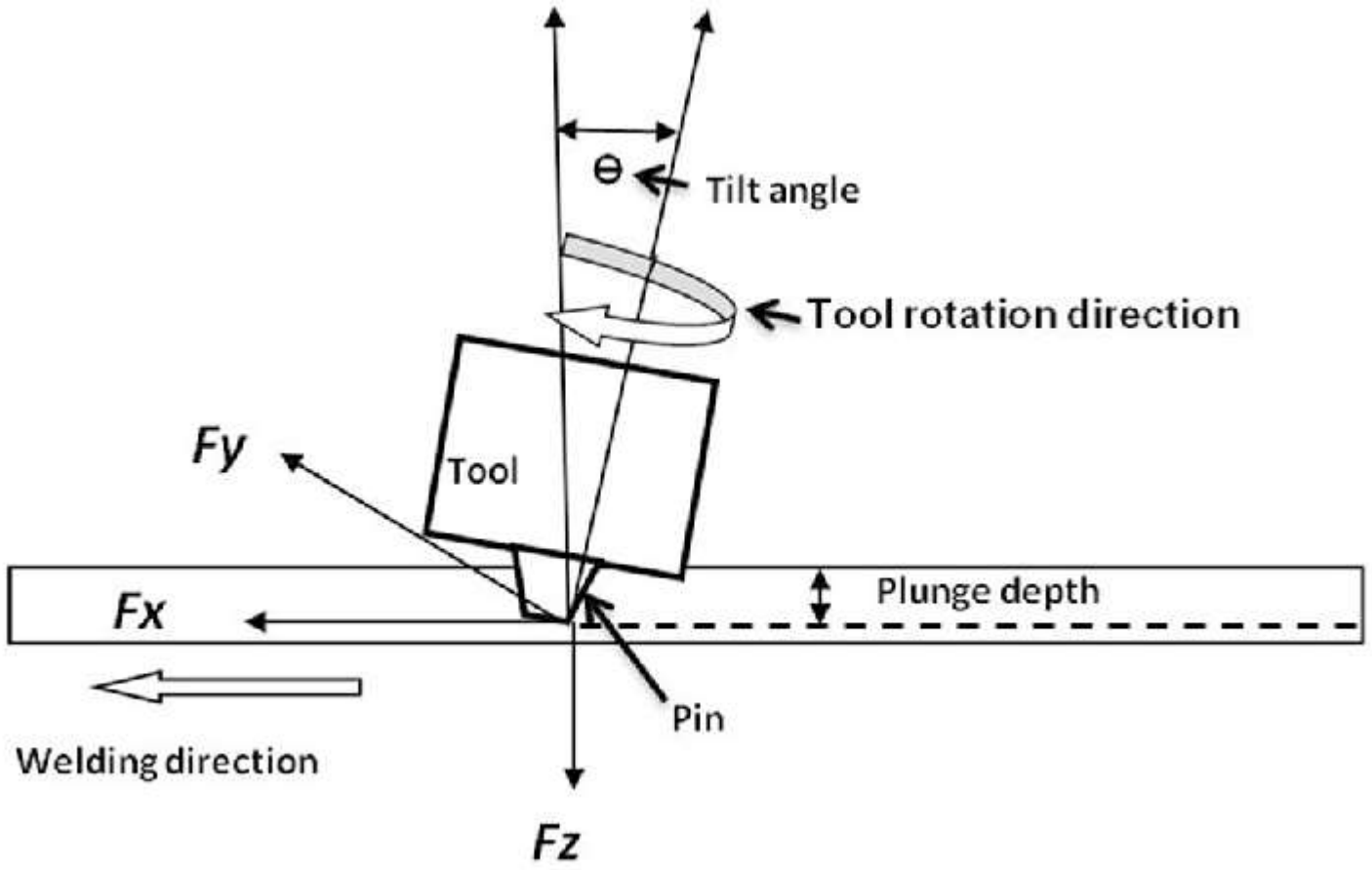
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Tool rotation and traverse speeds

- There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses along the interface



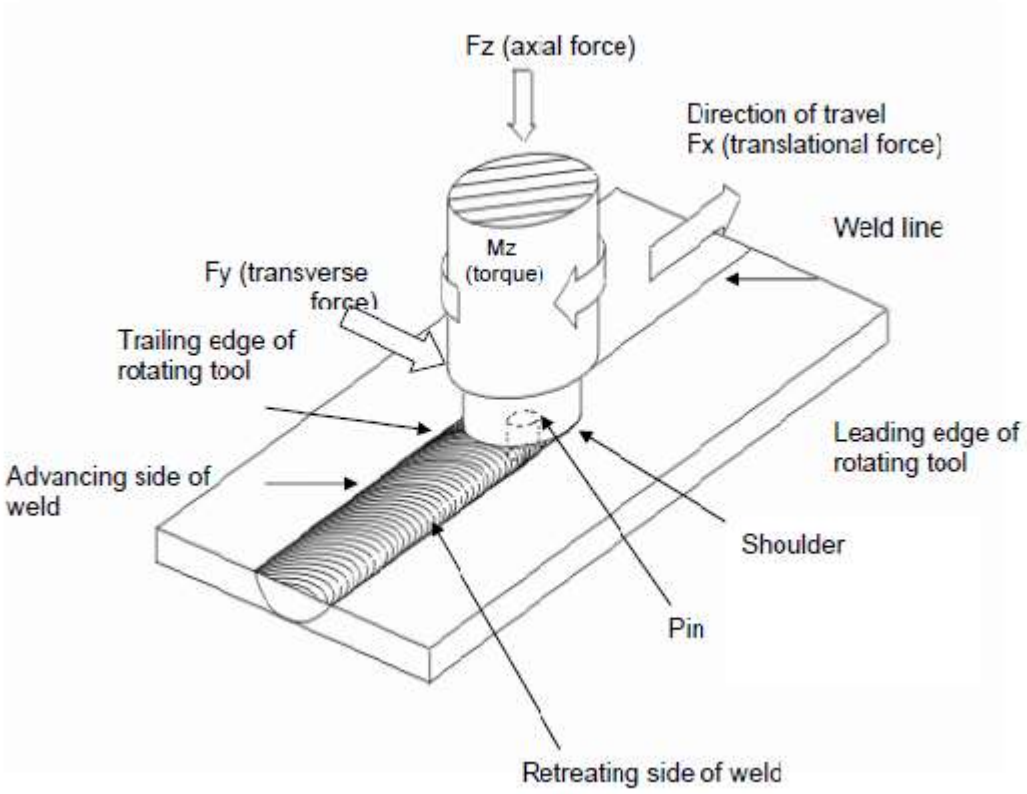
- **Tool tilt and plunge depth**



Welding forces

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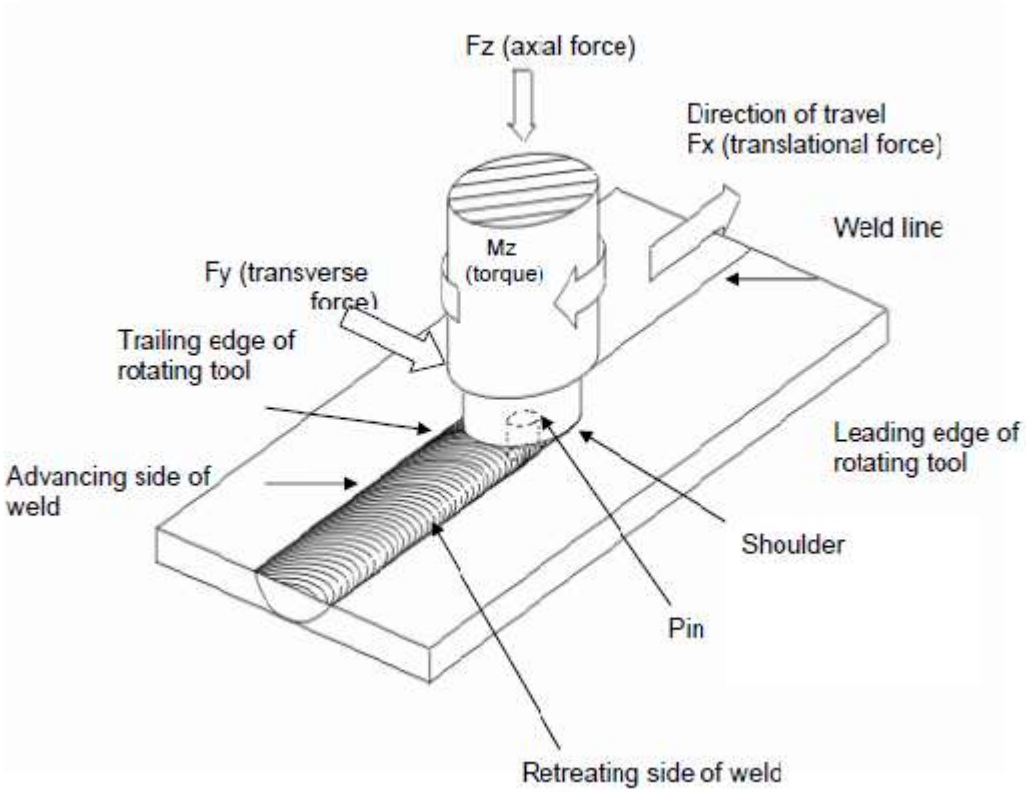
- A downwards force is necessary to maintain the position of the tool at or below the material surface.



Welding forces

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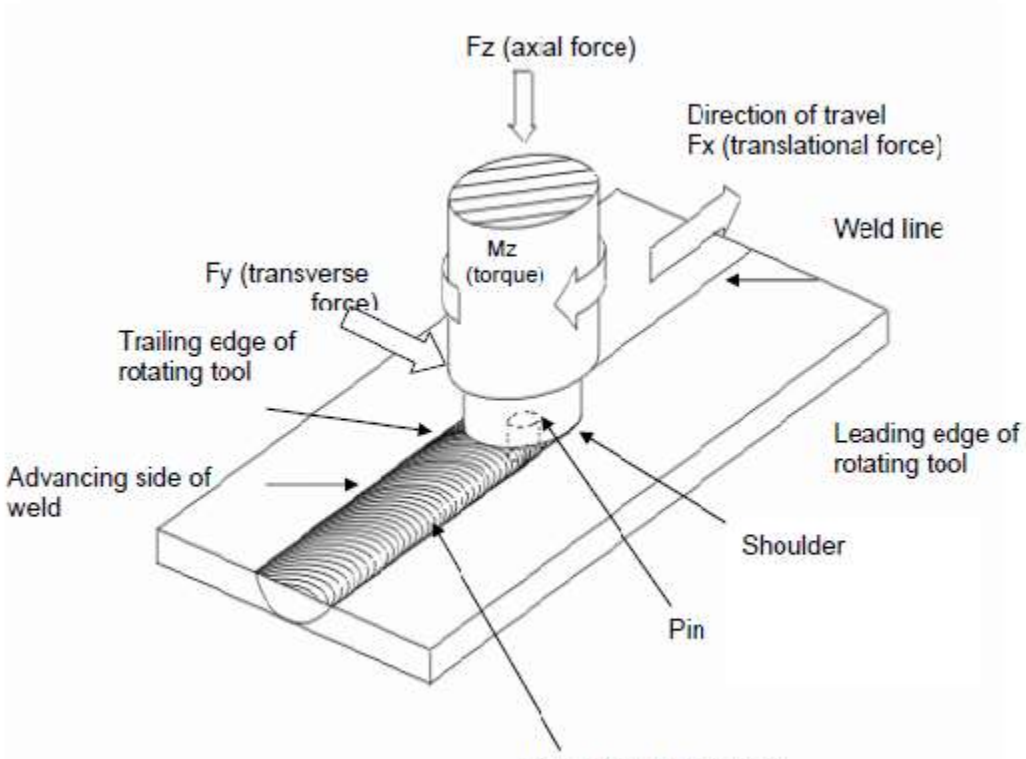
- The traverse force acts parallel to the tool motion and is positive in the traverse direction.



Welding forces

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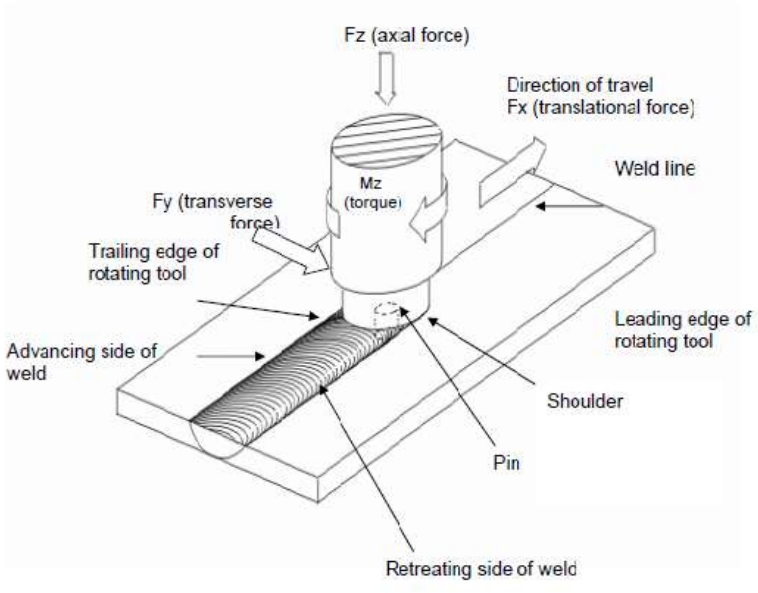
- The lateral force may act perpendicular to the tool traverse direction and is defined here as positive towards the advancing side of the weld.



Welding forces

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- Torque is required to rotate the tool, the amount of which will depend on the down force and friction coefficient (sliding friction) and/or the flow strength of the material in the surrounding region



Applications

- Shipbuilding and offshore
- Aerospace
- Automotive
- Railways
- Fabrication
- Robotics
- Personal computers

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Unit 5

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Non-destructive testing (NDT) of welds: Ultrasonic Testing

- Non-destructive testing of weld (NDT) is the process of testing, inspecting or evaluating materials, components or assemblies for discontinuities without causing damage.

- An error in welding process may cause damage of weld metals significantly resulting in loss of strength, durability and failure of structure.

- To ensure satisfactory performance of a welded structure, the quality of weld must be determined by adequate testing procedures.

- If a weld is required to withstand severe loading conditions, it is critical to meet its minimum quality standards and hence proof testing becomes essential under conditions that are same or more severe than the field.

- NDT of welds is commonly performed to examine weld integrity. Nondestructive testing of welds are essential as destructive testing necessitates replacing it with new but untested weld.

- Nondestructive tests are performed in the cases when test piece that is tested is too precious to be destroyed or to be re used after testing or test piece is in service.

- Nondestructive testing of welds detects internal flaws that could cause weld failure.

Types of Non-destructive testing of welds

- Visual inspection
- Magnetic particle inspection
- Dye penetrant inspection
- Radiography testing
- Ultrasonic testing

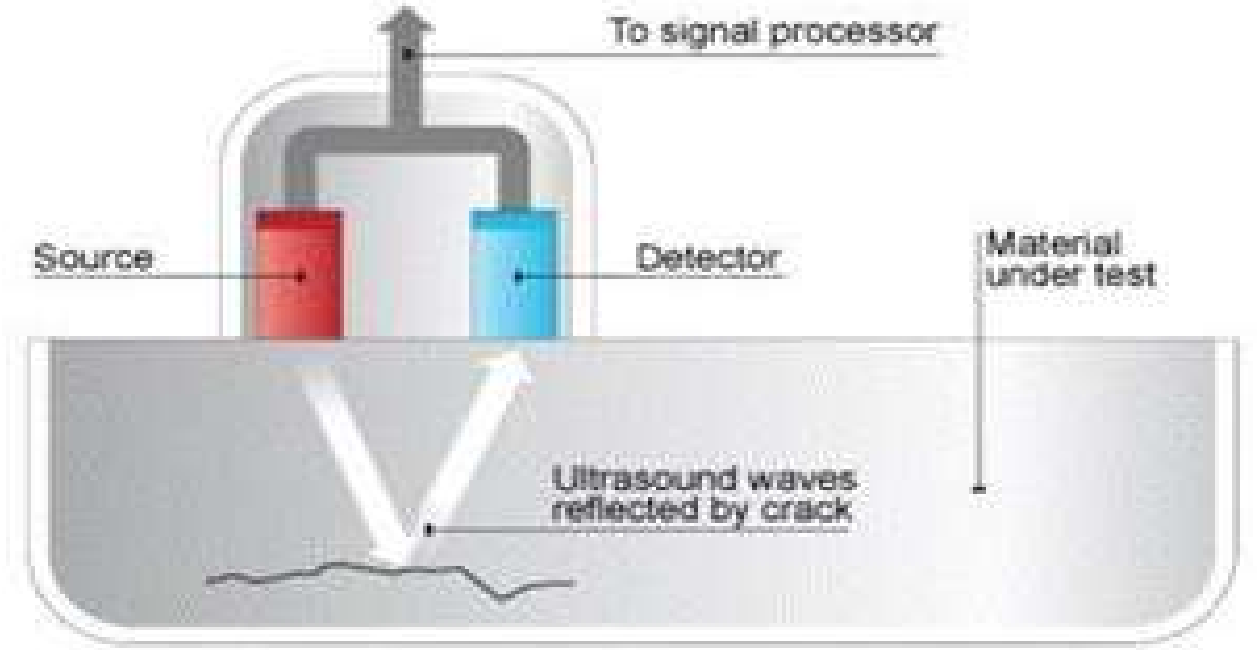


Ultrasonic testing:

- Ultrasonic test is one of the common methods of NDT of materials.
- The biggest advantage of this method is it does not harm human operator.
- This method involves using mechanical vibrations in the form of ultrasonic waves for internal flaw detection.
- The first step in ultrasonic testing involves removal of all the paint and rust from welding seams.
- Then, the piezoelectric transducer is connected to a flaw detector. Now the transducer is placed over object under test.
- For more accurate results, weld seam and the metal surface around weld seam should be treated with "**couplant**".

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- This couplant efficiently transmits sound energy from transducer into the object.
- Now a beam of ultrasonic energy is directed into the object to be tested.
- This beam travels through object with insignificant loss till it is intercepted and reflected by a discontinuity.



Ultrasonic test can be performed using any of the following methods:

- **Pulse echo transmission**: In this method, transducer alone emits and receives the ultrasonic energy. This method uses echo signal at an interface (usually at an imperfection) to reflect the waves back to the transducer. The results are shown graphically, with amplitude representing intensity of reflection on Y-axis and distance or time on X-axis.

- **Through transmission**: In this method, separate emitter to emit ultrasonic waves and receiver to receive reflected waves is used. Imperfection in the material causes lesser amount of sound waves at the receiver so that the location of flaw is detected.

Ultrasonic testing can also be split again into two main types:

- **Contact ultrasonic testing**: This type of ultrasonic testing is typically useful for onsite inspections. This test is only applicable when one side of test specimen is reachable and the parts to be tested are large, irregular in shape or difficult to transport.

- **Immersion ultrasonic testing**: This type of ultrasonic testing is lab-based test and mainly applicable for curved components, complex geometries. In this method, the material under test is immersed in water which acts as a couplant. Immersion Ultrasonic testing utilises pulse-eco method and robotic probe trajectories can be used to inspect complex surfaces which are hard to cover with contact probes. Immersion UT is used for detecting wide range of wall thickness and material types.

Advantages of ultrasonic testing:

- High sensitivity which allows detection of very small flaws.
- This test is useful for thicker sections and when only one side of an object is accessible.
- This test can detect finer lines or plainer defects which cannot be detected in radiographic testing.
- Estimates size, shape and orientation and nature of defects.
- Non hazardous to the human operator.
- Portable operations are possible.
- Immediate results are obtained.

Disadvantages of ultrasonic testing:

- Requires trained and experienced technicians for data interpretations
- Some times this method gives false positive results, also known as spurious signals. This may result in tolerance anomalies.
- Surface preparations such as removal of loose paint is necessary. But clean properly bonded paint can be left in place.
- Couplants are necessary.

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WELDING PROCEDURE SPECIFICATIONS (WPS)

Welding Procedure Specifications

- To define and document the details that are to be carried out in welding specific materials.
- The content should be sufficient, detailed to ensure that the welding will meet all requirements of the applicable code and standard.

Base Metals and applicable specifications

1. Give the chemical composition.
2. Indicate condition of base metal before welding

   (Normalized, annealed, quenched and tempered, solution treated) .

3. The fabricator must know the identity of all materials

   The rolling direction of plate should be identify

Welding process (partial listing)

1. Oxyacetylene "OAW" 2. Brazing 3. "SMAW" 4. "GMAW" 5. "FCAW"
6."GTAW" 7. "SAW" 8. "ESW" 9. "SW"

Type, classification, composition of filler metal

- Composition, classification designation of the filler metal must be included
- Also included in specifications

  a. Size of electrode or filler metal for varying (positions, metal thickness)

  b. Storage requirements Low hydrogen "electrodes require a dry (120 C)

Type of current and current range

- AC or DC (DCRP or DCSP).
- Current range should be listed for each of the welding variables (position, thickness, electrode size).

Welder qualification requirements

- Welding operator qualification.
- Make reference to applicable welder qualification specifications

Joint designs and tolerances

- Indicate joint design details as well as welding sequence.
- Use crops sectional sketches that show the thickness of material and details. of the joint or refer to standard drawings or specifications.
- Give tolerances for all dimensions.
- Joint preparation and cleaning of surfaces for welding (Before or after welding or cutting).
- Joint welding details, give details for (i.e. amps, electrode size, sequence of passes, weave limitations, etc.).

Preheat and inter pass temperatures

- measured by touching the work piece close to the weld joint with .

Peening

- If peening is to be used, give details of its application and verify the results during qualification test welding
- Peening the middle layer of a weld distributes and balances distortion.

Heat input

- Heat-treated alloy steels, must not heat above the final tempering temperature used by the steel mill.
- Specify the preheat and inter pass temperature range “maximum”.
- Arc voltage range “maximum”.
- Welding current range “maximum”.
- Travel speed “minimum”.

Root preparation prior to welding from second side

- Describe how (Chipping, grinding, air carbon arc gouging, oxyacetylene gouging, or whatever).

Removal of weld section for repair

- May be the same procedure used for preparing the root from the second side .

Repair Welding

- Give details of any repair welding methods and procedures .

Examination

- Type of examination for each joint will receive (i.e. radiography, magnetic particle, etc.).
- Visual inspection of every weld is routinely required

Post heat treatment

- Give a full description or reference drawing, or document.
- heat-treated alloy steels should not exceed the final tempering temp that was given the base metal.
- If a full reheat treatment is intended, do the welding with the metal in the annealed condition.

Marking

- Require that welder identification marks be made on or near each weld.
- Maintaining a record of welds made by the welders.
- “I.D.” marking made with low stress steel die stamps.

Records

- Indicate detailed records of the welding joints.

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Welding Procedure Specification

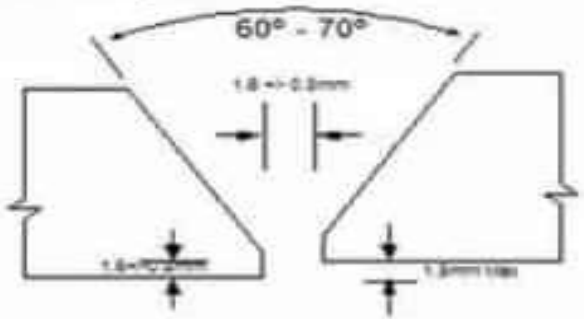
Client:	Mobil	Project:	221010Goatee	REF No.	WPS 6 R1
Procedure Description:	12" Heavy Wall Offshore Tie-in			0290/1/WPS5	
Material:	AS3679.1 Grade 250API 5L X65	Diameter:	168.3	Thickness:	18.3
Position:	6G	Clamp Type:	Internal		
Preheat °C (Min):	100	Interpass °C (Max):	300		

	ROOT	HOT PASS	FILL & CAP
Welding Process	SMAW	SMAW	SMAW
Welding Direction	Vertical Down	Vertical Down	Vertical Down
Filler	Lincoln SA70+	Lincoln SA70+	Bohler BVD90M
Polarity	DC +ve	DC +ve	DC +ve
Shielding Gas	N/A	N/A	N/A
Purge Gas	N/A	N/A	N/A

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Pass No	Filler Size (mm)	Amps	Volts	Speed (mm/sec)	Heat Input (kJ/mm)
1	3.2mm	70-130	15-33	3.3-6.6	0.4-0.8
2	4.0mm	110-210	15-35	2.9-6.8	0.6-1.3
FILL	4.0mm	145-260	16-27	1.6-7.0	0.8-2.2
CAP	4.0mm	130-230	16-26	1.8-5.3	0.8-1.7

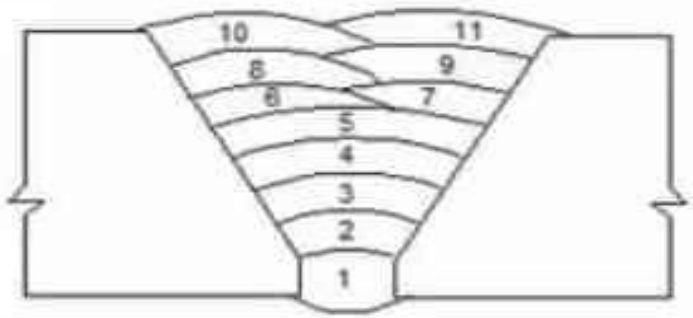
Weld Preparation



NOTES

1. API Std 1104BP3094-SP-PL-3010R1
2. Clamp removal stage : **100% completion of root (external clamp may be used in the event of a breakdown – removed after 50% minimum completion of the root.)**
3. Time lapse between root and second pass : **16 Minutes**
4. Time lapse between second pass and 1st fill : **12 Minutes**
5. Minimum number of passes before pipe movement : **2 passes**
6. Minimum number of passes before break in welding : **3 passes**
7. Minimum Number of welders- **Root & second pass: 2 , Fill & Cap : 1**
8. Method of cleaning : **Grinder / Wire brush**
9. Method of Preheat : **Gas Torch**
10. Qualification reference number : **48280/PP/WP6 R1**

Pass Location



Company Welding Engineer Approved ..... **Approved for Client** .....