Gas Metal Arc Welding

Examining metal transfer modes, electrodes, and shielding gases

The American Welding Society (AWS) defines gas metal arc welding (GMAW) as "an arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the workpiece. Shielding is obtained entirely from an externally supplied gas."

The essential elements of a basic GMAW process are shown in **Figure 1**.

GMAW is an arc welding process that incorporates the automatic feeding of a continuous, consumable electrode that is shielded by an externally supplied gas (see **Figure 2**). Since the equipment provides for automatic control of the arc, the only manual controls required by the welder for semiautomatic operation are the gun positioning, guidance, and travel speed.

GMAW is used to weld all the commercially important metals, including steel, aluminum, copper, and stainless steel. The process can be used to weld in any position, including flat, vertical, horizontal, and overhead. It is usually connected to use direct current electrode positive (DCEP).

Metal Transfer Modes in GMAW

The GMAW process has five distinct metal transfer modes:

1. Short circuiting
2. Globular
3. Spray
4. Pulsed spray
5. High-current density (rotational and nonrotational spray)

The metal transfer mode is determined by many factors, including current, wire diameter, arc length or voltage, power supply characteristics, and shielding gas.

Short-Circuit Gas Metal Arc Welding (GMAW-S)

AWS defines short-circuit gas metal arc welding (GMAW-S) as "a gas metal arc welding process variation in which the consumable electrode is deposited during repeated short circuits."

In the short-circuiting mode, metal transfer occurs when the electrode is in contact with the weld pool. In this mode of metal transfer, the relationship between the electrode melt rate and its feed rate into the weld zone determines the intermittent establishment of an arc and the short circuiting of the electrode to the workpiece.

Specifically, the electrode is fed at a constant speed at a rate that exceeds the melt rate. When it contacts the molten pool, a short circuit occurs, at which time there is no arc. The current then begins to rise and heats the wire to a plastic state. At the same time, the wire begins to deform or neck down because of electromagnetic pinch effect.

Eventually, the current value and resulting pinch force cause a drop of metal to detach into the weld puddle. At this point, an arc is established. This sequence repeats itself about 50 to 250 times per second (see **Figure 3**).

Since there is no arc established during the short circuit, the overall heat input is low, and the depth of fusion is relatively shallow. Thus, care must be exercised in selecting the procedure and weld technique to ensure complete fusion when welding thick metal.

Because of its low heat input characteristics, the process produces small, fast-freezing weld puddles, which makes it suitable for welding in all positions. Short-circuiting transfer is also adaptable to welding sheet metal with minimum distortion and for filling gapped or poorly fitted parts with less tendency for burn-through of the part being welded.
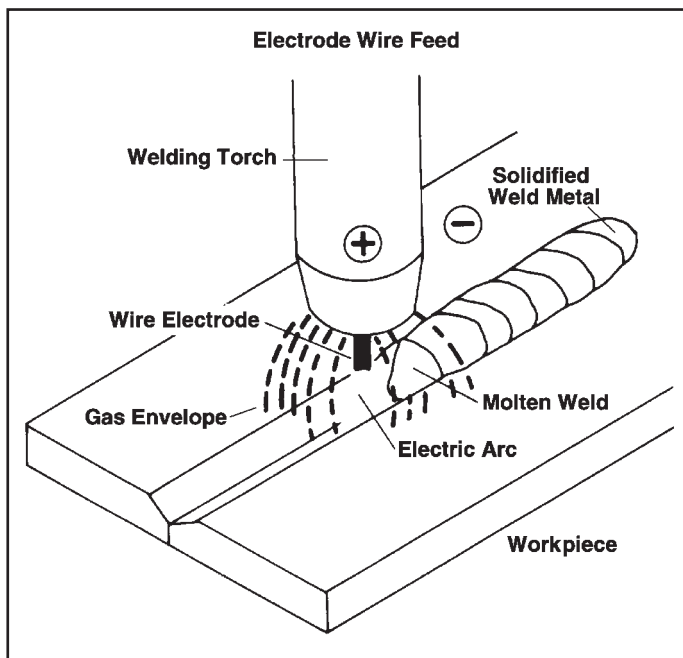

Figure 1
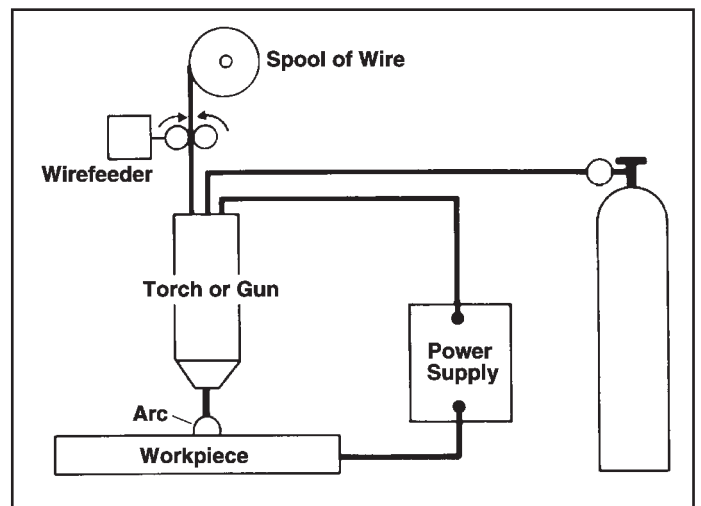**This shows the essential elements of a basic GMAW process.**

Figure 2
GMAW incorporates the automatic feeding of a continuous, consumable electrode that is shielded by an externally supplied gas.
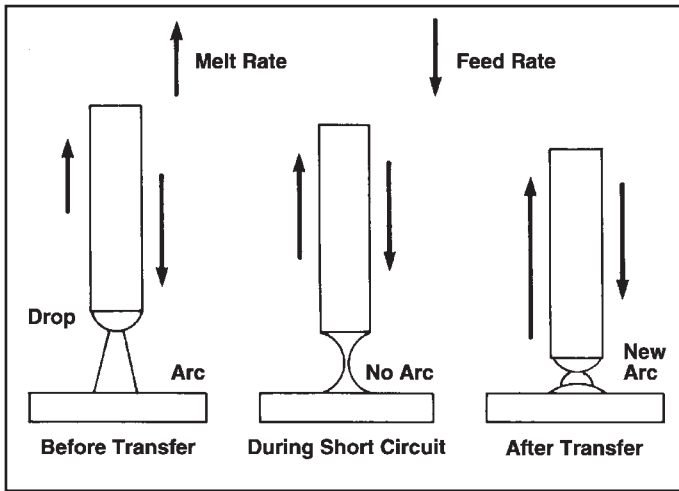
Figure 3
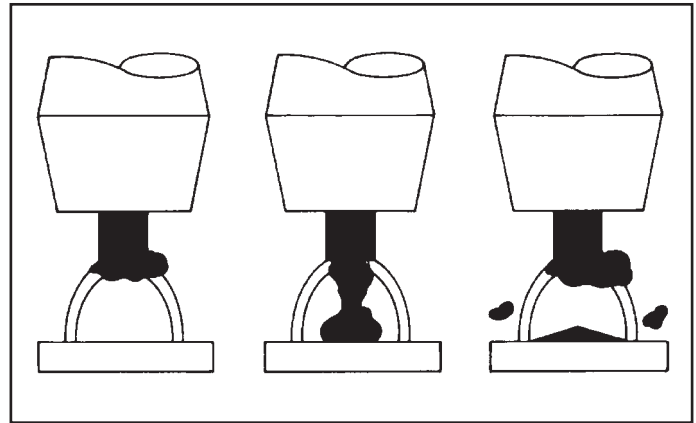The short-circuiting transfer sequence is illustrated here.

Figure 4
Globular transfer is characterized by a drop size about two to four times greater than the diameter of the electrode.

▌Globular Transfer

Globular transfer is characterized by the transfer of molten metal in large drops across the arc. This transfer mode takes place when the current and arc voltage are between the short-circuiting and spray transfer current and voltage levels and occurs with all types of shielding gas. Carbon dioxide yields this type of transfer at all usable welding currents above the short circuiting range.

Globular transfer is characterized by a drop size about two to four times greater than the diameter of the electrode (see **Figure 4**).

With carbon dioxide, the droplet is not propelled across the arc because of the repelling forces acting upward toward the wire tip. These forces tend to hold the droplet on the end of the wire. During this time, the drop grows in size and eventually either transfers by gravity due to its weight or short circuits across the arc gap.

▌Spray Transfer

In spray transfer, the molten metal is propelled axially across the arc in small droplets. In a gas blend of at least 80 percent argon (see **Figure 5**), the electrode metal transfer changes from globular to spray mode as welding current increases for any given electrode diameter. The change takes place at a value called the globular-spray transition current. Spray transfer in argon has a constricted arc column and pointed electrode tip (see

Electrode Type	Wire Dia. (In.)	Shielding Gas	Spray Arc Current
Low Carbon Steel	0.023	98% Argon - 2% O_2	135
	0.030	98% Argon - 2% O_2	150
	0.035	98% Argon - 2% O_2	165
	0.045	98% Argon - 2% O_2	220
	0.062	98% Argon - 2% O_2	275
	0.035	95% Argon - 5% O_2	155
	0.045	95% Argon - 5% O_2	200
	0.062	95% Argon - 5% O_2	265
	0.035	92% Argon - 8% CO_2	175
	0.045	92% Argon - 8% CO_2	225
	0.062	92% Argon - 8% CO_2	290
	0.035	85% Argon - 15% CO_2	180
	0.045	85% Argon - 15% CO_2	240
	0.062	85% Argon - 15% CO_2	295
	0.035	80% Argon - 20% CO_2	195
	0.045	80% Argon - 20% CO_2	255
	0.062	80% Argon - 20% CO_2	345
Stainless Steel	0.035	99% Argon - 1% O_2	150
	0.045	99% Argon - 1% O_2	195
	0.062	99% Argon - 1% O_2	265
	0.035	Argon - Helium - CO_2	160
	0.045	Argon - Helium - CO_2	205
	0.062	Argon - Helium - CO_2	280
	0.035	Argon - Hydrogen - CO_2	145
	0.045	Argon - Hydrogen - CO_2	185
	0.062	Argon - Hydrogen - CO_2	255
Aluminum	0.030	Argon	95
	0.047	Argon	135
	0.062	Argon	180
Deoxidized Copper	0.035	Argon	180
	0.045	Argon	210
	0.062	Argon	310
Silicon Bronze	0.035	Argon	165
	0.045	Argon	205
	0.062	Argon	270

Figure 5
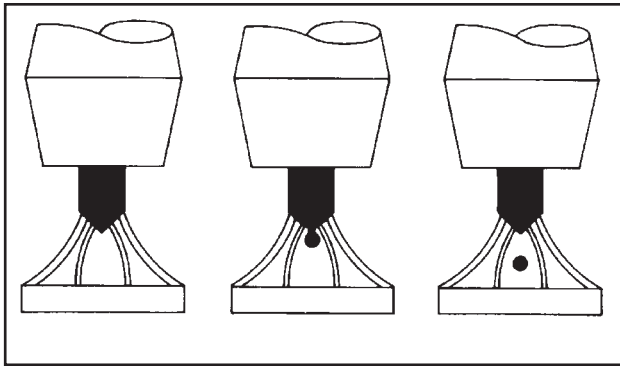This table lists the globular-to-spray transition currents.

Figure 6
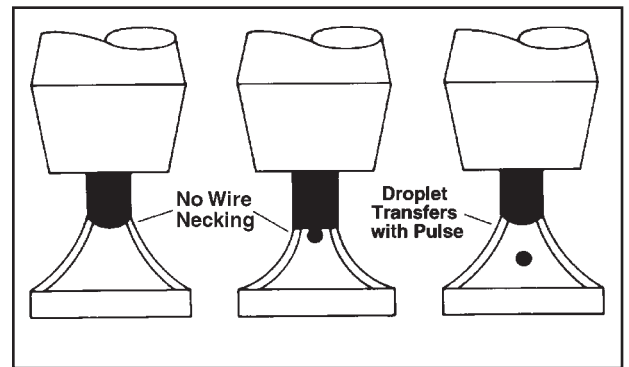Spray transfer in argon has a constricted arc column and pointed electrode tip.

Figure 7
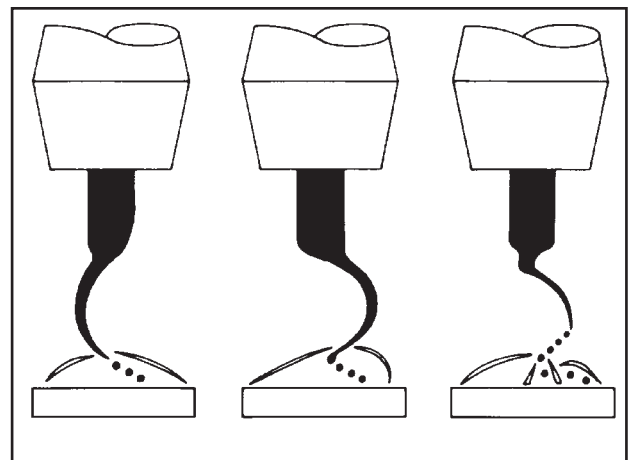Ideally in pulse spray welding, one droplet is transferred during each pulse.

Figure 8
In rotational spray high current density transfer, the electromechanical forces generated by the current flow in the wire cause the molten wire end to rotate in a helical path.

In spray transfer, the molten metal is propelled axially across the arc in small droplets.

Figure 6).

Molten metal transfers across the arc as small droplets equal to or less than the electrode diameter. The metal transfer is axially directed to the workpiece. Since the metal droplets are small, the transfer rate can be as high as several hundred droplets per second.

Pulsed Gas Metal Arc Welding (GMAW-P)

In pulsed gas metal arc welding (GMAW-P), the power source provides two output levels: a steady background level, too low in magnitude to produce any transfer but able to maintain an arc; and a pulsed, high-output level which causes melting of droplets from the electrode that are then transferred across the arc.

This pulsed high output (peak) occurs at regular controlled intervals. The current can be cycled between a high and low value at up to several hundred cycles per second. The net result is to produce a spray arc with average current levels much below the transition current required for a particular diameter and type of electrode.

In pulsed spray welding, the shielding gas must be able to support spray transfer. Metal is transferred to the workpiece only during the high current pulse. Ideally, one droplet is transferred during each pulse (see **Figure** 7).

The pulsing rate can be varied depending on the base material, thickness, and weld position. The period of background current maintains the arc and heat input. The resulting lower average current level allows the welding of base metals less than ⅛ inch thick with a spray type metal transfer. Pulsed spray welding may be used to weld in all positions.

High Current Density Metal Transfer

High current density metal transfer is a name given to a GMAW process having specific characteristics created by a unique combination of wire feed speed, wire extension, and shielding gas. Weld metal deposition rates range between 10 and 55 pounds per hour with a practical upper limit of 40 pounds per hour, whereas most GMAW spray arc is in the 8- to 12-pound range.

The arc characteristics of high density metal transfer are further divided into rotational spray transfer and nonrotational spray transfer.

When using a solid carbon steel wire, a high wire feed speed is combined with a long electrode extension and an argon/carbon dioxide/oxygen shielding gas to create an arc phenomenon known as rotational spray arc transfer.

The long electrode extension creates high resistance heating of the wire electrode, causing the electrode end to become molten. The electromechanical forces generated by the current flow in the wire cause the molten wire end to rotate in a helical path (see **Figure 8**).

The shielding gas affects the rotational transition current by changing the surface tension at the molten electrode end. Some blends produce rotational spray transfer at deposition rates of 10 to 55 pounds per hour with 0.035 and 0.045 diameter wires using contact-tip to workpiece distances of ⅞ inch to 1½ inch.

Nonrotational spray high current density transfer is produced when the molten wire end does not rotate. This develops a deposition rate of 10 to 30 pounds per hour. Rotation is suppressed when the thermal conductivity of the shielding gas increases and the surface tension of the molten electrode end increases. The droplet rate decreases, resulting in larger droplets across the arc.

Shielding gases with higher carbon dioxide or helium percentages will raise the rotational spray transition current and suppress the tendency for the arc to rotate. The arc appears elongated and diffused but looks similar to conventional spray transfer.

The plasma stream is axial and more narrow than rotational spray transfer. Because the heat source is more concentrated, the depth of fusion is greater than rotational spray transfer at the same welding current.

▌Metal-Cored Electrodes

Welding using metal-cored wires is considered a variation of GMAW. AWS classifies metal-cored wire as a solid wire because it operates like a solid wire and has low fume, no slag, and high deposition efficiency (95 percent or better) despite its cored wire type construction.

A metal-cored wire is a composite filler metal electrode consisting of a metal tube that contains alloying materials. These alloying materials provide arc stabilization and fluxing of oxides. Metal-cored wires provide high deposition rates with excellent deposition efficiency and can be used to weld in all positions.

Metal-cored wires are designed to give quality welds over rust and mill scale using argon-based shielding gases. They generally have high levels of deoxidizers that allow good bead profile with excellent puddle control. This type of wire allows the high deposition rate of flux-cored wires with the deposition efficiency and fume levels of a solid wire. The weld metal mechanical properties are comparable to carbon steel solid wires and, as with solid wires, little slag is formed over the welds.

The advantages of metal-cored wire are:

1. High deposition rates.
2. High deposition efficiency.
3. Quality welds over rust and mill scale.
4. Low spatter levels.
5. Little slag cleanup.
6. Easy to use.
7. All-position welding possible.
8. Lower fume levels..

Metal-cored carbon steel wires operate best in an argon/carbon dioxide blend (5 percent to 20 percent carbon dioxide) or argon/carbon dioxide/oxygen blend, while stainless wires operate best in an argon/oxygen blend with low oxygen or carbon dioxide additions.

▌Shielding Gases for GMAW

Argon. Argon is used on nonferrous base metals such as aluminum, nickel, copper, magnesium, alloys, and on reactive metals such as zirconium and titanium. Argon provides excellent arc welding stability, penetration, and bead profile on these base metals. When welding ferrous-based metals, argon is usually mixed with other gases, such as oxygen, helium, carbon dioxide, or hydrogen.

The low ionization potential of argon helps create an excellent current path and superior arc stability. Argon produces a constricted arc column with high current density that causes the arc energy to be concentrated over a small surface area. The result is a penetration profile having a distinct "finger-like" shape.

Carbon Dioxide. Carbon dioxide, a reactive gas, dissociates into carbon monoxide and free oxygen in the heat of the arc. Oxygen then combines with elements transferring across the arc to form oxides that are released from the weld pool in the form of slag and scale, generating a great deal of fume. Although carbon dioxide is an active gas and produces an oxidizing effect, sound welds can be consistently achieved.

Carbon dioxide is often used for welding carbon steel because it is readily available and produces good welds at low cost. However, the low cost per unit of gas does not always translate to the lowest cost per foot of deposited weld. Other factors, such as lower deposition efficiency due to spatter loss, can influence the final weld cost and should be carefully considered.

Carbon dioxide will not support spray transfer. Metal transfer is restricted to the short-circuiting and globular modes. Carbon dioxide causes harsh globular transfer with its characteristic spatter.

The weld surface resulting from carbon dioxide shielding is usually heavily oxidized. An electrode with higher amounts of deoxidizing elements is needed to compensate for the loss of alloying elements across the arc. The advantages of carbon dioxide are good width of fusion and the achievement of good mechanical properties.

Helium. Helium is a chemically inert gas that is used for welding applications requiring higher heat inputs. Helium may improve wetting action, depth of fusion, and travel speeds. It does not produce the stable arc provided by argon.

Helium has higher thermal conductivity than argon and produces a wider arc column. The higher voltage gradient provides a higher heat input than argon, promoting greater weld pool fluidity and better wetting action. This is an advantage when welding aluminum, magnesium, and copper alloys.

Argon/Oxygen Blends. The addition of small amounts of oxygen to argon greatly stabilizes the welding arc, increases the filler metal droplet rate, lowers the spray transition current, and influences bead shape. The weld pool is more fluid and stays molten longer, allowing the metal to flow out toward the weld toes.

Argon/Carbon Dioxide Blends. Argon/carbon dioxide blends are mainly used on carbon and low-alloy steels and have limited application on stainless steels. Carbon dioxide added to argon at higher current levels increases spatter.

In GMAW, a slightly higher current level must be reached when using argon/

carbon dioxide to establish and maintain stable spray transfer. Above about 20 percent carbon dioxide, spray transfer becomes unstable, and periodic short-circuiting and globular transfer occurs.

Argon/Helium Blends. Helium is often mixed with argon to obtain the advantages of both gases. Argon provides good arc stability and cleaning action while helium promotes wetting with a broad width of fusion.

Argon/helium blends are used primarily for nonferrous base metals, such as aluminum, copper, nickel alloys, magnesium alloys, and for reactive metals. Helium additions to an argon base gas will increase the heat input.

Generally, the thicker the base metal, the higher the percentage of helium. Small percentages of helium, as low as 20 percent, will affect the arc. As helium percentages increase, the arc voltage, spatter, and weld width to depth ratio increase, while porosity is minimized in aluminum.

The argon percentage must be at least 20 percent when mixed with helium to produce and maintain a stable spray transfer.

Argon/Oxygen/Carbon Dioxide Blends. Mixtures containing argon, oxygen, and carbon dioxide are versatile because of their ability to operate using short-circuiting, globular, spray, pulsed, and high-density transfer modes. Several three-gas compositions are available, and the application depends on the desired metal transfer mode.

Argon/Helium/Carbon Dioxide Blends. Helium and carbon dioxide additions to argon increase the heat input to the weld, which improves wetting, fluidity, and weld bead profile. ∎