A New Look at GMAW Metal Transfer

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An understanding of how liquid metal drops are formed, and transferred to the weld puddle, will help make you a better welder.

Introduction

Typical spray transfer in Gas Metal Arc Welding (GMAW) is shown in Figure 1.

Fig. 1 Typical spray transfer

This article describes how the liquid metal drop, on the arc end of the electrode extension, is created and then ejected (transferred) into the molten metal weld pool. The piece of wire electrode, that forms the drop, passes from a wire reel at room temperature and is fed through the contact tip. It then travels from the contact tip into, and through, the electrode extension zone, on its way to the arc zone. During its passage through the electrode extension, toward the arc, it is JOULE heated by the current which passes from the contact tip, through the electrode extension resistance, to the arc. There it is melted by the heat of the arc.

With GMAW spray transfer the liquid metal drops are transferred toward the weld puddle by the combined forces due to surface tension, gravity, and electromagnetic pinch. (To be precise, there are other forces which can play a part in the transfer process, but these three are the major factors.) When a drop is on the end of the electrode, surface tension acts to keep the drop from transferring. Both gravity and electromagnetic pinch act to transfer the drop, then, when the drop touches the weld puddle, surface tension acts to complete the transfer of the drop into the puddle.

Fig. 2 Typical forces

How much electrode makes a typical drop?

When a drop is the same diameter as the electrode a simple calculation will show it takes a piece of electrode (cylinder) that is 2/3 as long as its diameter.

The Calculation

Drop volume = $V_d = (4/3)\pi r_d^3$
Cylinder volume = $V_c = (h)\pi r_c^2$

Where Drop radius = r_d
Cylinder radius = r_c
cylinder length = h

When $r_d = r_c$ and $2r$ = diameter (D)
Let $V_d = V_c$ and solve for (h)

Then $(h) = (2/3)D$

For example: When welding with a 0.045 inch diameter electrode, a drop with the same diameter as the electrode needs a piece of electrode 0.030 inches <(2/3)D> long. If the electrode extension is about 0.300 inches (Somewhere, typically between 0.250 and 0.500 inches) that means there is enough material in the electrode extension to make 10 drops (10 X 0.030 = 0.300).

Each of the 2/3D pieces starts out from a reel of electrode wire, at room temperature, as it is fed into, and through, the contact tip on its way to the arc zone. During its travel to the arc zone the 2/3D piece is heated internally by the current passing through its electrical resistance, according to the JOULE HEAT equation.

I^2Rt = Joules (watt seconds)
Where: I = Current, amperes
R = Resistance, Ohms
t = heating time, seconds

Each 2/3D piece can be thought of as sharing its "heat" with its neighbor. Therefore, the electrode extension's temperature will average out, and rise steadily as each 2/3D piece travels through the electrode extension zone on its way to the arc zone. In this example, by the time a 2/3D piece reaches the arc zone it can be thought of as having been heated 10 times.

When the 2/3D piece finally reaches the arc zone it will be part way to melting. Typically, for steel, it will have reached a few hundred degrees Celsius. The internal I^2Rt heating is almost 100% efficient, since the electrode feed rate is greater than the thermal diffusivity (the speed of heat travel in the electrode extension metal) and only a small amount of heat is lost due to radiation and convection.

What happens to the drop size when the 2/3D length is changed?

A calculation will show when twice as much electrode is used for each drop (2 x 2/3D), the drop diameter will be 1.26 times the electrode diameter. When half as much electrode is used for each drop (1/2 x 2/3D) the drop diameter will be 0.794 times the electrode diameter. The range of 1.26 to 0.794 illustrates a typical drop diameter does not vary a great deal from the one diameter size. Therefore, the remainder of this discussion will be based on the 2/3D length.

What happens to the 2/3D piece when it reaches the arc?

When a 2/3D piece finally reaches the arc, on the end of the electrode extension, it begins to be heated by the Watts of the arc. The arc Watts are created by the current passing through the arc's anode voltage, or cathode voltage, as the case may be. The arc Watts cause a rapid rise in the temperature of the 2/3D piece. As the heat of the arc Watts is transferred into the 2/3D piece, more and more of it melts and it becomes a drop.

With GMAW spray transfer, as shown in Fig. 1, the drop is transferred from the end of the electrode, through the arc by the combined forces of gravity, electromagnetic pinch and surface tension. When the transferred drop merges with the weld puddle surface tension completes the transfer.

With GMAW Short Circuit transfer (GMAW-S), as shown in Fig. 3, the continuing electrode feed rate causes the drop to contact the surface of the weld pool. There it is transferred by the forces mainly due to surface tension and electromagnetic pinch. The effect of gravity is minimal.

Fig.3 A typical GMAW-S transfer cycle

With GMAW-S, although the electromagnetic pinch force can help transfer the liquid drop, it is the surface tension force that dominates the transfer. Some power supplies even decrease, or eliminate, the current during the instant of transfer. Thus, minimizing or eliminating the electromagnetic pinch force. This allows only the surface tension force to complete the drop transfer into the puddle.

As a consequence of the dominance of the surface tension force, and the uniformity of the drop size, the drop transfer sequence does not vary greatly. Transfer time is relatively constant for a specific material, welding condition, etc. For example: with steel electrodes the measured transfer time ranges between 0.002 seconds and 0.003 seconds per transfer.

What happens to the drop size as the current magnitude changes?

With lower current, the electromagnetic pinch force is less. Therefore, the drop will increase in size because gravity is the only force left to overcome the retaining force of surface tension.

With higher current, the electromagnetic pinch force is greater. Therefore, the drop will decrease in size because the pinch force will assist gravity, in overcoming the surface tension retaining force.

What can you do to promote better metal transfer?

The best metal transfer occurs when drop size and drop frequency are stable. In other words, when drops have the same size, shape and frequency of transfer. Therefore it is essential that surface tension is uniform. Uniform surface tension depends on surface chemistry (composition) of the drop. This requires excellent gas shielding (type and amount). Do not be careless in setting the gas flow rate.

Uniform electrode wire surface condition is very important for maintaining a stable surface tension and feed rate. Keep the wire shielded from dusts and contamination. A clean electrode wire will have a more stable feed rate. A stable feed rate helps promote a stable drop size.

Most important is your welding technique. Be careful to maintain a consistent arc length and manipulation when you weave, or move the arc. Stability promotes uniform drop size. Finally, do not fuss with the power source settings. Use the settings recommended for the welding condition. Remember, everything you do can effect drop size and frequency. Stable transfer makes the best welds.

References:

"Welding Processes and Practices"; Koelhoffer, Manz and Hornberger, John Wiley and Sons, 1988, pages 343 and 346

"Advances in Power Supplies for Industry"; Welding Journal, Sept. 1963, Vol. 42, No. 9, pages 719-724

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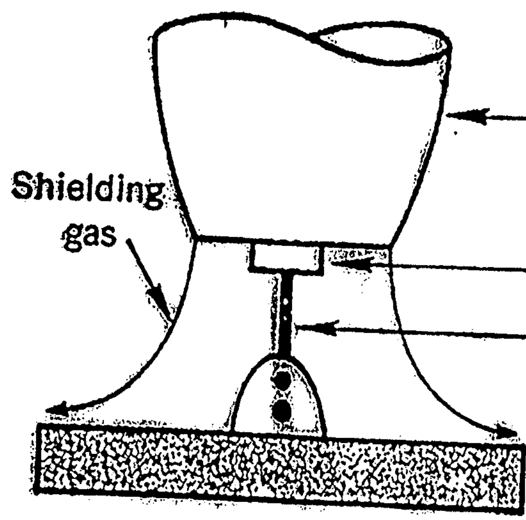

Fig. 1

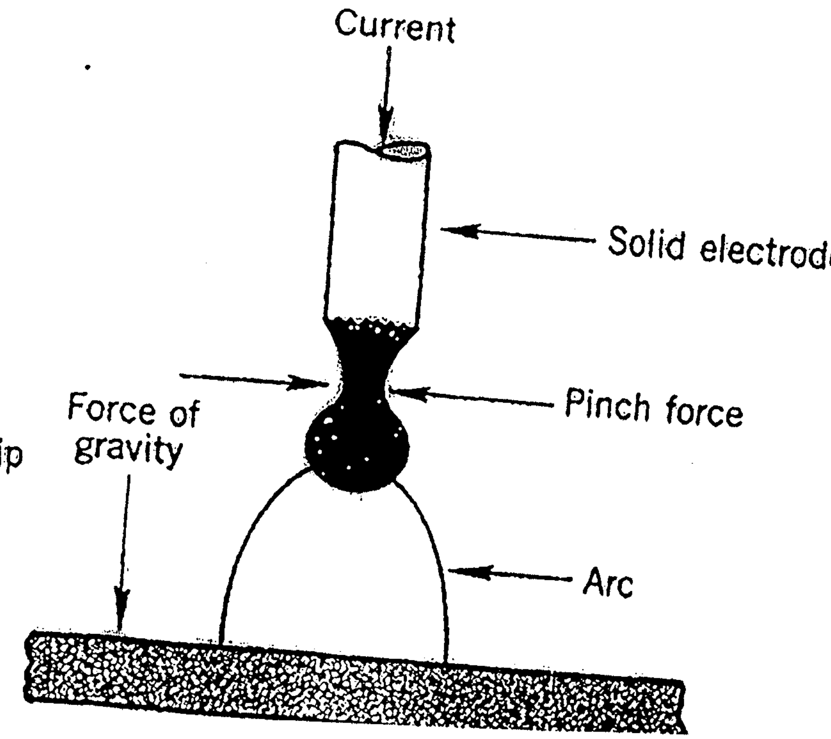

Fig. 2

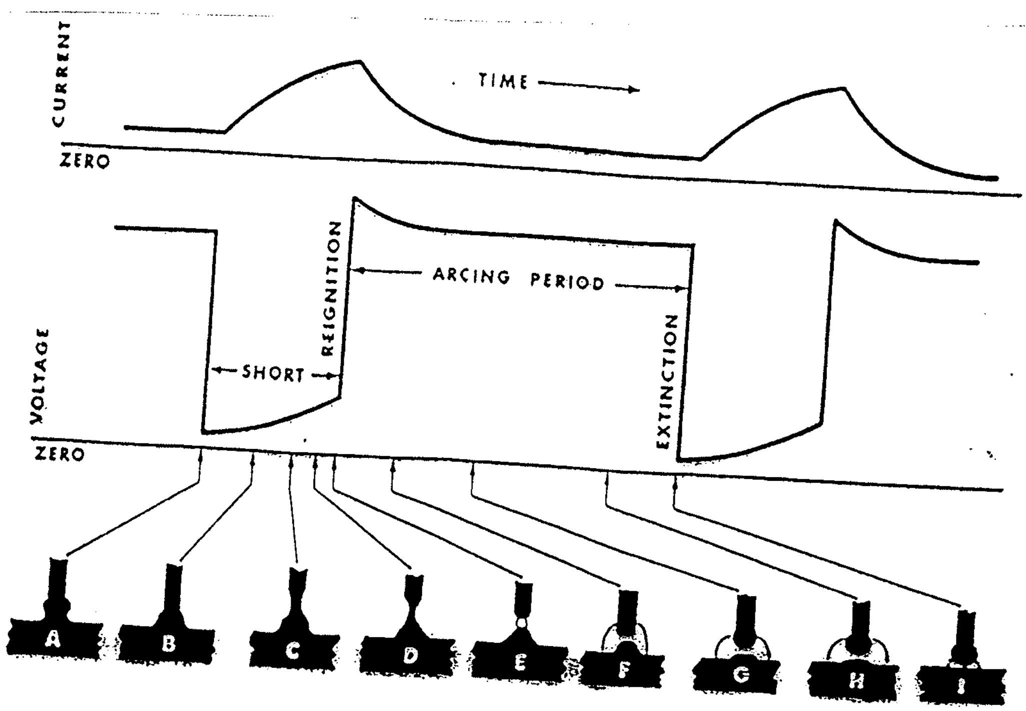

Fig. 3