

Recommended Practices for Plasma-Arc Welding



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RECOMMENDED PRACTICES FOR PLASMA-ARC WELDING

Prepared by
AWS Arc Welding and Arc Cutting Committee

Under the Direction of
AWS Technical Activities Committee

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Foreword

Plasma-arc welding was introduced as a practical fabricating process approximately fifteen years ago. Early applications involved melting, cutting, and spray-coating metallic materials. In the past several years, rapid advances have been made in the development of this technique, and plasma-arc welding has now achieved acceptance as an efficient metal joining process.

During the recent period of progress, sufficient data have been gathered and organized to yield an authoritative source of technical information on plasma-arc welding. Accordingly, the AWS Arc Welding and Arc Cutting Committee has prepared these recommended practices through the work of the Subcommittee on Plasma-Arc Welding. These recommended practices are based on a survey of plasma-arc welding as used in the metal fabricating industry.

The description of plasma-arc welding and its salient features is presented here as clearly and concisely as possible. Because the plasma-arc process is similar to gas tungsten-arc welding, similarities in the processes are not described in detail, to keep the text as brief as possible. The plasma-arc welding process, however, does have unique features in operation and equipment that are advantageous for a certain range of metal thicknesses. These features are fully explored in the text.

The Committee developed these guidelines in the hope that they would lead to further development of the plasma-arc welding process and thus to higher quality and performance standards. Comments on this publication will be most welcome. They should be addressed to the Secretary, AWS Arc Welding and Arc Cutting Committee, American Welding Society, 2501 N.W. 7th Street, Miami, Florida 33125.

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RECOMMENDED PRACTICES FOR PLASMA-ARC WELDING

1. Scope

1.1 These recommended practices present a description of the plasma-arc welding process and practical procedures as applied to joining parts and surfacing. These discussions apply to a wide variety of metals and represent methods used in industry.

2. Definitions of Terms*

2.1 General. Some of the terms used in describing plasma-arc welding are the same as those used in gas tungsten-arc welding. Other terms listed are peculiar to the plasma-arc welding process. Many of these terms are shown in Fig. 1.

2.2 Plasma arc. A plasma—a gas heated to a condition of at least partial ionization that is capable of conducting electric current—exists during any arc occurrence. In nature, the gas ionized by a lightning bolt constitutes a plasma. The same ionization phenomenon occurs in welding arcs, carbon-arc lights, and arc furnaces. In recent years, however, the expression “plasma arc” has become associated with those processes employing a constricted arc. Arc constriction is brought about by forcing the arc to pass through a small nozzle or opening as it passes from the electrode to the workpiece.

2.3 Plasma-arc welding. An arc welding process wherein coalescence is produced by heating with a constricted arc between an electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the hot, ionized gas issuing from the orifice which may be supplemented by an auxiliary source of shielding gas. The shielding gas may be inert or a mixture of gases. Pressure may or may not be used, and filler metal may or may not be supplied.

2.4 Constricted arc. An arc column shaped by a constricting nozzle orifice.

2.5 Constricting nozzle. A water-cooled copper nozzle surrounding the electrode and containing the constricting orifice.

2.6 Constricting orifice. The hole in the nozzle through which the arc passes.

2.7 Double arcing. A condition in which the main arc does not pass through the constricting orifice but transfers to the inside surface of the nozzle. A secondary arc is simultaneously established between the outside surface of the nozzle and the workpiece. Double arcing usually damages the nozzle.

*For AWS terms and definitions, refer to the latest edition of publication AWS A3.0, Terms and Definitions. Please note that some of the terms and definitions used in this publication are not included in AWS A3.0. They are either new terms defined after the last revision of A3.0 or they are used to clarify this publication.

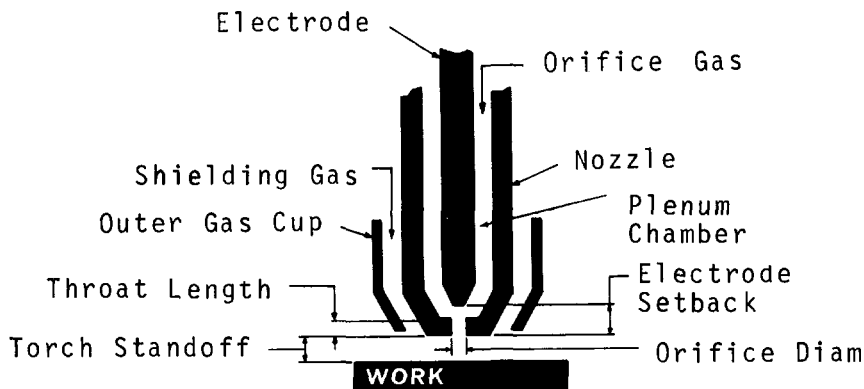


Fig. 1 – Plasma-arc torch terminology.

2.8 Electrode setback. The distance the electrode is recessed behind the constricting orifice measured from the outer face of the nozzle.

2.9 Keyhole. A condition in which the plasma column penetrates completely through the workpiece at the leading edge of the weld puddle. As the torch progresses, the molten metal, supported by surface tension, flows in behind the keyhole to form the weld bead.

2.10 Lack of fill. Slight and blending reduction of thickness at the toe(s) of the weld generally associated with keyhole-type welds.

2.11 Multiport nozzle. A constricting nozzle containing two or more orifices located in a configuration to achieve a degree of control over the arc shape.

2.12 Nontransferred arc. An arc established between the electrode and the constricting nozzle. The workpiece is not in the electrical circuit.

2.13 Orifice gas. The gas directed through the plenum chamber and constricting orifice to form the plasma column.

2.14 Pilot arc. A low-current arc established between the electrode and the nozzle to ionize the orifice gas and facilitate starting the main welding arc.

2.15 Plenum or plenum chamber. The space between the inside wall of the constricting nozzle and the electrode.

2.16 Shielding gas. A protective gas provided at the outer periphery of the arc to prevent air contamination of the weld and/or base metal.

2.17 Single port nozzle. A constricting nozzle containing one orifice, located below and concentric with the electrode.

2.18 Throat length. The length of the constricting orifice.

2.19 Torch standoff. The distance from the bottom of the constricting nozzle to the workpiece.

2.20 Transferred arc. An arc established between the electrode and the workpiece.

3. Fundamentals

3.1 Process Description

3.1.1 General Description

3.1.1.1 The distinguishing feature of the plasma-arc welding process lies in the use of a constricting orifice. Arc constriction by a nozzle brings about several changes in arc characteristics. The most important of these is that the arc can be projected as a stream of ionized gas similar to a water stream from a hose nozzle, with strong directional stability.

3.1.2 Arc-Constricting Nozzle

3.1.2.1 A wide variety of nozzles has been made and evaluated. These include the single port nozzles and multiport nozzles with holes arranged in

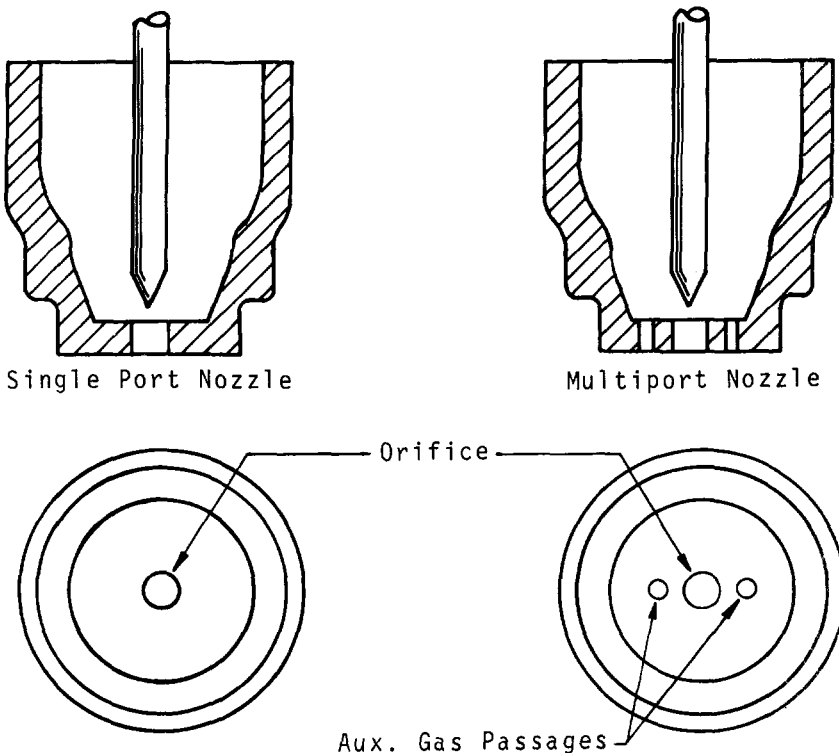


Fig. 2 – Single port and multiport nozzles.

circles, rows, and other geometric patterns. The single port nozzles are most widely used. Among the multiport nozzles, the most widely used design is the one in which the center orifice is bracketed by two smaller ports, with a common centerline for all three openings. These more common nozzle types are shown in Fig. 2.

3.1.2.2 The electrode in the plasma-arc torch is recessed in the arc-constricting nozzle. As the arc passes through the nozzle, it is collimated and focused so that the arc heat is concentrated on a relatively small area of the workpiece. This increased heat concentration, coupled with the characteristically more forceful plasma stream, can produce a narrower weld fusion zone in a certain range of metal thicknesses.

3.1.2.3 With the single port nozzles, the arc and all of the orifice gas pass through the single orifice. With the multiport nozzle shown in Fig. 2, the arc and some of the orifice gas pass through the larger center orifice, while the remainder of the orifice gas is discharged through the two smaller ports that bracket the center orifice. The effect of the gas flow from the side ports is to squeeze the cross section of the circular plasma-arc column into an oval or elongated shape. This is particularly desirable in keyhole-mode welding.

3.1.3 Keyhole-Mode Welding

3.1.3.1 In plasma-arc welding of certain metal thicknesses special combinations of plasma-gas flow, arc current, and weld travel speed will produce a relatively small weld puddle with a hole penetrating completely through the base metal at the leading edge of the weld puddle (called the keyhole). The plasma-arc process is the only gas-shielded welding process with this unusual characteristic.

3.1.3.2 In a stable keyhole-mode operation, molten metal is displaced to the top bead surface by the plasma stream (in penetrating the plate) to form the characteristic keyhole. As the plasma-arc torch is mechanically moved along the weld joint, metal melted by the arc is forced to flow around the plasma stream, along the molten side surfaces of the keyhole and to the rear where the weld puddle is formed and solidified. This motion of molten metal, and the complete penetration of the metal thickness by the keyhole allow gases and impurities to flow to the surface or be expelled more readily before solidification. This action is similar to "magnetic stirring" developed for gas tungsten-arc welding. The maximum weld puddle volume and the resultant root surface profile are largely determined by the effects of a force balance between the molten weld metal surface tension and the plasma stream velocity characteristics. The bead appearance for a butt weld made in the keyhole mode is pictured in Fig. 3.

3.1.3.3 With appropriately designed weld joints, the multiport nozzle shown in Fig. 2 can be used to advantage. When the multiport nozzle is aligned to place the common centerline of the side ports perpendicular to the weld groove, the arc is elongated in line with the joint. This allows an increase of keyhole-mode welding speeds of from 30 to 50% over those obtained with single port nozzles, without undercutting and with welds having narrower fusion and heat-affected zones.

3.1.4 Comparison of Nonconstricted and Constricted Arcs

3.1.4.1 Typical electrical and thermal differences between constricted and nonconstricted arcs are shown in Fig. 4. The schematic representation of a

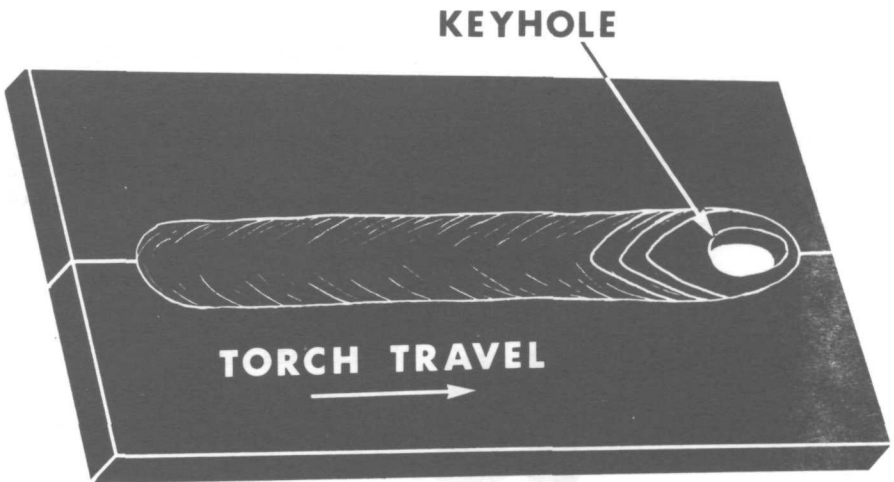


Fig. 3a – Pictorial representation of the keyhole effect.

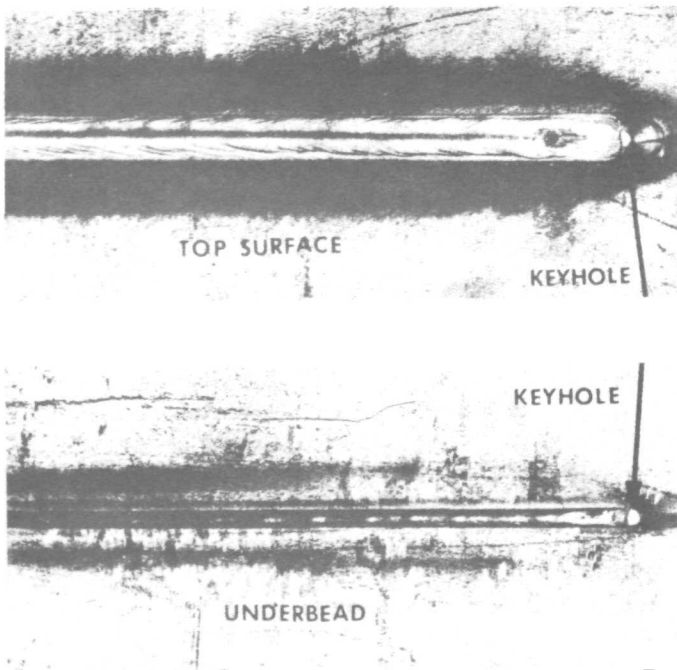


Fig. 3b – Top and bottom view of a keyhole-mode weld on 0.25 in. thick plate.



nonconstricted gas tungsten-arc is shown on the left side of the figure. Arc conditions are 200 amperes (A) at 15 volts (V) with 40 cfh of argon. The right side of Fig. 4 is a schematic view of a tungsten-arc that has been constricted by passing it through a 3/16 in. diameter orifice. Note that, with the same current and gas flow, arc voltage doubles to 30 volts. Note also that the very high temperature zones of the arc have been projected downward where they can be directly applied to the workpiece. Constricting the arc tends to concentrate the arc energy over a smaller area of the workpiece because the constricted arc does not have the angle of divergence of the nonconstricted arc.

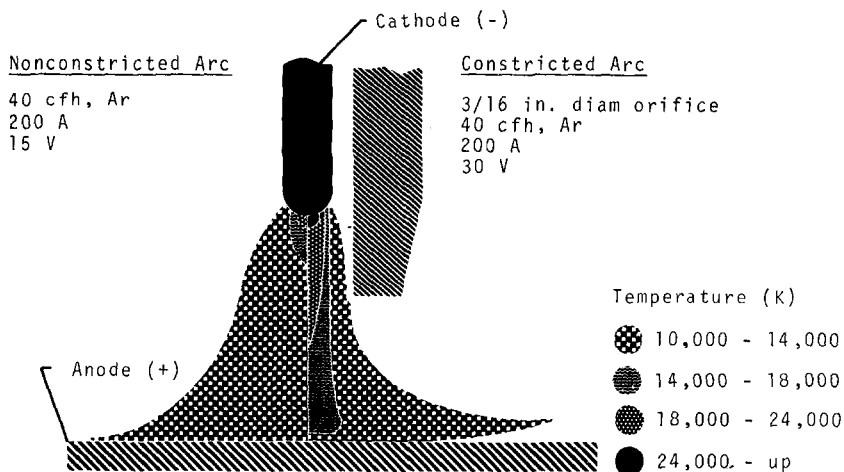


Fig. 4 – Effect of arc constriction on temperature and voltage.

3.1.5 Arc Modes

3.1.5.1 Two arc modes are used in plasma-arc welding: transferred arc and nontransferred arc. With a transferred arc, the arc is established between the workpiece and the electrode within the torch. With a nontransferred arc, the workpiece is not in the arc circuit; the arc is established between the constricting orifice and the electrode inside the torch. Transferred arcs have the advantage of greater energy transfer to work, but they require an electrically conductive workpiece. Nontransferred arcs are useful for cutting and joining nonconductive workpieces or when lower energy concentration is desirable. Figure 5 illustrates the two modes of arc transfer.

3.2 Principles of Operation

3.2.1 Manual Plasma-Arc Welding

3.2.1.1 Manual plasma-arc welding was developed to obtain a stable, controllable arc for welding thin gage metal. It combines a continuously operating pilot arc within the torch for positive welding current initiation, and transferred arc

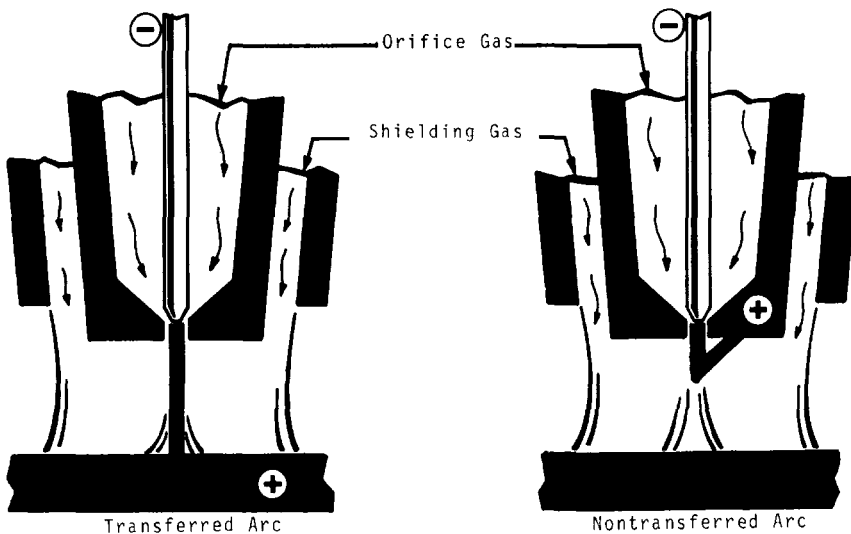


Fig. 5 – Modes of plasma generation: left, transferred arc; right, nontransferred arc.

constriction to provide a stable arc at currents as low as 0.1 ampere. The manual process is well adapted to welding metal thicknesses up to 0.125 in. The low-current volt-ampere (VA) characteristics of the plasma arc operating in argon are shown in Fig. 6. Note that the slope of the low-current plasma-arc VA curve is essentially flat in this range.

3.2.1.2 A needle-like plasma jet is obtained by passing a low-current arc through a small diameter orifice. The low-current plasma jet has good directional properties and heat concentration, excellent arc stability, and reduced sensitivity to variations in torch-to-work spacing.

3.2.1.3 A typical electrical circuit for low-current manual plasma-arc welding is shown in Fig. 7. Note that the system utilizes two separate power supplies—one for the pilot arc and one for the transferred arc.

3.2.2 Mechanized Plasma-Arc Welding

3.2.2.1 Mechanized plasma-arc welding utilizes a transferred, constricted arc and is generally operated with high current. Figure 8 illustrates the general characteristics of a typical high current plasma-arc welding system, as well as the electrical circuit used. A direct current (dc) power supply is used to furnish the welding current, and a high frequency generator is used to initiate a pilot arc between the electrode and the constricting nozzle. A current-limiting resistor and condenser network completes the electrical circuit to the power supply.

3.2.2.2 As the orifice gas passes through the torch to the work, it is heated by the arc, expands and passes through the arc-constricting nozzle at an accelerated rate. The plasma-gas flow range usable for welding is limited because too forceful a plasma stream can cause plasma cutting. This orifice-gas flow alone is not adequate to protect the molten puddle from atmospheric contamination. Auxiliary

shielding gas is needed and is provided through an outer gas nozzle on the torch. See 5.12 for typical orifice- and shielding-gas flow rates.

3.2.3 Powder Surfacing

3.2.3.1 This fully mechanized application of the plasma-arc welding process utilizes a constricted arc torch and filler metal in powder form. The application is shown schematically in Fig. 9. In addition to the orifice- and shielding-gas supplies used in plasma-arc welding, the surfacing application requires a third gas flow to convey the powdered filler metal from a storage hopper to the torch. Argon is generally used for all three gas systems.

3.2.3.2 The gas-borne powder is introduced into an annular powder chamber in the torch that uniformly distributes the powder into the arc immediately beneath the arc-constricting orifice. After entering the arc, the powder particles are heated and deposited on the workpiece. These particles are completely melted upon contacting the weld puddle, thus forming a homogeneous deposit, fusion-bonded to the workpiece.

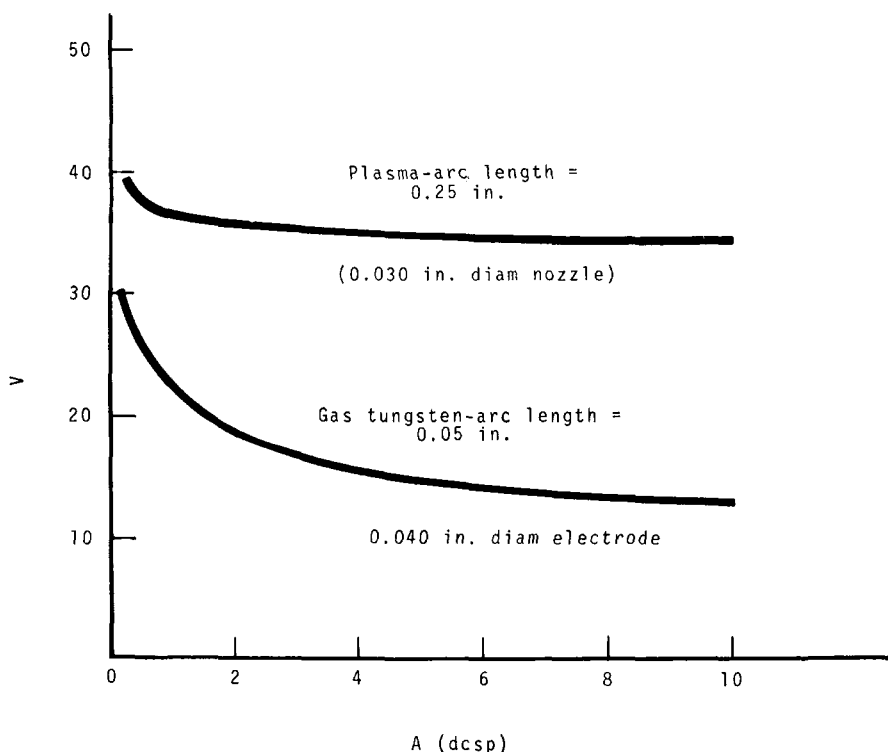


Fig. 6 – Low-current plasma-arc volt-ampere (VA) characteristic curves at arc currents below 10 A in argon.

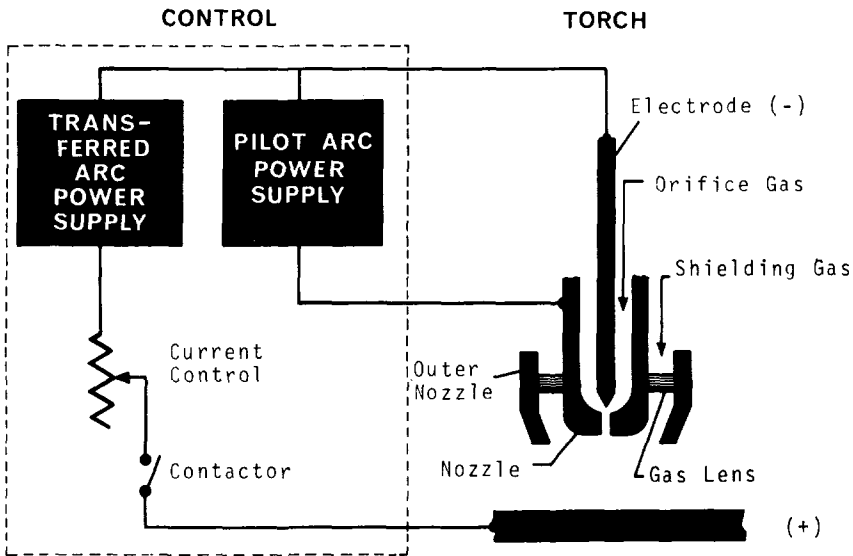


Fig. 7 – Schematic representation of low-current manual plasma-arc welding.

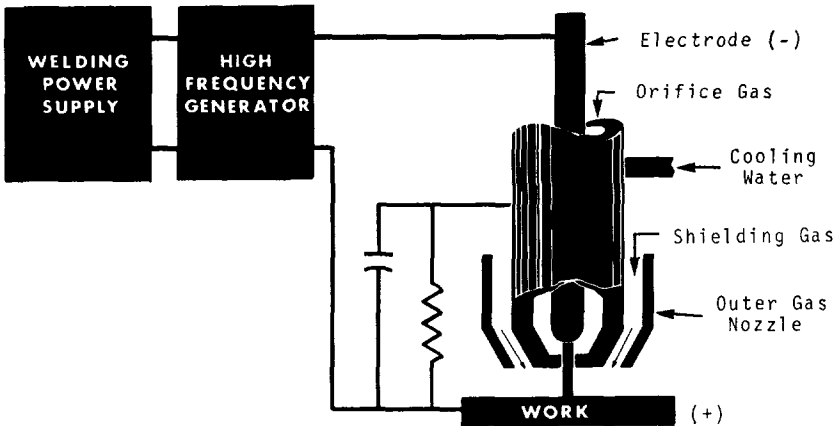


Fig. 8 – Schematic representation of mechanized plasma-arc welding system.

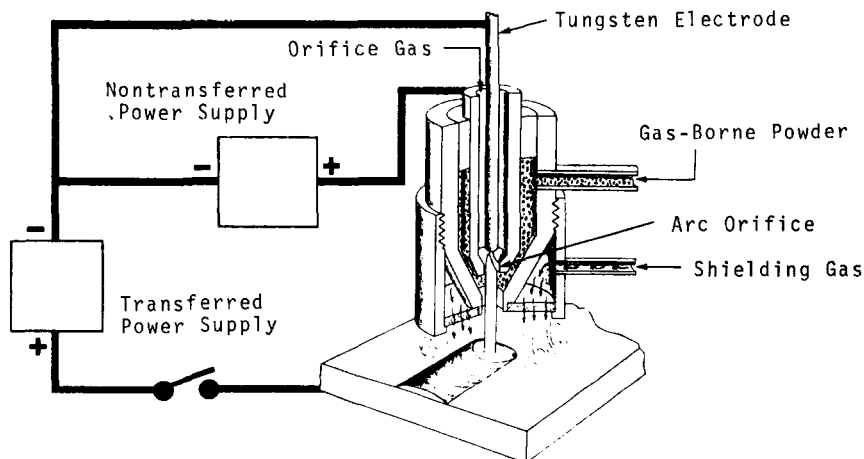


Fig. 9 – Schematic representation of powder surfacing with the plasma-arc welding process.

3.2.4 Hot-Wire Surfacing

3.2.4.1 In the application of the plasma-arc welding process to hot-wire surfacing, filler metal in wire form is resistance heated and deposited on the workpiece in the puddle formed by a plasma-arc torch. This application is shown schematically in Fig. 10.

3.2.4.2 The electrical circuit and apparatus used for plasma-arc surfacing are similar to the requirements for plasma-arc welding.

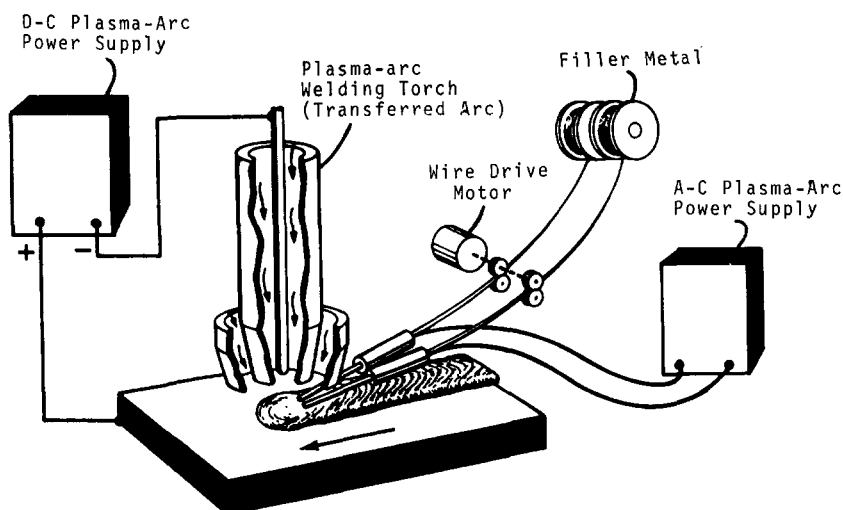


Fig. 10 – Schematic representation of hot-wire surfacing with the plasma-arc welding process.

4. Equipment and Apparatus Requirements

4.1 Manual Welding

4.1.1 General Requirements

4.1.1.1 A complete system for manual plasma-arc welding consists of a torch, control, power supply, orifice- and shielding-gas supplies, source of cooling water, and accessories such as foot switch, rheostat, timers, and remote current controls. Apparatus is presently available for operation with low welding current of 0.1 and high of 100 amperes. Development of higher range torches and power supplies has begun.

4.1.2 Power Supply

4.1.2.1 Transferred Arc Power Supply. Rectifier type power supplies with a drooping VA characteristic are generally used for plasma-arc welding.

4.1.2.2 Pilot Arc Power Supply. Pilot arc supplies are preset to deliver approximately 5 A continuously to provide a stream of ionized gas for instant ignition of the main welding current.

4.1.3 Control Unit

4.1.3.1 Incorporated in the control unit are the main power supply, pilot arc supply, flowmeters, solenoid valves for controlling orifice and shielding gases, and water flow. Indicating current meters, control switches, and connections for remote current control are generally available.

4.1.4 Torches

4.1.4.1 Low current plasma-arc torches are lightweight and designed primarily for manual welding. A supply of cooling water at a flow rate of about 1 qt/min and 40 psi input pressure is necessary to dissipate heat generated in the constricting nozzle by the pilot and main welding arcs. The tungsten electrode is automatically centered in relation to the constricting orifice by a ceramic bushing. Auxiliary shielding gas is supplied through a separate gas system. Some manual plasma-arc welding torches are available for operation on direct current straight polarity (dcsp) at currents up to 225 amperes. Standard torch holders can be used to mount the torch for mechanized use.

4.1.5 Filler Metal

4.1.5.1 Filler metal can be added during manual welding in the same manner as during gas tungsten-arc welding. Wire diameters should be of suitable size for the currents used. See 5.3.

4.1.6 Gases

4.1.6.1 See 5.4.

4.2 Mechanized Welding

4.2.1 General Requirements

4.2.1.1 Mechanized equipment must be used to achieve the welding speed and penetration advantages associated with high current plasma-arc welding. A mechanized installation consists of a power supply, control unit, welding torch, torch stand or carriage, cooling water pump, high-frequency generator and a

supply of orifice and shielding gas. Accessory units such as an arc-voltage control and filler metal feed system may be used as required.

4.2.2 Power Supply

4.2.2.1 Direct current power supplies with a drooping VA characteristic are used for plasma-arc welding. Rectifier-type units are preferred over motor generators for this service because rectifier output is less sensitive to variations in operating temperature. Also, automatic current sloping is simple with rectifiers. Rectifiers with an open circuit voltage in the range of 65 to 80 V (i.e., those used for gas tungsten-arc welding) are satisfactory for plasma-arc welding with argon or an argon-hydrogen gas mixture containing up to 7% hydrogen. However, if helium or an argon-hydrogen gas mixture containing more than 7% hydrogen is used, additional open circuit voltage is required for reliable arc ignition. This may be obtained by connecting two power supplies in series. An alternate approach requiring the use of only one power supply is to strike the arc in pure argon and then automatically switch over to the desired argon-hydrogen mixture or helium for the welding operation. Power supplies with current slope control are required for welding circumferential joints where the keyhole must be initiated and closed out gradually. Recent development work in plasma-arc welding aluminum and magnesium alloys indicates that the use of an alternating-current (a-c) power supply with a continuous high frequency arc can produce satisfactory welds.

4.2.3 Control System

4.2.3.1 A typical control system for mechanized high current plasma-arc welding consists of a main console control, a junction box for gas and water hoses, a welding operator's pendant control box, and a high frequency generator.

4.2.3.2 The main control unit sequences the power supply, high frequency generator, orifice, shielding and backing gases, torch travel, auxiliary wire feeding, and cooling water for the torch. Travel speed and wire feed rates are controlled by electronic governors.

4.2.3.3 Flowmeters are provided for metering the orifice, shielding, and backing gases. In addition, timers and a gas-tapering device are provided for up-and down-sloping of the orifice gas flow. An adequate supply of cooling water for the torch electrode and constricting nozzle is provided by a pump with about 6 qt/min capacity. A flow switch and interlocking circuitry assure that cooling water is flowing to the torch before arc ignition can take place.

4.2.4 Torches

4.2.4.1 Mechanized plasma-arc welding torches are available commercially for operation on either dcsp or dcrp (direct current reverse polarity) at currents up to 500 amperes. Straight polarity power is used with a tungsten electrode for most welding applications. Reverse polarity is used to a limited extent with water-cooled copper or tungsten electrodes for welding aluminum. Reverse polarity is also used with specially designed torches and copper electrodes for joining titanium and zirconium sponge compacts where freedom from tungsten or copper contamination is a prime consideration.

4.2.4.2 A water-cooled power cable is used to bring power and cooling water into the torch; other hoses are provided for orifice-gas input, shielding-gas

input, and water return. The electrode holder in a plasma-arc welding torch is designed to center the electrode very accurately with respect to the central port in the nozzle. Misalignment of the electrode with the central port tends to cause melting of the copper nozzle near the orifice and to shorten its life.

4.2.4.3 The relatively low orifice-gas flows used for welding do not provide adequate protection for the molten weld puddle. Accordingly, auxiliary shielding gas is supplied through an outer gas nozzle assembly on the torch. For some applications, additional trailing-gas shields may be required.

4.2.4.4 A variety of nozzle designs exists for different welding applications. The diameter of the nozzle's orifice used in a particular application depends on the welding current to be used. Higher currents require larger diameter orifices.

4.2.5 Wire Feeders

4.2.5.1 Conventional auxiliary wire feeding and hot-wire systems can be used with the plasma-arc welding process.

4.2.6 Gases

4.2.6.1 See 5.4.

4.3 Powder Surfacing

4.3.1 General Requirements

4.3.1.1 All installations consist of a dual power supply, surfacing torch, control box, powder-dispenser unit, plumbing box, high-frequency generator, torch oscillator, cooling-water pump, and remote-control pendant.

4.3.2 Power Supply

4.3.2.1 The dual power supply used for surfacing houses both the nontransferred and transferred arc power sources (see Fig. 9). Both sections have drooping VA characteristics similar to those used in gas tungsten-arc welding. The nontransferred arc section is connected between the tungsten electrode and the arc-constricting orifice. Its function is to maintain the 40-75 A nontransferred pilot arc used to initiate the main arc and, in some applications, to supplement the heat of the main transferred arc. The pilot arc is started by a high-frequency spark. The transferred arc power source is connected between the tungsten electrode and the workpiece to supply main arc currents between 20 and 500 amperes. Both power supplies are connected for desp operation.

4.3.3 Control Unit

4.3.3.1 The control unit contains relays and timers for proper sequencing of electrical functions and electronic governors to control the powder-dispensing rate and carriage travel speed. Flowmeters are provided for metering orifice-, shielding-, and powder-dispensing gas flow rates, and a water-flow switch is provided for regulating the flow of cooling water to the torch. A remote pendant box is provided so the welding operator can control starting and stopping functions in close proximity to the work.

4.3.4 Torches

4.3.4.1 The torch incorporates a standard tungsten electrode, an arc-constricting orifice, a means of directing gas-borne surfacing powders into the arc, a means of directing shielding gas around the weld puddle, and provisions for

water cooling the constricting orifice and other critical areas. The arc-constricting orifice is larger than that used for welding and ranges between 1/8 in. and 3/16 in. in diameter. A heavy-duty nozzle assembly is available for some applications.

4.3.5 Powder Feeders

4.3.5.1 Powders are stored and metered from a dispensing unit and transported to the surfacing torch in a stream of argon. Powder flow rates are adjusted by varying the speed of a rotating dispensing drum and the height of the dispensing nozzle above the drum.

4.3.6 Gases

4.3.6.1 Argon is generally used for all three systems.

4.4 Hot-Wire Surfacing

4.4.1 General Requirements

4.4.1.1 The surfacing system consists of a control panel assembly, plasma-arc power supply, hot-wire power supply, plasma-arc torch, two hot-wire guns with a trailing shield, an oscillator, and a voltage control head.

4.4.2 Power Supply

4.4.2.1 Plasma-Arc Power Supply. The plasma-arc power supply is a conventional direct current unit with provisions for remote current adjustment. Control of the plasma-arc current is provided by a "raise-lower" toggle switch on the pendant box.

4.4.2.2 Hot-Wire Power Supply. Power for the hot wires is provided by a special a-c constant potential supply. Its operating voltage is below the arc threshold which prevents an inadvertant sustained arc between the wires.

4.4.3 Control Unit

4.4.3.1 The control cabinet for hot-wire surfacing with the plasma-arc welding process contains the preset control elements that generally do not need to be monitored during a surfacing operation. These controls include the preflow and postflow timers, the wire delay timers, the weld finish sequence timer, the flowmeters for the plasma-torch orifice and shielding-gas flow, the trailing shield-gas flow, and the crater-fill gas flow. The governor controls for the oscillator and wire feed motors, the arc voltage control, and an arc time meter are also mounted in the control cabinet. A high-frequency generator for starting the plasma arc, gas and water solenoids, meter shunts, and service connections are housed in a separate junction box. A pendant box is provided so the welding operator can position the welding head and start or stop the weld cycle from a remote location.

4.4.4 Torches

4.4.4.1 The plasma-arc torch, hot-wire guns, oscillator, arc-voltage control head, and wire feeders are assembled as a self-contained unit which can be mounted on a boom or other type of fixturing.

4.4.4.2 A single hot-wire feeding system may be used. The plasma-arc torch provides heat to fuse the deposit to the base metal. The hot-wire guns supply power for resistance heating of the filler metal and also serve as guides to direct the wires

into the puddle. Running adjustments are provided to control the position of the wires relative to the puddle.

4.4.4.3 A trailing shield provides inert gas coverage for the weld puddle and serves as a mounting bracket for the hot-wire guns. The assembly is designed to permit removing the torches for servicing without disturbing wire adjustments.

4.4.4.4 Cooling water is required for the plasma-arc welding torch, the hot-wire guns, and the trailing shield. The cooling water requirements are two gallons per minute at 100 psi. A recirculating cooling unit or any other suitable water supply may be used.

4.4.4.5 Oscillator Assembly. The oscillator assembly serves as a mount for the torch assembly and provides the transverse motion required for surfacing. The oscillation frequency is adjustable up to 80 cycles per minute, and the stroke is adjustable between 3/4 in. and 2 1/2 in.

4.4.4.6 Arc-Voltage Control-Head Assembly. This component is a rigid, motorized slide controlled by a servo-system to maintain constant plasma-arc voltage, hence constant torch-to-work distance. This system assures uniformity of deposit despite variations in vessel roundness, etc. Manual jogging of the slide provides motorized positioning of the torches in the vertical direction.

4.4.5 Wire Feeders

4.4.5.1 The two wires are driven by a dual-wire feeder through standard wire feed accessories. Wire supply mountings accommodate either wire spools or coils. Two rotary, motor-driven straighteners are used to remove helix and cast from the wires. These wire straighteners are necessary to maintain a constant relationship in the wire entry into the weld puddle and assure uniformity of deposit over long operating cycles.

4.4.6 Gases

4.4.6.1 Three separate gas flows are used for hot-wire surfacing with the plasma-arc welding process. A 55 cfh flow of a 75% helium-25% argon mixture passes through the plasma-arc torch orifice to support the transferred arc. Thirty to sixty cfh of argon passes through the torch shield to protect the arc zone. Another flow of 30 to 60 cfh of argon is used in the trailing shield assembly to protect the surfacing deposits.

5. Application of the Plasma-Arc Welding Process to Metal Joining

5.1 General Areas of Application

5.1.1 The plasma-arc welding process is applicable to metals weldable by the gas tungsten-arc welding process.

5.1.2 For plate thicknesses in the 1/4 in. range, square-groove welds are made in butt joints without filler metal addition at up to twice the travel speed of the gas tungsten-arc welding process, with the keyhole mode of the plasma-arc welding process. Table 1 illustrates the welding speeds typical on stainless steel tubing. At thicknesses from 1/16 in. down to 0.002 in., the low-current nonkeyhole mode of