Plasma Arc Welding (PAW)

Process Fundamentals

Process characteristics

- Plasma welding is very similar to TIG as the arc is formed between a pointed tungsten electrode and the workpiece.

- However, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope.

- Plasma is then forced through a fine-bore copper nozzle which constricts the arc.
Plasma Arc Welding (PAW)

Process Fundamentals

Comparison TIG versus Plasma
Plasma Arc Welding (PAW)

Process Fundamentals

Comparison TIG versus Plasma

Figure 6: Welding velocity when TIG and plasma welding
Three operating modes:

1 - Micro-plasma: 0.1 to 15A.

The micro-plasma arc can be operated at very low welding currents. The columnar arc is stable even when arc length is varied up to 20 mm.
Three operating modes:

2 - **Medium current**: 15 to 200A.

The process characteristics of the plasma arc are similar to the TIG arc, but because the plasma is constricted, the arc is stiffer and less sensitive to variations of the stand-off (distance torch-to-workpiece).

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Bevel comparison between TIG (75º groove) and Plasma (60º groove) processes:
Three operating modes:

2 - Medium current: 15 to 200A.

Bevel comparison

3 - Keyhole plasma: over 100A.

- A very powerful plasma beam is created which can achieve full penetration in a material, as in laser or electron beam welding.

- During welding, the hole progressively cuts through the metal with the molten weld pool flowing behind to form the weld bead under surface tension forces.

- This process can be used to weld thicker material (up to 10mm of stainless steel) in a single pass.
3 - Keyhole plasma: over 100A.

Face

Root
3 - Keyhole plasma: over 100A.
3 - Keyhole plasma: Forces acting in keyhole

Note: keyhole stability depend on the stability of the force balance

\[ P_b + P_v = \frac{2\gamma}{r} + \rho g h \]

a) At the bottom of the keyhole

(h—total penetration of keyhole – max. depth)

\[ P_b + P_v - \frac{2\gamma}{r} \]

\[ h = \frac{\rho g}{r} \]

b) At the sides of the keyhole

Pressure vapour versus surface tension and gravitational inertia effect at the keyhole cylinder walls

\[ P_v > \frac{\gamma}{r} + \rho g x \]  

… condition to maintain a stable keyhole, preventing it from closing @ x – depth

Power source

• Operated with a DC, drooping characteristic power source. A plasma control console can be added on to a conventional TIG power source.

Arc starting

• Although the arc is initiated using high frequency (HF), it is first formed between the electrode and plasma nozzle. This ‘pilot’ arc is held within the body of the torch until required for welding.

• The pilot arc system ensures reliable arc starting and, as the pilot arc is maintained between welds, it obviates the need for HF which may cause electrical interference.
Arc starting

Figure 3: Plasma arc ignition with negative poled electrode

Arc starting

Transferred Arc

Non Transferred Arc
Electrode

• The electrode is typically Tungsten-2% thoria and the plasma nozzle is copper. The electrode tip diameter is not as critical as for TIG but the tip angle is very important (e.g. 30 and 60 degree chamfer).

• It is prudent to use the largest bore diameter for the operating current level.

NOTE: Too large a bore diameter, may give problems with arc stability and maintaining a keyhole.

Plasma and shielding gases

• The normal combination of gases is argon for the plasma gas, with argon + 2 to 5% hydrogen for the shielding gas.

Gases: Shielding + Plasma + Purge

Ar - Has low thermal conductivity which means it is not a good conductor of heat. Thus the concentration of energy in the arc is high. The higher density is good for key-hole stability
Plasma welding equipment: torch

Plasma equipment: constriction nozzle
General Advantages of Plasma Welding

1. Less sensitivity to changes in Arc length.

2. Recessed electrode reduces the possibility of tungsten inclusions in the weld and can substantially increase the period between electrode dressings resulting in increased life.

3. Weld in a single pass up to 6 mm plates in square butt position and 10 mm plates in only two passes.

4. Keyhole mode of welding gives smaller heat affected zone resulting in reduced strength loss at the joint for heat treated metals, promotes less grain growth which gives better ductility.

5. Higher welding speeds and thus reduced weld time results in less embrittlement by carbides and complex intermetallic compounds for stainless steel and super alloys.


7. Less filler metal required in keyhole mode significantly reduces porosity.

Productivity and Cost Advantages of Plasma Welding
Heat input Advantages of Plasma Welding

Parameters

Key Variables

- **Current**
  - AC or DCEN or Pulse

- **Voltage**

- **Travel Speed**

- **Shielding gas**
  - Composition and flow
  - Preflow and postflow time
  - Inner diameter of ceramic nozzle

- **Filler Metal**

- **Electrode**
  - Diameter
  - Composition
  - Pre heat time
  - Distance electrode-constraining nozzle
  - Tip geometry
Parameters

Current: AC versus DC

- **AC:**
  - Aluminium; aluminium alloys;
  - Magnesium; magnesium alloys
- **DC** (remaining weldable engineering alloys):
  - Plain steel; HSLA; stainless steel; etc…
  - Copper; copper alloys
  - Titanium
  - Niobium, etc…

Parameters

Current: Why AC in Aluminium?

- **Aluminium core** ($T_f=600^\circ$C):
  - Because of refractory superficial layer
  - $\text{Al}_2\text{O}_3$ ($T_f=2100^\circ$C)

May result in burn-through defects
**Parameters**

*Current: Why AC in Aluminium?*

- **DCEN period:**
  - Workpieces heated to fusion
  - No electrode contamination

- **DCEP period:**
  - Cleaning effect of refractory superficial layer
  - Electrode contamination

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**Parameters**

*Current: AC*

![Oscilloscope representation of AC waveforms](image)

*Figure 2.4* An oscilloscope representation of normal 50 and 60 Hz in relation to increased frequency rate.

*Figure 2.5* Comparison of the three different AC waveforms all representing a time balanced condition and operating at 200 amperes.
Parameters
Current: AC Balancing

<table>
<thead>
<tr>
<th>Balance Control Waveform Examples</th>
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</thead>
<tbody>
<tr>
<td>Balanced 30</td>
</tr>
<tr>
<td>50% Electrode Positive</td>
</tr>
<tr>
<td>50% Electrode Negative</td>
</tr>
<tr>
<td>More Penetration 100</td>
</tr>
<tr>
<td>32% Electrode Positive</td>
</tr>
<tr>
<td>68% Electrode Negative</td>
</tr>
<tr>
<td>More Cleaning 0</td>
</tr>
<tr>
<td>55% Electrode Positive</td>
</tr>
<tr>
<td>45% Electrode Negative</td>
</tr>
</tbody>
</table>

- Varying the current from a high peak amperage level to a lower background amperage level at regular intervals.
- Pulse controls also adjust for the number of pulse per second and the percent of time spent at the peak amperage level.
- Pulsing is used to control heat input and allow for improved weld profile.

Parameters
Current: Pulsed
Parameters
Current: Pulsed

Pulse:

- Theory

\[ I_m = \frac{I_p t_p + I_b t_b}{t_p + t_b} \]

- Real

\[ I_m < I_{conventional} \Rightarrow E_{c\_pulse} < E_{c\_conventional} \]
Applications

Micro-plasma welding

- Traditionally used for welding thin sheets (down to 0.1 mm thickness), and wire and mesh sections. The needle-like stiff arc minimises arc wander and distortion

Medium current welding

- Alternative to conventional TIG. The advantages are deeper penetration (from higher plasma gas flow), and greater tolerance to surface contamination including coatings
- The major disadvantage lies in the bulkiness of the torch, making manual welding more difficult

Keyhole welding

- Deep penetration and high welding speeds. Can penetrate plate thicknesses up to 10 mm, but when welding using a single pass technique, it is more usual to limit the thickness to 6 mm
- The normal method is to use the keyhole mode with filler to ensure smooth weld bead profile (with no undercut)
- For thicknesses up to 15 mm, a V joint preparation is used with a 6 mm root face. This technique is only suitable for mechanised welding
- It can be used for positional welding, usually with current pulsing, it is normally applied in high speed welding of thicker sheet material (over 3 mm) in the flat position
Hot Wire (Filler Metal) Application

Plasma Welding - Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Material</th>
<th>Benefits</th>
<th>Laminations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argon Plasma/ Argon Shield</td>
<td>All-including reactive metals (Ti)</td>
<td>Inert</td>
<td>Lowest heat input</td>
</tr>
<tr>
<td>Argon Plasma Helium Shield</td>
<td>All-particularly high conductivity materials</td>
<td>Inert, higher heat input</td>
<td>May reduce arc pressure and limit keyhole technique</td>
</tr>
<tr>
<td>Argon Plasma/ argon 5% hydrogen shield</td>
<td>Austenitic steels</td>
<td>Improves constriction and heat transfer. Removes oxide</td>
<td>Cannot be used with hydrogen sensitive materials such as ferritic alloys steels, copper, aluminium</td>
</tr>
</tbody>
</table>
Plasma welding – Health & Safety

The safety hazards associated with plasma welding are the same as those for GTAW;

- Ultraviolet radiation
- Infra-red radiation
- High intensity visible light – fume
- Electric shock
- Compressed inert gases
- Ignition of combustible material

For micro-plasma welding at currents up to 15 amps welding filter shades down to number 6 may be used. At higher currents the recommended filter shades are the same as those indicated for GTAW.