# WELDING

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## CONTENTS



## 1. Introduction

- **Welding** is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence.
- This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the *weld pool*) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld.
- This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the workpieces to form a bond between them, without melting the workpieces.

## Historical Background

- **Late 19th Century**
    - Scientists/engineers apply advances in electricity to heat and/or join metals (Le Chatelier, Joule, etc.)
- **Early 20th Century**
    - Prior to World War I welding was not trusted as a method to join two metals due to crack issues
- **1930's and 40's**
    - Industrial welding gains acceptance and is used extensively in the war effort to build tanks, aircraft, ships, etc.
- **Modern Welding**
    - The nuclear/space age helps bring welding from an art to a science

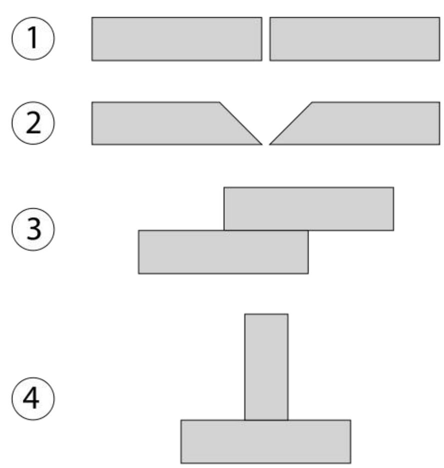


**Fig. 2 Common welding joint types – (1) Square butt joint, (2) V butt joint, (3) Lap joint, (4) T-joint**

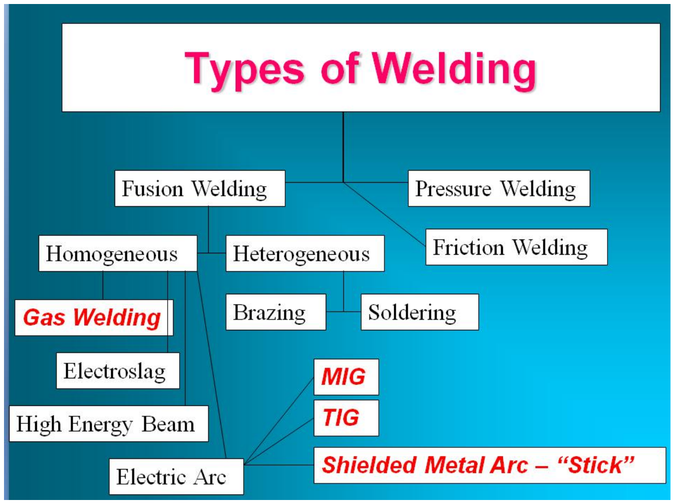


**Fig. 3 Types of Welding Process**

## Weldability of a metal

- Metallurgical Capacity
  - Parent metal will join with the weld metal without formation of deleterious constituents or alloys
- Mechanical Soundness
  - Joint will be free from discontinuities, gas porosity, shrinkage, slag, or cracks
- Serviceability
  - Weld is able to perform under varying conditions or service (e.g., extreme temperatures, corrosive environments, fatigue, high pressures, etc.)

## Fusion Welding Principles

- Base metal is melted
- Filler metal may be added
- Heat is supplied by various means
  - Oxyacetylene gas
  - Electric Arc

- Plasma Arc
- Laser

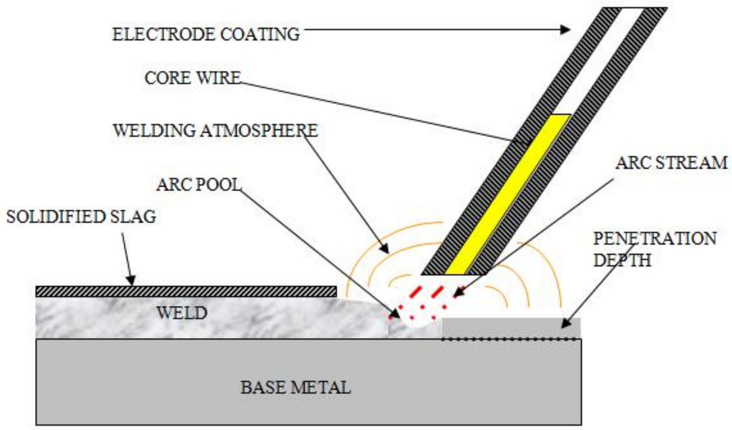


**Fig.4 Fusion Welding**

**Fusion Welding**

- During fusion welding, the molten metal in the weld "puddle" is susceptible to oxidation
- Must protect weld puddle (arc pool) from the atmosphere
- Methods
  - Weld Fluxes
  - Inert Gases
  - Vacuum

**Weld Metal Protections**

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**Welding fluxes**

- $SiO_2$, $TiO_2$, FeO, MgO, $Al_2O_3$
- Produces a gaseous shield to prevent contamination
- Act as scavengers to reduce oxides
- Add alloying elements to the weld
- Influence shape of weld bead during solidification

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**Types of Fusion Welding**

- Oxyacetylene Cutting/Welding
- Shielded Metal Arc ("Stick")
- Metal Inert Gas (MIG)
- Tungsten Inert Gas (TIG)

**Manual Metal Arc Welding / Shielded Metal Arc (Stick)**

- An electric arc is generated between a coated electrode and the parent metal
- The coated electrode carries the electric current to form the arc, produces a gas to control the atmosphere and provides filler metal for the weld bead
- Electric current may be AC or DC. If the current is DC, the polarity will affect the weld size and application

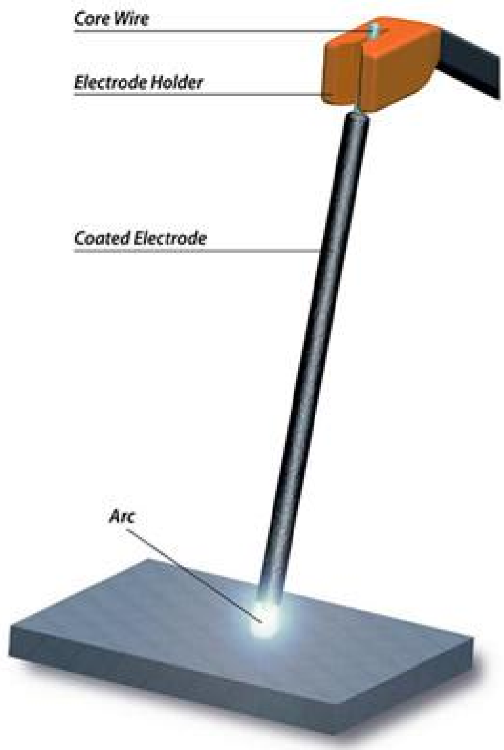


Fig. 5. Manual Metal Arc Welding

- In this process an arc is drawn between a coated consumable electrode and the work piece.
- The metallic core-wire is melted by the arc and is transferred to the weld pool as molten drops.
- The electrode coating also melts to form a gas shield around the arc and the weld pool as well as slag on the surface of the weld pool, thus protecting the cooling weld pool from the atmosphere. The slag must be removed after each layer.
- Manual Metal Arc welding is still a widely used hardfacing process.
- Due to the low cost of the equipment, the low operating costs of the process and the ease of transporting the equipment, this flexible process is ideally suited to repair work.

**Benefits of MMA Welding**

• Flexible

• Low Cost

• Mobile

• Ideal for Repairs

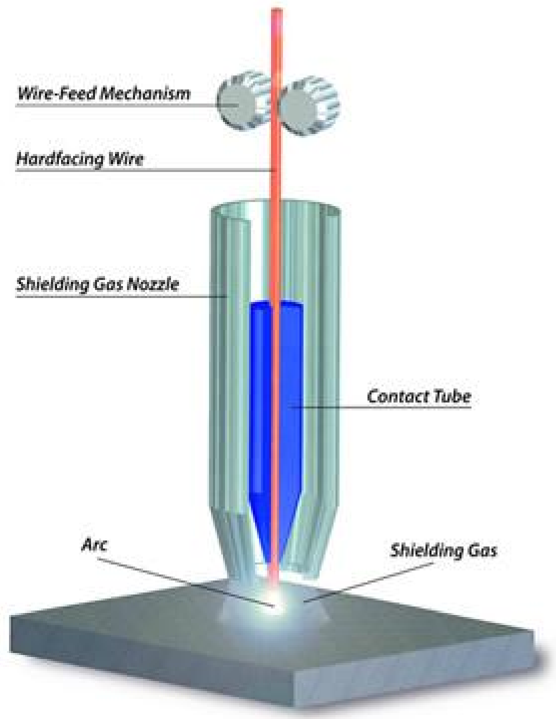


Fig. 6. Metal Inert Gas Welding

**Metal Inert Gas Welding**

- This is an arc welding process where hardfacing wire is fed continually from a spool through the welding torch into the arc, where it is melted and transferred to the work piece.
- In the case of MIG/MAG welding, the weld pool is protected from the atmosphere with a stream of shielding gas. These MIG/MAG processes are very flexible, i.e. they can be partially or fully mechanised and they are suitable for a wide range of applications.
- Wire is also used as the hardfacing consumable in the submerged arc process. In this process a mineral based fluxing powder flows around the consumable wire and is melted

by the arc. It forms a gaseous shield around the arc and also forms a slag on top of the weld pool, thereby shielding the cooling weld pool from the atmosphere.

**Benefits of MIG**

- Flexible Operation
- Can Be Partially Or Fully Mechanized
- Suitable For Wide Range Of Applications

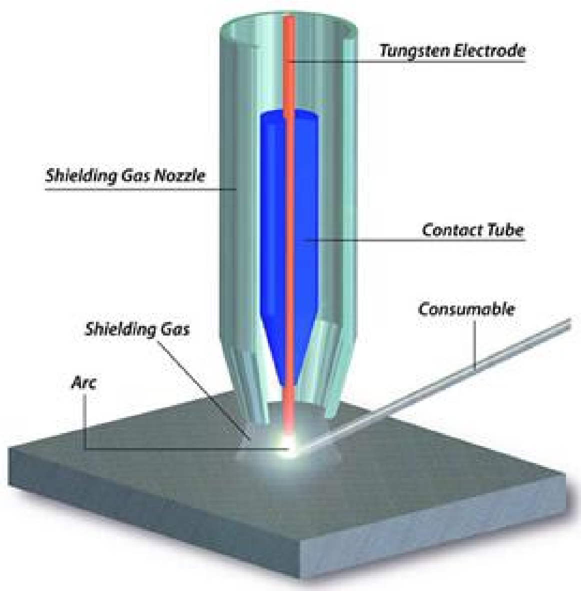


Fig. 7 Tungsten Inert Gas Welding

- In TIG (Tungsten Inert Gas) welding, an arc is drawn between a non-consumable tungsten electrode and the work piece.
- The electrode, the arc and the weld pool are protected from the atmosphere with an inert shielding gas. For manual welding the hardfacing material is in the form of a rod.
- Advantages of the TIG process include simple manual operation and good control of the welding arc.
- The process can also be mechanized, in which case a manipulator is used to move the work piece in relation to the welding torch and the hardfacing rod.

- Rods are also used for hardfacing with the Oxy Acetylene welding process. With the correct operation, a very low level of iron dilution can be achieved in the overlay.

**Benefits of TIG Welding**

• Manual Operation
• Can Be Mechanized
• Low Dilution

Figure 8 Pipe Root Weld

The blue area results from oxidation at a corresponding temperature of 600 °F (316 °C) **[Fig.6]**. This is an accurate way to identify temperature, but does not represent the HAZ width. The HAZ is the narrow area that immediately surrounds the welded base metal.

**Laser Beam Welding**

**Introduction**

**Laser beam welding** (**LBW**) is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications, such as in the automotive industry.

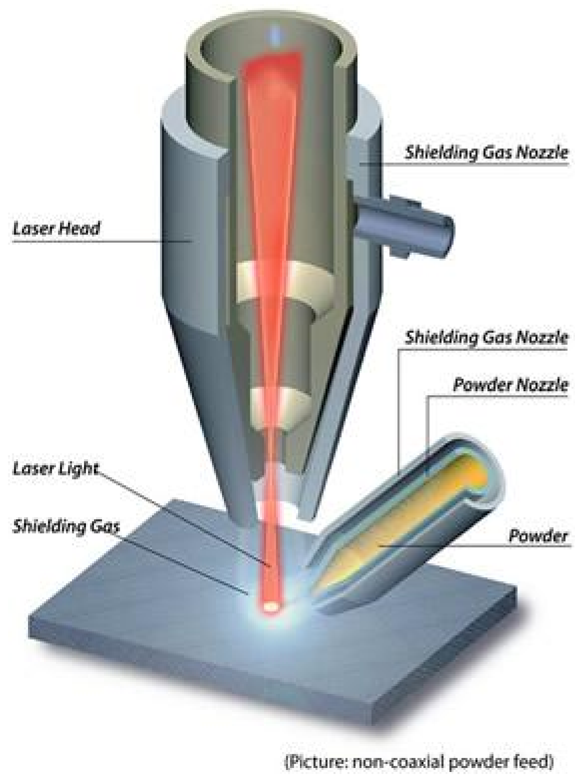


Fig. 9 Laser Beam Welding

**Process**

- When overlaying with a laser an optical arrangement is used to focus the laser beam on the work piece and heat it. Simultaneously hard-facing material in the form of powder is introduced into the laser beam and melted.
- Due to the narrow heat affected zone and the fast cooling rate the heat input is low, thereby producing an almost stress free overlay.

- Compared with other welding processes with higher heat inputs, for a given hardfacing alloy the fast cooling rate of the laser process produces an overlay with a significantly higher hardness and finer microstructure.

**Benefits of Laser**

- Low Heat Input
- Fast Cooling
- Almost Stress Free Overlays
- High Hardness
- Fine Microstructure

**Plasma Arc Cutting**

- PAC is a thermal material removal process that is primarily used for cutting thick sections of electrically conductive materials.
- Plasma can be defined as a "superheated, electrically ionized gas."

Fig. 10 Plasma Arc Cutting

**Process**

- PAC uses a high velocity jet of plasma (Temperatures range from 10,000 to 14,000 $^{o}$C) to cut through the metal by melting it.

- The high gas flow rate facilitate the removal of molten metal through the kerf
- Stream pressures can reach up to 1.4 MPa.

**Advantages**

- Cuts any metal.
- 5 to 10 times faster than oxy-fuel.
- 150 mm thickness ability.
- Easy to automate.

**Limitations**

- Large heat affected zone.
- Rough Surfaces
- Difficult to produce sharp corners.
- Smoke and noise.
- Burr often results.


Fig. 11 Plasma Arc Cutting