Plasma arc welding

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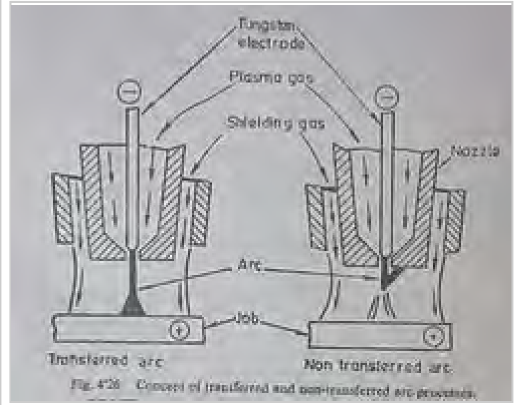
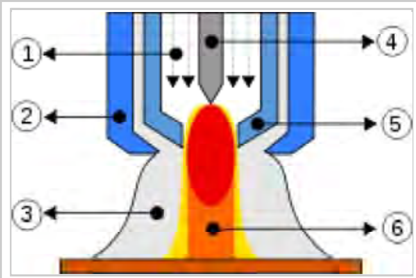
Plasma arc welding (**PAW**) is an arc welding process similar to gas tungsten arc welding (GTAW). The electric arc is formed between an electrode (which is usually but not always made of sintered tungsten) and the workpiece. The key difference from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (approaching the speed of sound) and a temperature approaching 28,000 °C (50,000 °F) or higher.



Plasma arc types.

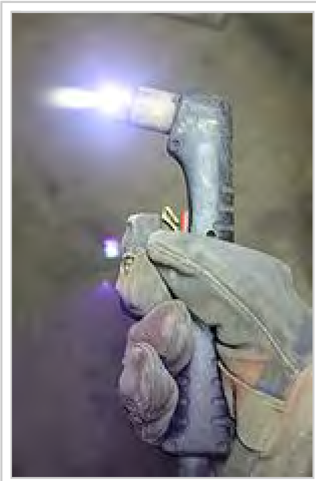
Just as oxy-fuel torches can be used for either welding or cutting, so too can plasma torches, which can achieve plasma arc welding or plasma cutting.



1. Gas plasma, 2. Nozzle protection, 3. Shield Gas, 4. Electrode, 5. Nozzle constriction, 6. Electric arc

Arc plasma is the temporary state of a gas. The gas gets ionized after passage of electric current through it and it becomes a conductor of electricity. In ionized state atoms break into electrons (−) and cations (+) and the system contains a mixture of ions, electrons and highly excited atoms. The degree of ionization may be between 1% and greater than 100% i.e.; double and triple degrees of ionization. Such states exist as more electrons are pulled from their orbits.

The energy of the plasma jet and thus the temperature is dependent upon the electrical power employed to create arc plasma. A typical value of temperature obtained in a plasma jet torch may be of the order of 28000 °C(50000 °F) against about 5500 °C (10000 °F) in ordinary electric welding arc. Actually all welding arcs are (partially ionized) plasmas, but the one in plasma arc welding is a constricted arc plasma.


Plasma cutting torch.

Contents

Metal cutting by plasma arc.

Concept

Plasma arc welding is an arc welding process wherein coalescence is produced by the heat obtained from a constricted arc setup between a tungsten/alloy tungsten electrode and the water-cooled (constricting) nozzle (non-transferred arc) or between a tungsten/alloy tungsten electrode and the job (transferred arc). The process employs two inert gases, one forms the arc plasma and the second shields the arc plasma. Filler metal may or may not be added.

History

The plasma arc welding and cutting process was invented by Robert M. Gage in 1953 and patented in 1957. The process was unique in that it could achieve precision cutting and welding on both thin and thick metals. It was also capable of spray coating hardening metals onto other metals. One example was the spray coating of the turbine blades of the moon bound Saturn rocket.[1]

Principle of operation

Plasma arc welding is a constricted arc process. The arc is constricted with the help of a water-cooled small diameter nozzle which squeezes the arc, increases its pressure, temperature and heat intensely and thus improves arc stability, arc shape and heat transfer characteristics. Plasma arc welding processes can be divided into two basic types:

Non-transferred arc process

The arc is formed between the electrode(-) and the water cooled constricting nozzle(+). Arc plasma comes out of the nozzle as a flame. The arc is independent of the work piece and the work piece does not form a part of the electrical circuit. Just like an arc flame (as in atomic hydrogen welding), it can be moved from one place to another and can be better controlled. The non transferred plasma arc possesses comparatively less energy density as compared to a transferred arc plasma and it is employed for welding and in applications involving ceramics or metal plating (spraying). High density metal coatings can be produced by this process. A non-transferred arc is initiated by using a high frequency unit in the circuit.

Transferred arc process

The arc is formed between the electrode(-) and the work piece(+). In other words, arc is transferred from the electrode to the work piece. A transferred arc possesses high energy density and plasma jet velocity. For this reason it is employed to cut and melt metals. Besides carbon steels this process can cut stainless steel and nonferrous metals where an oxyacetylene torch does not succeed. Transferred arc can also be used for welding at high arc travel speeds. For initiating a transferred arc, a current limiting resistor is put in the circuit, which permits a flow of about 50 amps, between the nozzle and electrode and a pilot arc is established between the electrode and the nozzle. As the pilot arc touches the job main current starts flowing between electrode and job, thus igniting the transferred arc. The pilot arc initiating unit gets disconnected and pilot arc extinguishes as soon as the arc between the electrode and the job is started. The temperature of a constricted plasma arc may be of the order of 8000 - 25000^0C.

Equipment

The equipment needed in plasma arc welding along with their functions are as follows:

Power Supply

A direct current power source (generator or rectifier) having drooping characteristics and open circuit voltage of 70 volts or above is suitable for plasma arc welding. Rectifiers are generally preferred over DC generators. Working with helium as an inert gas needs open circuit voltage above 70 volts. This higher voltage can be obtained by series operation of two power sources; or the arc can be initiated with argon at normal open circuit voltage and then helium can be switched on.

Typical welding parameters for plasma arc welding are as follows:

Current 50 to 350 amps, voltage 27 to 31 volts, gas flow rates 2 to 40 liters/minute (lower range for orifice gas and higher range for outer shielding gas), direct current electrode negative (DCEN) is normally employed for plasma arc welding except for the welding of aluminum in which cases water cooled electrode is preferable for reverse polarity welding, i.e. direct current electrode positive (DCEP).

High frequency generator and current limiting resistors

A high frequency generator and current limiting resistors are used for arc ignition. The arc starting system may be separate or built into the system.

Plasma Torch

It is either transferred arc or non transferred arc typed. It is hand operated or mechanized. At present, almost all applications require automated system. The torch is water cooled to increase the life of the nozzle and the electrode. The size and the type of nozzle tip are selected depending upon the metal to be welded, weld shapes and desired penetration depth.

Shielding gases

Two inert gases or gas mixtures are employed. The orifice gas at lower pressure and flow rate forms the plasma arc. The pressure of the orifice gas is intentionally kept low to avoid weld metal turbulence, but this low pressure is not able to provide proper shielding of the weld pool. To have suitable shielding protection same or another inert gas is sent through the outer shielding ring of the torch at comparatively higher flow rates. Most of the materials can be welded with argon, helium, argon+hydrogen and argon+helium, as inert gases or gas mixtures. Argon is very commonly used. Helium is preferred where a broad heat input pattern and flatter cover pass is desired without key hole mode weld. A mixture of argon and hydrogen supplies heat energy higher than when only argon is used and thus permits keyhole mode welds in nickel base alloys, copper base alloys and stainless steels.

For cutting purposes a mixture of argon and hydrogen (10-30%) or that of nitrogen may be used. Hydrogen, because of its dissociation into atomic form and thereafter recombination generates temperatures above those attained by using argon or helium alone. In addition, hydrogen provides a reducing atmosphere, which helps in preventing oxidation of the weld and its vicinity. (Care must be taken, as hydrogen diffusing into the metal can lead to embrittlement in some metals and steels.)

Voltage control

Voltage control is required in contour welding. In normal key hole welding a variation in arc length up to 1.5 mm does not affect weld bead penetration or bead shape to any significant extent and thus a voltage control is not considered essential.

Current and gas decay control

It is necessary to close the key hole properly while terminating the weld in the structure.

Fixture

It is required to avoid atmospheric contamination of the molten metal under bead.

Process Description

Technique of work piece cleaning and filler metal addition is similar to that in TIG welding. Filler metal is added at the leading edge of the weld pool. Filler metal is not required in making root pass weld.

Type of Joints: For welding work piece up to 25 mm thick, joints like square butt, J or V are employed. Plasma welding is used to make both key hole and non-key hole types of welds.

Making a non-key hole weld: The process can make non key hole welds on work pieces having thickness 2.4 mm and under.

Making a keyhole welds: An outstanding characteristics of plasma arc welding, owing to exceptional penetrating power of plasma jet, is its ability to produce keyhole welds in work piece having thickness from 2.5 mm to 25 mm. A keyhole effect is achieved through right selection of current, nozzle orifice diameter and travel speed, which create a forceful plasma jet to penetrate completely through the work piece. Plasma jet in no case should expel the molten metal from the joint. The major advantages of keyhole technique are the ability to penetrate rapidly through relatively thick root sections and to produce a uniform under bead without mechanical backing. Also, the ratio of the depth of penetration to the width of the weld is much higher, resulting narrower weld and heat-affected zone. As the weld progresses, base metal ahead the keyhole melts, flow around the same solidifies and forms the weld bead. Key holing aids deep penetration at faster speeds and produces high quality bead. While welding thicker pieces, in laying others than root run, and using filler metal, the force of plasma jet is reduced by suitably controlling the amount of orifice gas.

Plasma arc welding is an advancement over the GTAW process. This process uses a non-consumable tungsten electrode and an arc constricted through a fine-bore copper nozzle. PAW can be used to join all metals that are weldable with GTAW (i.e., most commercial metals and alloys). Difficult-to-weld in metals by PAW include bronze, cast iron, lead and magnesium. Several basic PAW process variations are possible by varying the current, plasma gas flow rate, and the orifice diameter, including:

- Micro-plasma (< 15 Amperes)
- Melt-in mode (15–100 Amperes)
- Keyhole mode (>100 Amperes)
- Plasma arc welding has a greater energy concentration as compared to GTAW.
- A deep, narrow penetration is achievable, with a maximum depth of 12 to 18 mm (0.47 to 0.71 in) depending on the material.[2]
- Greater arc stability allows a much longer arc length (stand-off), and much greater tolerance to arc length changes.
- PAW requires relatively expensive and complex equipment as compared to GTAW; proper torch maintenance is critical
- Welding procedures tend to be more complex and less tolerant to variations in fit-up, etc.
- Operator skill required is slightly greater than for GTAW.
- Orifice replacement is necessary.

Process variables

Gases

At least two separate (and possibly three) flows of gas are used in PAW:

- Plasma gas – flows through the orifice and becomes ionized.
- Shielding gas – flows through the outer nozzle and shields the molten weld from the atmosphere
- Back-purge and trailing gas – required for certain materials and applications.

These gases can all be same, or of differing composition.

Key process variables

- Current Type and Polarity
- DCEN from a CC source is standard
- AC square-wave is common on aluminum and magnesium

- Welding current and pulsing - Current can vary from 0.5 A to 1200 A; Current can be constant or pulsed at frequencies up to 20 kHz
- Gas flow rate (This critical variable must be carefully controlled based upon the current, orifice diameter and shape, gas mixture, and the base material and thickness.)

Other plasma arc processes

Depending upon the design of the torch (e.g., orifice diameter), electrode design, gas type and velocities, and the current levels, several variations of the plasma process are achievable, including:

- Plasma arc cutting (PAC)
- Plasma arc gouging
- Plasma arc surfacing
- Plasma arc spraying

Plasma arc cutting

When used for cutting, the plasma gas flow is increased so that the deeply penetrating plasma jet cuts through the material and molten material is removed as cutting dross. PAC differs from oxy-fuel cutting in that the plasma process operates by using the arc to melt the metal whereas in the oxy-fuel process, the oxygen oxidizes the metal and the heat from the exothermic reaction melts the metal. Unlike oxy-fuel cutting, the PAC process can be applied to cutting metals which form refractory oxides such as stainless steel, cast iron, aluminum, and other non-ferrous alloys. Since PAC was introduced by Praxair Inc. at the American Welding Society show in 1954, many process refinements, gas developments, and equipment improvements have occurred.

References

1. U.S. Patent # 2,806,124 Sept. 10th 1957, awarded to Robert M. Gage
2. Degarmo, Black & Kohser 2003, p. 953.

Bibliography

- Oberg, Erik; Jones, Franklin D.; Horton, Holbrook L.; Ryffel, Henry H. (2000), *Machinery's Handbook* (26th ed.), New York: Industrial Press Inc., ISBN 0-8311-2635-3.

Further reading

- American Welding Society, *Welding Handbook,* Volume 2 (8th Ed.)

External links

Plasma Arc Welding

- http://mewelding.com/plasma-arc-welding-paw/

Microplasma welding

- https://www.youtube.com/watch?v=T8g1lULZryk
- https://www.youtube.com/user/multiplazslovenia#p/u/6/SWbUJh4XuMQ

Arc spray welding

- https://www.youtube.com/watch?v=BtsywbmjKIE&NR=1
- https://www.youtube.com/watch?v=ibPPbQC5LeE&feature=related

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