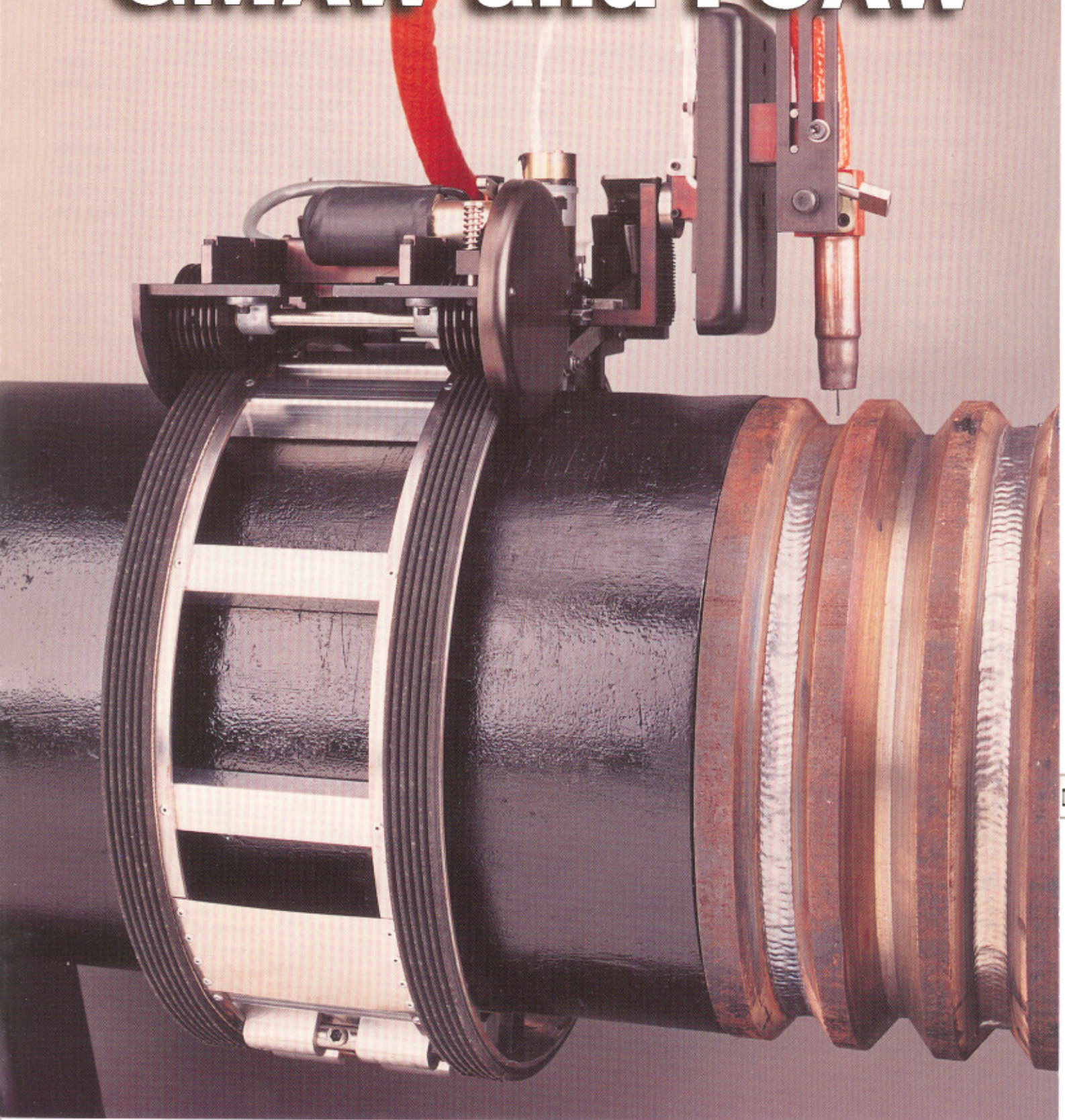


Welding Pipe with GMAW and FCAW



Two viable processes for orbital welding applications

By John Emmerson

Orbital gas tungsten arc welding (GTAW) equipment for pipe welding is available from numerous manufacturers worldwide and has been accepted by many industries welding to a variety of standards. First developed 30 years ago as exotic tools for the aerospace and nuclear power industries, the products available today represent a mature industry.

The mechanized pipe welding industry has continued to grow for a number of reasons:

1. Increasing shortage of skilled welders worldwide
2. Increasingly stringent weld quality standards in industries previously not covered by code standards
3. The need to reduce labor costs
4. The development of pipe materials requiring tight control over weld parameters to maintain desired metallurgical characteristics

In fact, certain industries—including semiconductor, pharmaceutical, biotechnology, and food processing—no longer permit the use of manual welding.

Orbital pipe welding equipment using the GTAW process can produce high-quality welds in all pipe orientations where it is not possible or practical to rotate the pipe. The chief limitation of the GTAW process is that it is slow. The practical limit for 360-degree orbital welding is 1 pound (0.45 kilograms) per hour deposition rate.

Certain techniques and process variations can increase this somewhat. "Hot wire" GTAW, in which an electrical current is used to preheat the filler wire, allows the deposition rate to be increased to about 3 pounds (1.4 kilograms) per hour. This comes, however, with added complexity in both equipment and operator skill requirements.

For these reasons, orbital GTAW has been primarily used for fusion welding of small-diameter tubing and welding of pressure pipe requiring filler wire addition up to about 12 inches (32.3 centimeters).

With the exceptions of a few special applications, orbital GTAW is usually too slow for welding larger-diameter or heavy-wall pipe.

The GMAW and FCAW Processes

The gas metal arc welding (GMAW) process became commercially available in the late 1940s. A continuous solid wire (electrode) is passed through an electrically hot contact tip, which causes an arc between the wire and the weld pool and subsequent melting of the filler wire. The solid wire is shielded with a protective gas that prevents the molten weld puddle from oxidizing.

The flux core arc welding (FCAW) process (see **Figure 1**) substitutes the tubular wire with a core of fluxing elements in a powdered form. A slag cover is deposited on the face of the weld bead. The process is similar to GMAW and also uses either inert or active shielding gases.

The flux contained in the electrode serves two basic purposes:

1. The composition of the flux can affect the chemistry and metallurgy of the deposited metal.
2. The flux controls the rate of solidification of the molten weld puddle. Therefore, certain fluxes allow welding "out of position," a process usually prevented by gravity. All-position flux core wires contain flux which causes the puddle to freeze before gravity can act upon it.

Externally supplied shielding gas is still used in conjunction with flux core filler wire. The fluxing material aids wetting of the puddle edges, helps improve bead contour, and helps cleanse the weld puddle of impurities.

Manual GMAW and FCAW equipment consists of a power source, a filler wire feeder, and a torch. Manual GMAW (often referred to as semiautomatic) allows a welder to deposit up to 4 pounds (1.8 kilograms) per hour when welding a pipe that cannot be rotated.

So why do most shops not use the GMAW or FCAW process for orbital welding of pipe and tube, especially for

applications such as heavy-wall or larger-diameter pipe?

Early in its development, short-circuit GMAW developed a bad reputation. With proper application and appropriate parameters, excellent welds can be produced using short-circuit GMAW. However, if the welder is not careful to follow established procedures, a number of serious weld defects can occur.

The most significant of these defects is lack of sidewall fusion; the molten puddle of metal does not fully fuse with the pipe sidewalls, and a "cold lap" defect occurs. This is a significant structural defect that is difficult to identify with commonly used nondestructive inspection methods such as radiography. So while the GMAW and FCAW processes have gained popularity for many applications, they have not been considered serious options for most pipe welding operations.

This poor reputation is no longer deserved, however. Continuous development in both power supply and consumable technology have made this process a viable alternative to manual GTAW or shielded metal arc welding (SMAW) of pipe (see **Figure 2**).

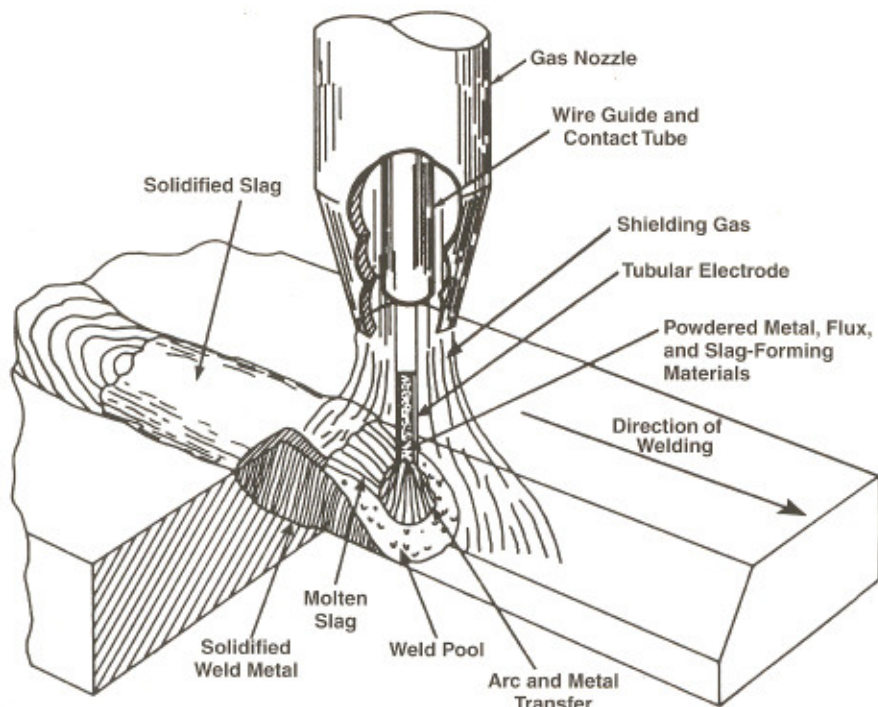
GMAW Transfer Characteristics

It is best to think of GMAW/FCAW as a closely related family of processes. However, all of the variants of GMAW have the following characteristics in common:

1. A continuous consumable electrode is used, with the arc forming between the end of the electrode and the workpiece.
2. The consumable electrode is automatically fed into the weld puddle.
3. External shielding gas is used to prevent the electrode and weld puddle from oxidizing and to influence the metallurgical characteristics of the deposited weld metal.

The characteristics of the GMAW process are best described in terms of the basic means by which metal is transferred from the electrode to the work:

1. Short-circuiting transfer



Courtesy of American Welding Society

Figure 1

This drawing shows the details of the FCAW process.

2. Globular transfer
3. Spray transfer
4. Pulsed-spray transfer

The mode of transfer is determined by number of factors:

1. Welding amperage level
2. Electrode diameter
3. Shielding gas
4. Electrode type/composition
5. Electrode stick-out (extension from the contact tip)
6. Power source design

The **short-circuiting transfer** mode of GMAW (commonly known as short arc) is associated with low average currents and voltage levels. The electrode actually contacts the weld pool, initiating a short circuit that causes a rapid rise in current flow and the subsequent melting of the electrode tip.

This short-circuiting process occurs from 20 to more than 200 times per second. No metal is transferred across the arc gap. This results in a rather violent transfer of the molten metal, which causes high spatter.

Until recently, only limited attempts have been made to control the dynamics of the short-circuiting process. Because of its lower relative heat input, great care must be taken to avoid lack-of-fusion defects. This has resulted in a rather poor reputation for the short-circuiting process for applications requiring high weld quality and integrity.

As the voltage and amperage of the process increase, the electrode starts to melt before contacting the workpiece surface, and metal is transferred across the arc. At a transition point, **globular transfer** occurs, which is characterized by a droplet with a diameter greater than that of the electrode. The large droplet size is affected by gravity, limiting this operating mode to the flat position.

With increasing currents and voltages, and with the use of argon-rich shielding gas, a transition occurs to **spray transfer**. Spray transfer is characterized by drops smaller than the electrode diameter that are formed and detached at the rate of hundreds per second. They are accelerated across the arc gap by arc forces at speeds sufficient to overcome the effect of gravity.

This transfer mode results in deeper penetration and lower spatter levels than either the short-circuiting or globular modes. Spray transfer can produce high-quality welds meeting any quality standards. Its one serious limitation, however, is that the large puddle size that rapidly forms from the high heat input is acted upon by gravity, making this unsuitable for out-of-position welding.

Pulsed-spray transfer was developed in the 1960s to circumvent some of the limitations of spray transfer. Spray transfer occurs above a certain transition current. Pulsed-spray alternates the current level to peaks above the transition level during which spray transfer occurs, alternating with substantially lower levels below this transition current.

The background current provides some energy to melt the wire, but not enough to transfer metal. The pulses of current complete the melting, adding enough energy to transfer the molten droplet. The average current level is actually maintained below the transition current. Pulsed-spray transfer provides high penetration and low spatter with lower heat input and allows welding in all positions.

Recent Advances in GMAW Power Sources

Although pulsed-spray GMAW theoretically overcame many problems with out-of-position welding, it was difficult to implement on the shop floor environment. The goal of the pulsed-spray process is to detach one droplet of wire with each energy pulse applied to the electrode. Applying precisely this amount of energy at precisely the correct time produces a stable arc, optimal puddle formation conditions, and minimizes spatter.

However, a number of variables—high pulse current level, background current level, peak pulse time duration, and pulse frequency—must be precisely controlled for this to happen. The interdependence and sensitivity of these parameters make it difficult for the practical user to properly adjust a pulsing power supply outside of a laboratory setting.

Power supply manufacturers came to terms with this problem by developing power sources capable of “synergic” or single-knob operation. Essentially, syner-

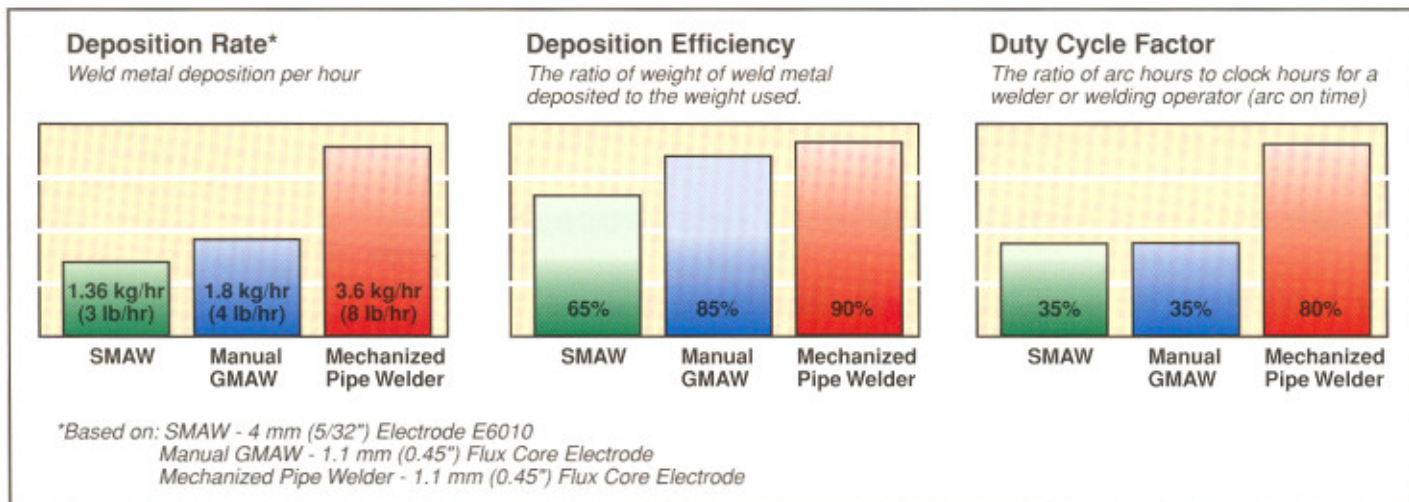


Figure 2

Deposition characteristics and duty cycle factors for three methods of orbital pipe welding are compared here.

gic programming is based on the concept that the pulse parameters are factory-pre-programmed for a given wire diameter, material, and shielding gas.

The wire feeder interacts with the factory-preset program, which automatically adjusts one or more of the pulse variables to maintain a uniform energy output per unit of wire. The welder is then free to simply increase or decrease the wire feed without worrying about the pulse parameters, which are automatically adjusted to maintain a stable arc.

The "synergic" power source was the first attempt to provide a variable control for a complex process that was essentially transparent to the welder. However, when "synergic operation" was first developed, it was usually too simplistic. For example, simple preprogrammed relationships between two parameters such as wire feed speed and pulse frequency are useful but are often inadequate for optimal control of the complex GMAW/FCAW processes.

The most recent evolution in power supplies is the use of artificial intelligence (AI) and fuzzy logic. These types of power sources can monitor multiple information inputs to regulate a desired output, similar to the way the human brain processes information. Previous use of microprocessors to regulate welding processes has essentially been to store preprogrammed parameters.

AI and fuzzy logic allow more complex control systems, in which multiple input parameters might control a desired

optimal output parameter. For example, power source pulse frequency and operating characteristics—constant current (CC) or constant voltage (CV)—might be changed based on both wire speed and arc voltage.

The inverter-based power module designs introduced in the 1980s allowed superior control because of the fast response possible in the power supply output by modifying the nature and shape of the pulse waveform or momentarily changing the power supply output characteristic.

"Fuzzy logic control provides automatic adjustment of arc voltage to provide optimum arc characteristics. This provides good stability despite fluctuations in tip-to-workpiece distance and sudden changes in travel speed, making the process more forgiving and suitable for unskilled welders," states Bill Guest of Daihen, Inc./OTC, Charlotte, N.C.

Power supplies are available that use AI to modify the nature and shape of the pulse wave form. "This allows welds to be made at low voltages with short arc lengths. It is ideal for out-of-position welding because of the fast-freezing puddle and low spatter at all voltages resulting from dynamic software control of the weld process," states Martin Weir of Panasonic Factory Automation, Franklin Park, Ill.

Solid wire has been a second-best choice for out-of-position pipe welding, without a flux to control the puddle, but recent research has made solid wire a viable option.

According to Darryll Dodson of Lincoln Electric, Cleveland, Ohio, "A new technology for short-circuiting transfer welding precisely controls the electrode current during the entire GMAW cycle and reduces or eliminates the common disadvantages of conventional 'short arc.' Since the process is not CC or CV, it is regarded as a new generation of inverter-based power sources.

"Even though the design has the same basic power platform as other inverter power sources, it uses electronics to more closely monitor and control the current waveform. Therefore, the power source must be able to change the electrode current in a few millionths of a second. It operates in a mode in which the electrode current is based on the instantaneous requirements of the arc. The idea behind it is independent control of wire feed speed and current."

Flux-Core Electrodes

The development of smaller-diameter (.052- and .045-inch) flux-core wires extended all-position capabilities, with smaller weld puddles required when welding overhead.

The first flux-core wires used an acidic rutile flux that sacrificed toughness to obtain high strength. In the 1990s, low-hydrogen, gas-shielded, all-position flux-core electrodes were developed that could produce welds with both high tensile strength and good low-temperature impact strength. Today's electrodes also exhibit lower spat-

