Welding Metallurgy

SESSION 02

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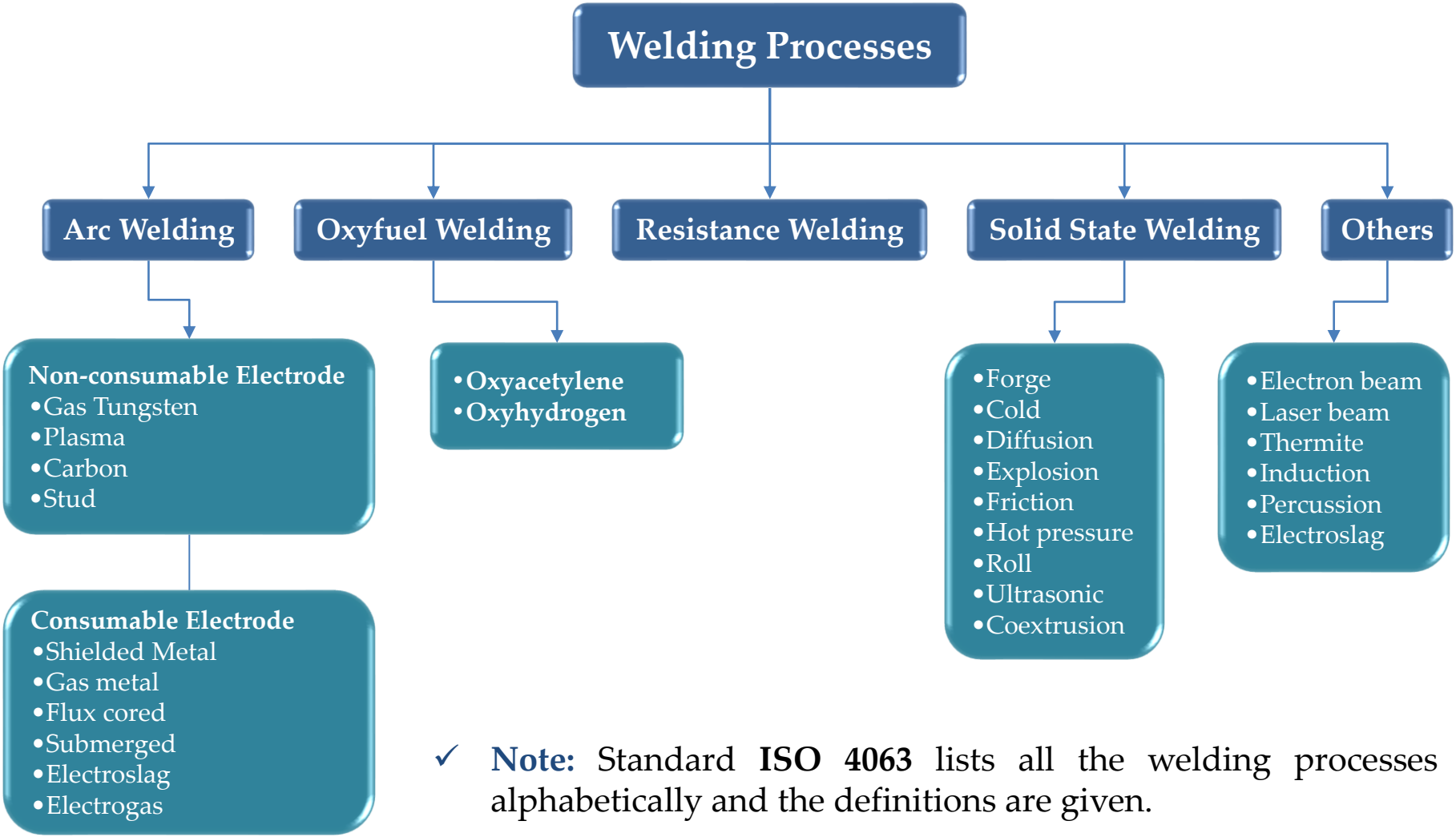
Grouping of welding processes

- ✓ The grouping of welding processes has been made according to the **mode of energy transfer** as a primary consideration.
- ✓ During the classification, the designation of **pressure** or **non-pressure** has been omitted since the factor of pressure is an element of operation of the applicable process.
- ✓ Other terms and factors, such as the type of current, whether the electrodes are **continuous** or **incremental** or the **method of application** are not considered.
- ✓ **Coalescence:** is defined as the growing together or growth into one body of the materials being welded and is applicable to all types of welding.

Classification of Welding Processes Welding



✓ **Note:** Standard **ISO 4063** lists all the welding processes alphabetically and the definitions are given.

Definition of Welding Groups

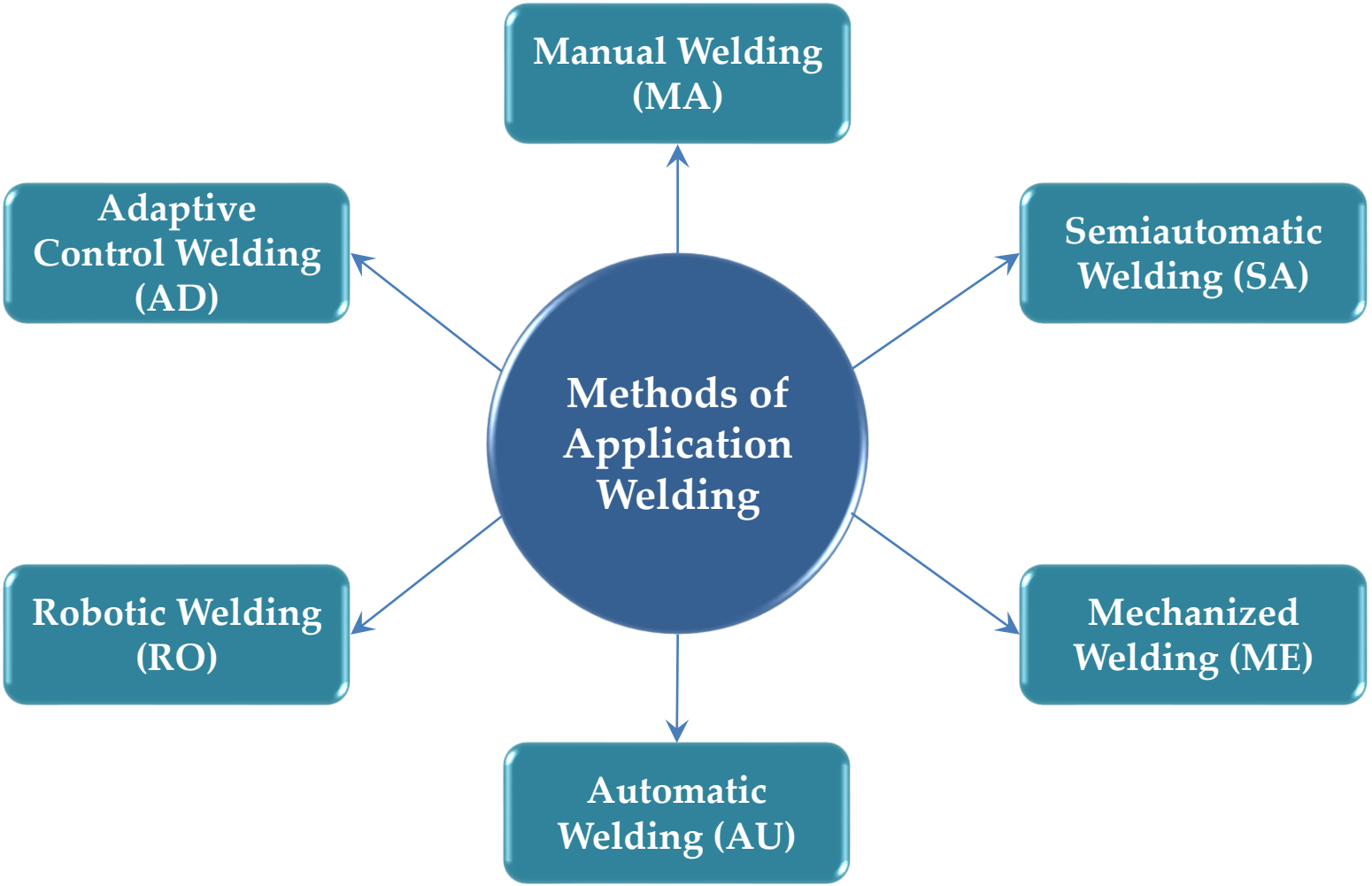
- **Arc welding:** A group of welding processes that produce coalescence of workpieces by heating them with an arc. The processes are used with or without the application of pressure and with or without filler metal.

- **Oxyfuel welding:** A group of welding processes that produces coalescence of workpieces by heating them with an oxyfuel gas flame. The processes are used with or without the application of pressure and with or without filler metal.

- **Resistance welding:** A group of welding processes that produces coalescence of the faying surfaces with the heat obtained from resistance of workpieces to the flow of the welding current in a circuit of which the workpieces are a part, an by the application of pressure.

- **Solid state welding:** A group of welding processes that produces coalescence by the application of pressure without melting any of the joint components.

Methods of Application Welding



Methods of Application Welding Definition

- **Manual welding (MA):** Welding with the torch, gun, or electrode holder held and manipulated Welding with the torch, gun, or electrode holder held and manipulated.

- **Semiautomatic Welding (SA):** Manual welding with equipment that automatically controls one or more of the welding conditions.

- **Mechanized Welding (ME):** Requires manual adjustment of the equipment controls in response to visual observation, with torch, gun or electrode holder by a mechanical device.

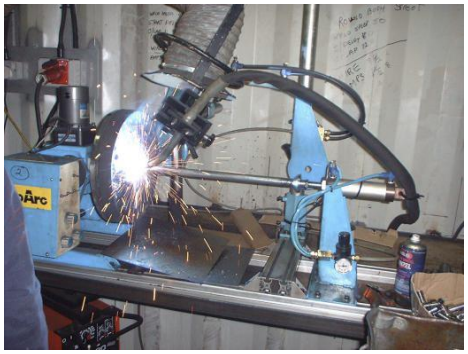
- **Automatic Welding (AU):** Requires only occasional or no observation of the welding and no manual adjustment of the equipment controls.

- **Robotic Welding (RO):** Welding that is performed and controlled by robotic equipment.

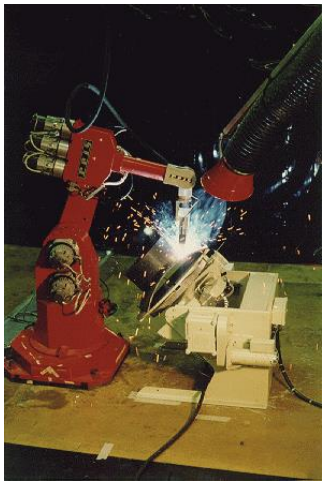
- **Adaptive Control Welding (AD):** Welding with a process control system that determines changes in welding conditions automatically and directs the equipment to take appropriate action.

Methods of Application Welding Figures

Manual Welding



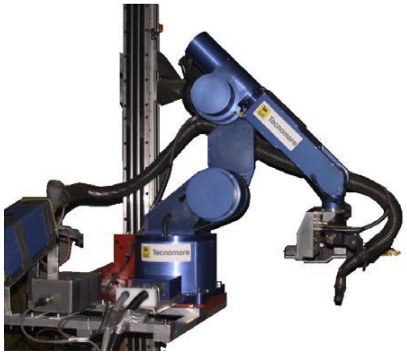
Semiautomatic Welding



Adaptive Control Welding

Mechanized Welding

Automatic Welding



Robotic Welding

Arc welding with a non-consumable electrode

- There are two basic types of welding arcs: One uses a **non-consumable electrode** and the other uses a **consumable electrode**..

- The non-consumable electrode does not melting the arc, and filler metal is not carried across the arc gap. The welding processes are:

  - ✓ Gas tungsten arc welding
  - ✓ Plasma arc welding
  - ✓ Carbon arc welding

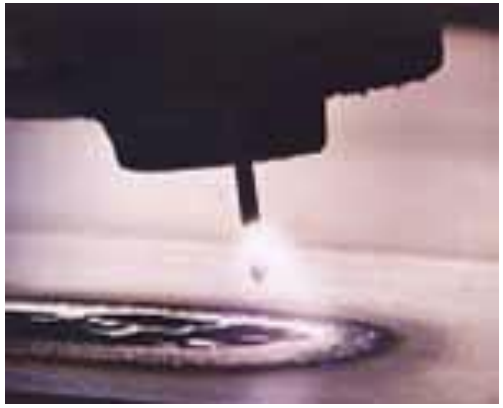
- The main function of the arc is to produce **heat**. At the same time it produces a bright light, noise, and ionic bombardment that removes the oxide surface of the base metal.

Arc Welding

- Arc welding is a sustained high-current, low-voltage electrical discharge through a high conducting plasma that produces sufficient thermal energy which is useful for joining metals by fusion.
- The arc welding occurs between the end of an electrode and a workpiece that carries current.

  - An arc starts from 1A ➔ 3000A
  - Voltage starts from 10V ➔ 40V

- Whether the electrode is positive or negative, the arc is restricted at the electrode and spread out toward the workpiece.
- The length of the arc gap is **proportional** to the voltage.
- **The arc length** for welding is the dimension equal to the electrode diameter, up to about four times the electrode diameter.

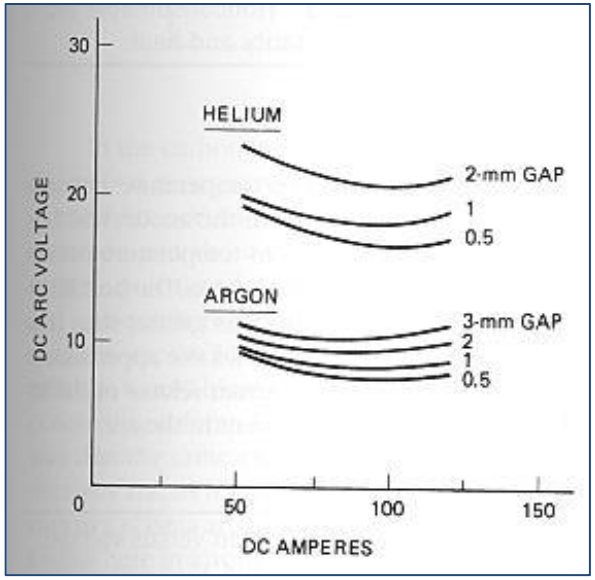


Arc Welding

Arc Welding

- The arc column is normally round in cross section and is made of two concentric zones: an inner core or plasma and an outer flame.
  - ✓ The plasma carries most of the current and has the highest temperature.
  - ✓ The outer flame of the arc is much cooler and tends to keep the plasma in the center.

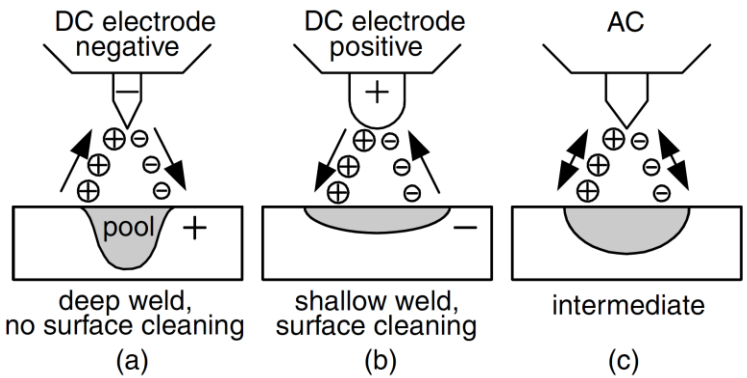
- The temperature and the diameter of the central plasma depend on the amount of current passing through the arc, the shielding atmosphere, electrode size, and type.
- The relationship between current and arc voltage is not a straight line. In general, the arc voltage increases slightly as the current increases.



Arc Characteristics volt – ampere curve

Polarity of Arc Welding (AW)

1. **Direct-Current Electrode Negative (DCEN)** This, also called the straight polarity, is the most common polarity in AW. The electrode is connected to the negative terminal of the power supply. As shown in **Figure a**, electrons are emitted from the tungsten electrode and accelerated while traveling through the arc. A significant amount of energy, called the work function, is required for an electron to be emitted from the electrode. When the electron enters the workpiece, an amount of energy equivalent to the work function is released. This is why in AW 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.
2. **Direct-Current Electrode Positive (DCEP)** This is also called the reverse polarity. The electrode is connected to the positive terminal of the power source. As shown in **Figure b**, the heating effect of electrons is now at the tungsten electrode rather than at the workpiece. Consequently, a shallow weld is produced. Furthermore, a large-diameter, water-cooled electrodes must be used in order to prevent the electrode tip from melting.
3. **Alternating Current (AC)** Reasonably good penetration and oxide cleaning action can both be obtained, as illustrated in **Figure c**. This is often used for welding aluminum alloys.



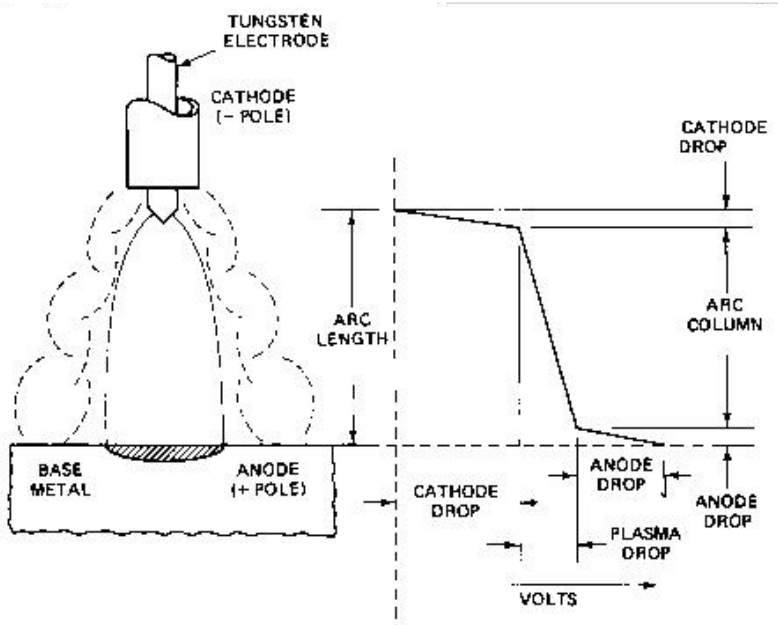
Three different polarities of Arc Welding AW

Arc Welding

- The arc length or gap between the electrode and the work can be divided into three regions:
  - a central region,
  - a region adjacent to the electrode, and
  - a region adjacent to the work.

- At the end regions the cooling effects of the electrode and the work cause a rapid drop in potential, known as anode and cathode drop.

- The length of the central region or arc column represents 99% of the arc length and is linear with respect to arc voltage.



Arc region vs voltage and heat.

Arc Welding Penetration

- **The thermal energy** generated in the arc is the product of **welding current** and **arc voltage**. The heat raises the temperature of the base metal, causing melting and resulting in a molten pool.

- The heat of the arc is distributed through **radiation, convection**, and **conduction** to the base metal.

- Penetration of the arc depends on;
  - ✓ Polarity of the arc
  - ✓ The composition of shielding gas
  - ✓ Mass of the base metal and its composition (thermal conductivity and melting temperatures)
  - ✓ Preheat temperature

Welding Current 

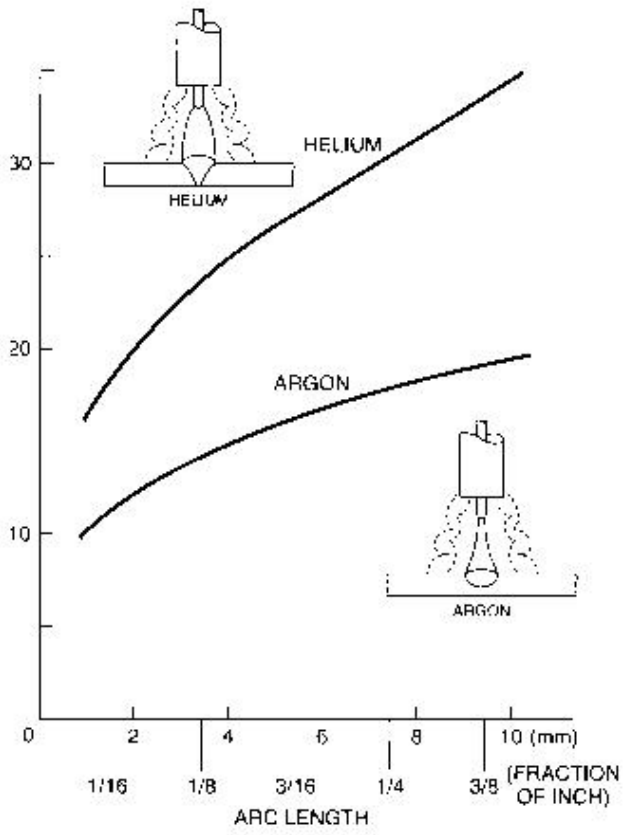
Travel Speed of Current 

Depth of Penetration 

Arc Welding Gas Composition

- The gas composition of the area surrounding the arc has an influence on the characteristics of the arc.
- The voltage of a helium-shielded arc is higher than that of an argon-shielded arc for the same length carrying the same current, due to the higher ionization for
  - helium ➔ (24.5V).
  - Argon ➔15.7V.

- The arc shielded with helium has more power (heat) and can do more work. The helium shielded arc column is;
  a) Larger.
  b) More penetration.
  c) Higher travel speed.
  d) Weld heavier base metals.



Arc Voltage and Arc Length

(GTAW) Principles of Operation

1. The process utilizes the heat (≈6100 °C) of an arc between a non-consumable tungsten electrode and the base metal, that is melted to form a melted pool.

2. Filler metal is not added when thinner materials, edge joints and flange joints are welded. This is called as **autogenous welding**.

3. For thicker materials an externally fed or cold filler rod is generally used.

4. The arc area is protected from the atmosphere by the inert shielding gas flown from the nozzle of the torch.

5. The shielding gas **displaces the air**, so that the oxygen and the nitrogen of the air do not come in contact with the molten metal or the hot tungsten electrode.

6. There is little or no spatter and little or no smoke.

7. The resulting weld is smooth and uniform and requires minimum finishing

(GTAW) Advantages and Major uses

1. High quality of welds in almost all metals and alloys.
2. Very little, if any, post-weld cleaning is required.
3. The arc and weld pool are clearly visible to the welder.
4. There is no filler metal carried across the arc, so little or no spatter.
5. Performed in all positions.
6. No slag produced that might be trapped in the weld.
7. Extreme control for precision work and high quality.
8. Heat can be controlled very closely and the arc can be accurately directed.
9. Used for mainly thinner materials.
10. Very useful for maintenance and repair work.
11. Welding for unusual metals.
12. Joining thin wall tubing and making root passes in a pipe joints.
13. Manual (mostly), mechanized, automatic and semiautomatic (limited) applications are available.

Material used to weld by (GTAW)

Base Metal	Weldability
Aluminium	Weldable
Bronze	Weldable
Copper	Weldable
Copper nickel	Weldable
Cast iron, malleable, nodular	Possible but not popular
Wrought iron	Possible but not popular
Lead	Possible
Magnesium	Weldable
Inconel	Weldable
Nickel	Weldable
Monel	Weldable
Precious metals	Weldable
Low-carbon steel	Weldable
Low-alloy steel	Weldable
High- and Medium carbon steel	Weldable
Alloy steel	Weldable
Stainless steel	Weldable
Tool steel	Weldable
Titanium	Weldable
Tunsten	Possible

(GTAW) Equipment

- Optional items:
  - Cold filler rod
  - Foot pedal used to regulate the current.
  - Cooling water used for welding torch at high current.
  - Direct current (DC) and Alternating current (AC) can be used.
- The main component is the welding **power source**. The **constant-current(CC)** power source is used.
- A GTAW machine has following features:
  - High-frequency stabilizer
  - Gas and water valves
- A GTAW machine operates with;
  - 3A to 200A of 5A to 300A
  - 10V to 35V

(GTAW) Equipment

- The torches used for GTAW are designed and used on for that purpose:
    1. Torches for automatic welding
    2. Torches for manual welding
    3. Air-cooled torches for lower current
    4. Water-cooled torches for high current welding

(GTAW) Material used

- **Filler metal**
    - Not used for extremely thin metals
    - Depends on the thickness of the base metal
    - In manual welding, weld rod is used. Coils or spools is used for automatic

(GTAW) Equipment

❖ **The tungsten electrode**

- Tungsten has the highest melting point of any metal (3410 °C)
- The diameter ranges from 0.5mm to 6.4mm. The length differs from 75mm to 610 mm

❖ **The shielding gas**

- Must be inert gas
- Only **argon** and **helium** are used
- Gas selection is based on metal to be welded
- Argon is more commonly used, and is **heavier** than air which provides for a more efficient arc shielding. Argon is better for arc starting and operates at a lower arc voltage.
- Helium is much **lighter** than argon and higher flow rates are required.
- In some cases, helium and argon are mixed for the optimum shielding gas

(GTAW) Variables

- ❖ There are a number of variables and each variable has a specific effect on the weld and there is an interrelationship among variables.
- ✓ Preselected variables:
  - Tungsten type, Tungsten size, Nozzle size, Gas type
- ✓ Primary variables:
  - Welding current, Arc voltage, Travel speed, Pulsing when used
- ✓ Secondary variables:
  - Rod feed speed, torch angles, tungsten angles
- ✓ Other factors:
  - Clamping, fixturing, heat sinks, heat buildup, backing, purging gas, high freq.

(GTAW) Limitations

1. The major limitation is the **low productivity**.
2. The power source and the torch are **more expensive.**
3. So many metals in thicknesses, positions not possible by shielded metal arc welding.

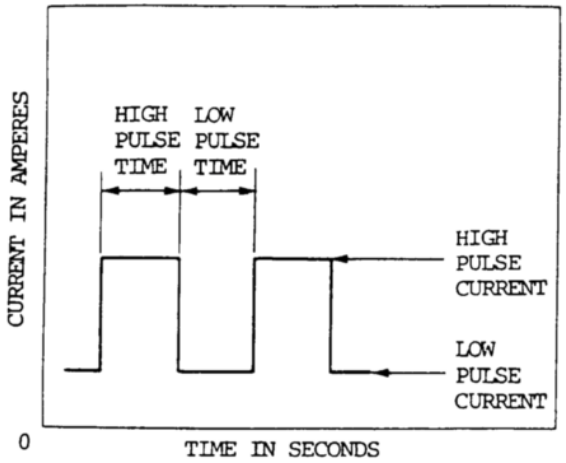
(GTAW) Variations

- **Pulsed-current GTAW:** the welding current continuously changes between two levels. During the period of high-pulsed current, heating and fusion take place, during the low-pulsed current period, cooling and solidification take place.

- **Manual programmed GTAW:** welding current rise and fall at specific rates to specific values are programmed. A switch mounted on the torch is used to start and stop the program. It is popular for welding tubing and root pass welding of pipe.

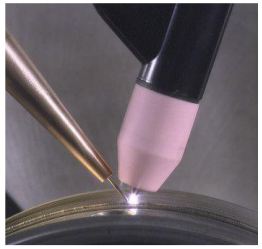
- **Hot-wire GTAW:** uses electrical power on filler metal. The filler rod that is fed into the weld puddle is electrically hot. It enters the weld pool at an elevated temperature and melts quickly. It is used for weld surfacing.

- **Dabber welding:** for the precise placement of weld metal on thin edges. The cold filler wire is fed continuously and the arc length is changed with the feeding of the cold wire. It is used to weld many special alloys, rebuilding jet engine seals, blades, valve seats, milling cutters, drill bits and other devices.



Pulsed Current

Manual



Dabber

(GTAW) Industrial use and typical applications

- ✓ The aircraft industry
- ✓ Space vehicles fabrication (shells, structures, various tanks)
- ✓ Thin-wall tubing
- ✓ Root-pass welds in piping
- ✓ Repair and maintenance industry
  - Repairing tools and dies
  - Repairing aluminium and magnesium parts
  - Repairing of highly critical items