Gas Metal Arc Welding (GMAW / “MIG”)

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The gas metal arc welding (GMAW / “MIG”) process utilizes an electric arc established between a consumable wire electrode and the workpiece. GMAW can be implemented as a manual, semi-automatic, or automatic process, and the flexibility offered by the various process variations is advantageous in many applications. GMAW provides a considerable increase in weld metal deposition rates compared to GTAW or SMAW, and when implemented as a semi-automatic process, less welder skill is typically required. However, GMAW equipment is more complex, less portable, and generally requires more routine maintenance than for the GTAW and SMAW processes. GMAW is the most common process for welding corrosion-resistant alloys and for performing thick-section welds.

In GMAW, the mechanism by which the molten metal at the end of the wire electrode is transferred to the workpiece has a significant effect on the weld characteristics. Three modes of metal transfer are possible with GMAW: short-circuiting transfer, globular transfer, and spray transfer. In addition, there is a variation of the spray transfer mode called pulsed spray.

Electrical polarity for GMAW of HASTELLOY® and HAYNES® alloys should be direct current electrode positive (DCEP / “reverse polarity”). Typical parameters for different GMAW transfer modes are provided in Table 2 for flat position welding. Since different GMAW power sources vary greatly in design, operation, and control systems, the parameters should be viewed as an estimated range for achieving proper welding characteristics with specific welding equipment. GMAW travel speeds are typically 6 to 10 inches per minute (ipm) / 150 to 250 mm/min.

Short-circuiting transfer occurs at the lowest current and voltage ranges, which results in low weld heat input. It is typically used with smaller diameter filler wire, and produces a relatively small and easily controlled weld pool that is well-suited for out-of-position welding and joining thin sections. However, the low heat input makes short-circuiting transfer susceptible to incomplete fusion (cold lap) defects, especially when welding thick sections or during multipass welds.

Globular transfer occurs at higher current and voltage levels than short-circuiting, and is characterized by large, irregular drops of molten metal. The globular transfer mode can theoretically be used to weld Ni-/Co-base alloys, but is seldom used because it creates inconsistent penetration and uneven weld bead contour that promotes the formation of defects. Since the force of gravity is critical for drop detachment and transfer, globular transfer is generally limited to flat position welding.

Spray transfer occurs at the highest current and voltage levels, and is characterized by a highly directed stream of small metal droplets. It is a high heat input process with relatively high deposition rates that is most effective for welding thick sections of material. However, it is mainly useful only in the flat position, and its high heat input promotes weld hot-cracking and the formation of secondary phases in the microstructure that can compromise service performance.

Pulsed spray transfer is a highly controlled variant of spray transfer, in which the welding current alternates between a high peak current, where spray transfer occurs, and a lower background current. This results in a stable, low-spatter process at an average welding current significantly below that for spray transfer. Pulsed spray offers lower heat input compared to spray transfer, but is less susceptible to the incomplete fusion defects that are common to short-circuiting transfer. It is useful in all welding positions and for a wide range of material thickness. In most situations, Haynes International highly encourages the use of pulsed spray transfer for GMAW of HASTELLOY® and HAYNES® alloys. The use of a modern power source with synergic control and the provision for waveform adjustment ("adaptive pulse") is highly beneficial for pulsed spray transfer. These advanced technologies have facilitated the use of pulsed spray transfer, in which pulse parameters such as pulse current, pulse duration, background current, and pulse frequency are included in the control system and linked to the wire feed speed.

Shielding gas selection is critical to GMAW procedure development. For Ni-/Co-base alloys, the protective shielding gas atmosphere is usually provided by argon or argon mixed with helium. The relatively low ionization energy of argon facilitates better arc starting/stability and its low thermal conductivity provides a deeper finger-like penetration profile. If used alone, helium creates an unsteady arc, excessive spatter, and a weld pool that can become excessively fluid, but when added to argon, it provides a more fluid weld pool that enhances wetting and produces a flatter weld bead. Additions of oxygen or carbon dioxide, while commonly used with other metals, is to be avoided when welding Ni-/Co-base alloys. These additions produce a highly oxidized surface and promote weld metal porosity, irregular bead surfaces, and incomplete fusion defects. The optimum shielding gas mixture is dependent on many factors, including weld joint design/geometry, welding position, and desired penetration profile. In most instances, a mixture of 75% Ar and 25% He is suggested; good results have been obtained with helium contents of 15 to 30%. During short-circuiting transfer, the addition of helium to argon helps to avoid overly convex weld beads that can lead to incomplete fusion defects. For spray transfer, good results can be obtained with pure argon or argon-helium mixtures. The addition of helium is generally required for pulsed spray transfer as it greatly enhances wetting.

Since argon and helium are inert gases, the as-deposited weld surface is expected to be bright and shiny with minimal oxidation. In this case, it is not mandatory to grind between passes during multipass welding. However, some oxidation or "soot" may be noted on the weld surface. If so, heavy wire brushing and/or light grinding/conditioning (80 grit) between weld passes is suggested in order to remove the oxidized surface and ensure the sound deposit of subsequent weld beads. Shielding gas flow rates should generally be in the 25 to 45 CFH (12 to 21 L/min) range. A flow rate that is too low does not provide adequate shielding of the weld, while excessively high flow rates can interfere with the stability of the arc. As with GTAW, back-purge shielding is recommended to ensure the root side of the weld joint does not become heavily oxidized. If back-purge shielding is not possible, the root side of the weld joint should be ground after welding to remove all oxidized weld metal and any welding defects. The weld joint can then be filled from both sides as needed.

During GMAW, the welding gun should be held perpendicular to the work-piece at both a work angle and travel angle of approximately 0°. A very slight deviation from perpendicular may be necessary for visibility. If the gun is positioned too far from perpendicular, oxygen from the atmosphere may be drawn into the weld zone and contaminate the molten weld pool. A water-cooled welding gun is always recommended for spray transfer welding and anytime higher welding currents are being utilized.

It should be recognized that some parts of the GMAW equipment, such as the contact tip and filler wire conduit/liner, experience high wear and should be replaced periodically. A worn or dirty liner can cause erratic wire feed that will result in arc instability, or cause the filler wire to become jammed, a situation known as a “bird nest”. It is recommended that sharp bends in the gun cable be minimized. If possible, the wire feeder should be positioned so that the gun cable is nearly straight during welding.

Table 2: Typical Gas Metal Arc Welding Parameters (Flat Position)

Wire Diameter		Wire Feed Speed		Welding Current	Average Arc Voltage	Shielding Gas
in	mm	ipm	mm/s	Amps	Volts	-
Short-Circuiting Transfer Mode						
0.035	0.9	150-200	63-85	70-90	18-20	75Ar-25He
0.045	1.1	175-225	74-95	100-160	19-22	75Ar-25He
Spray Transfer Mode						
0.045	1.1	250-350	106-148	190-250	28-32	100Ar
0.062	1.6	150-250	63-106	250-350	29-33	100Ar
Pulsed Spray Transfer Mode*						
0.035	0.9	300-450	127-190	75-150 Avg.	30-34	75Ar-25He
0.045	1.1	200-350	85-148	100-175 Avg.	32-36	75Ar-25He

*Detailed pulsed spray parameters are available upon request