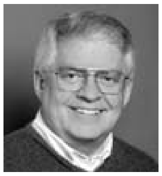

Technology Transfer

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Tandem GMAW: The Flexibility of Pulsed Spray Transfer

Suitable advances in technology foster change, and the changes that we are witnessing in the welding industry today are due to the forces of new power source technology. Moreover, it is no accident that much recent research and development work focuses on gas metal arc welding (GMAW). Historically, the bridge and structural fabrication industries have tended to view GMAW with derision, and with some cause. Issues regarding incomplete fusion set a precedent that has seriously limited the implementation of GMAW in code quality applications. However, recent advances in GMAW power source technology allow an opportunity to challenge conservative thinking regarding the use of gas metal arc welding.

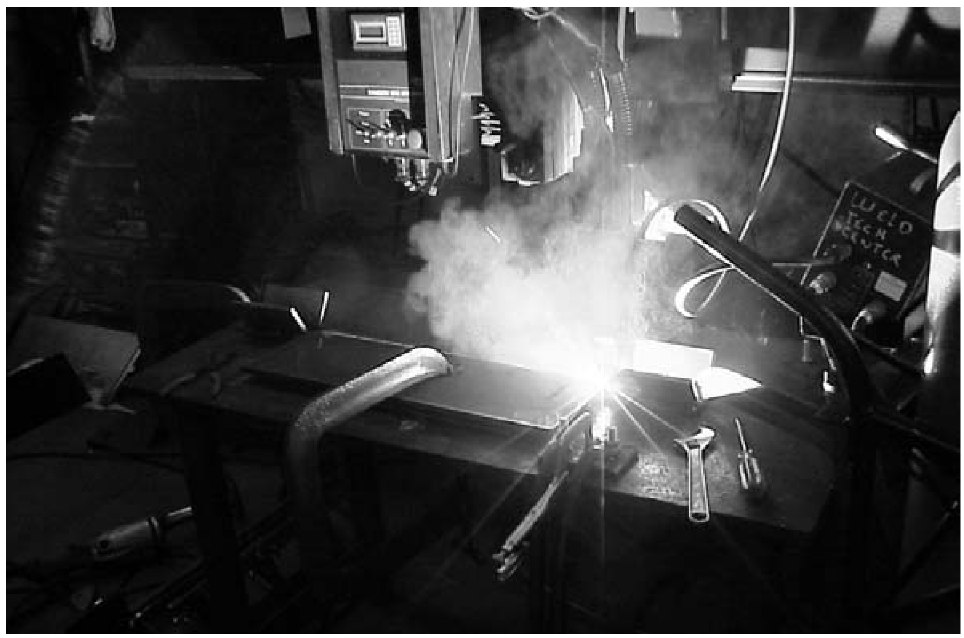

Figure 1. Welding ASTM 516 grade 70 base material test plates with tandem GMAW.

GMAW Process Review

Gas metal arc welding, by definition, is a process that produces coalescence of metals by heating them with an arc between a continuously fed filler metal electrode and the work. The process uses shielding from an externally supplied gas to protect the molten weld pool. The application of GMAW requires DC+ (reverse) polarity to the electrode.

In gas metal arc welding there are four traditional modes of metal transfer:

- Axial spray transfer is the higher energy mode and it provides the benefit of excellent fusion, but it is restricted to the flat and horizontal positions. Spatter is absent and the penetration profile is uniform.
- Pulsed spray metal transfer (GMAW-P) is a higher technology mode of metal transfer that provides the benefits of axial spray, but at a lower average current. The pulse exceeds the transition to spray transfer for a very short period, then it is reduced to a lower energy level often associated with short circuit transfer. Metal transfer only occurs during the pulse peak. This mode of metal transfer was developed because of its ability to lower spatter levels, overcome incomplete fusion defects, and be implemented in out-of-position welding applications.

Pulsed spray metal transfer provides the benefits of axial spray at a lower average current

- Globular metal transfer is historically associated with the use of 100% carbon dioxide shielding. The molten metal transfer occurs non-axially in droplets that are one and a half to three times larger than the diameter of the electrode. Globular transfer usually results in higher spatter levels, and it is prone to incomplete fusion.
- Short-circuit transfer is the low heat input mode of GMAW, in which metal transfer occurs as a result of physical contact between the elec-

Figure 2. Software employed to manipulate the pulsed spray mode of metal transfer. Note the nine pulsed spray transfer waveform components: Ramp Up Rate, Ramp Overshoot, Peak Current, Peak Time, Tailout Time, Tailout Speed, Step-off Current, Background Current, Background Time, and Frequency.

trode and the weld pool. This mode of metal transfer historically excels in the joining of sheet metal thickness material or open root pipe welding. When applied to a base material thicker than 3/16 in. (5 mm), short-circuit transfer can result in incomplete fusion.

New Developments

The transformation of GMAW, led by the development of software-driven inverters, has earned a second chance for critical code quality applications. Leading the way is the pulsed spray mode of metal transfer employed with Tandem GMAW (Figure 1). The newer features of the process invite several opportunities to reduce the manufacturing costs associated with both light and heavy steel fabrication. Consider the following:

- The arc can be tailored for penetration profile, heat input, and mechanical properties.
- The use of tandem GMAW, which incorporates two independent pulsed arcs in the same weld pool, leads to higher deposition rates and higher electrode efficiencies than was previously possible.
- GMAW produces lower levels of hydrogen and the process lends itself to a cost-effective alternative for joining high performance and high strength low alloy steels.
- Weld bead appearance is excellent.
- GMAW produces low levels of welding fumes, which can be an advantage for shop or other indoor fabrication.

The Tailorable Arc

Essential to the development or the manipulation of a particular welding waveform is an understanding of the relationship of the electrode type, its diameter, and the shielding gas employed. Shielding gas is central to determining the outcome of the finished weld and it has a profound effect upon penetration profile, bead shape, toe wetting, and mechanical properties. For example, the arc characteristics of a 95% argon + 5 % oxygen blend may be suitable for high travel speed welding on sheet metal thickness, but the penetration profile may be undesirable for plate thickness material. The electrode diameter, whether it is solid or metal cored, has an associated maximum current carrying capability. A 0.045 in. diameter (1.1 mm) electrode reaches its maximum current at approximately 420 Amps, and the maximum for a 0.035 in. diameter (0.9 mm) is approximately 220 Amperes.

The deposition rate is associated with a specific useable current range and, quite naturally, the higher the current the more energy there is to apply to the weld joint. For example, a solid 0.045 in. (1.1 mm) diameter electrode can carry more welding current than a 0.035 in. diameter (0.9 mm) electrode. Given similar wire feed speeds and arc travel speeds, we would expect that the penetration into the base material would be greater for the larger diameter than the smaller. Similarly, it would be true that the deposition rate potential would be higher for the larger diameter electrode. Selecting the electrode diameter and the shielding gas then becomes a choice based upon the needs of the joint, the base material type and thickness, the required mechanical properties, and through-put.

Advancing technology has produced astounding improvements in GMAW-P

Figure 3. The tandem torch permits the delivery of two electrodes: the lead arc and the trail arc. The nozzle provides uniform shielding gas coverage for the molten weld pool.

It is true, then, that each welding application carries specific user-defined requirements for the finished weld. Because the new technology permits

Both bridge and structural fabricators could take advantage of the tandem GMAW process

modification to the components of the GMAW-P waveform, these weld requirements may be more readily achieved.

Nine components are associated with the pulsed spray waveform (see Figure 2). Each component in combination with the others provides specific attributes to the finished weld. The energy level and appearance of the arc change with the manipulation of each of the components. For example, high pulsed frequency produces a narrow arc that may lend itself to use on flare-bevel type weld joints. Increasing the peak current results in an increase in energy associated with deeper weld penetration, and the opposite is also true. The use of higher front ramp rates stiffens the arc and thus increases the immunity of the arc to arc blow conditions.

Pulsed GMAW waveforms for the tandem GMAW process include a wide range of electrode diameters, from 0.030 in. to 1/16 in. (0.08 mm to 1.6 mm) and material types. Shielding gas selections include argon and carbon dioxide or argon and oxygen combinations. Ternary, three-part shielding gas blends are rarely employed. Tandem GMAW typically uses electrodes of the same diameter, but in some instances the diameter of the trail electrode may be smaller. The judgement about when to employ differing diameters generally follows a case-by-case evaluation.

Tandem GMAW

Tandem GMAW is a welding process that uses two DC electrode positive (DC+) arcs in the same weld pool, and they are identified as the *'Lead'* and the *'Trail'* arcs (Figure 3). Each arc uses its own power source and wire drive, and the possible combinations of modes of metal transfer employed in tandem GMAW are as follows:

- Axial Spray Transfer Lead Arc + Axial Spray Transfer Trail Arc
- Axial Spray Transfer Lead Arc + Pulsed Spray Transfer Trail Arc
- Pulsed Spray Transfer Lead Arc + Pulsed Spray Transfer Trail Arc

The lead arc, in all cases, determines the penetration level of the weld, and the trail arc provides the final bead shape and weld bead reinforcement. The programs that are created for tandem GMAW, particularly in the case of the Pulse + Pulse, are developed with DC+ arc compatibility in mind.

The development of tandem GMAW had higher arc travel speed as its core objective, and it is generally used with material the thickness of sheet metal. The travel speed on sheet metal applications is usually 1.5 to 1.9 times the travel speed for a single arc, and it is not uncommon to find travel speeds of more than 100 ipm (2.5 m/min).

For thicker sections of material where multiple pass welding is necessary, the deposition rate for tandem GMAW can vary from 20–45 lbs/hr (9–21 kg/hr). The arc travel speeds range from 25–45 ipm (0.6–1.2 m/min). To achieve anticipated mechanical properties, tandem GMAW may require the use of special welding techniques.

Testing Tandem GMAW

Two ASTM A516 grade 70 test plates were assembled, welded, and tested to the requirements of ANSI/AASHTO/AWS D1.5-96 "Bridge Welding Code," Section A. The welding procedure involved the use of two 0.052 in. (1.4 mm) diameter ER70S-6 electrodes in tandem, and the shielding gas employed was a 90% argon + 10

Table 1. Results of mechanical testing for each of 2 ASTM A516 grade 70 test plates.

Mechanical Properties	Test Plate #1	Test Plate #2
Tensile Strength	90,000 psi (620 Mpa)	89,600 psi (617 Mpa)
Yield Strength	73,300 psi (505 Mpa)	73,300 psi (505 Mpa)
Avg. Ft.-Lbs. @ -20° F	76	78
Avg. Joules @ -29° C	103	106

% carbon dioxide. Both the lead arc and the trail arc employed the pulsed spray mode of metal transfer. The effective deposition rate for the test was 32 lbs/hr (14.5 kg/hr). The results of the mechanical testing, for each of the two plates, were as shown in Table 1.

Discussion of Results

The results indicate that tandem GMAW using pulsed spray transfer with 0.052 in. (1.4 mm) diameter electrodes is viable for complete penetration weld joints in structural fabrication. In addition, it would be fair to assume that both bridge and structural fabricators could take advantage of the tandem GMAW process not only for complete penetration groove welds, but also for completing fillet welding on stiffeners. Moreover, it would appear that the use of robotic or specialized hard automation would in many cases provide both the motion and process control necessary to implement tandem GMAW.

Conclusion

Advancing technology permits the use of GMAW-P on a wide range of welding applications, including thicker section base materials. The use of tandem GMAW for depositing high quality weld metal with excellent fusion represents the culmination of several years of application research and development. The optimized arc condition permits the use of two DC+ pulsed arcs in the same molten puddle. Moreover, it represents a reasonable alternative for welding components of bridges and other structures.

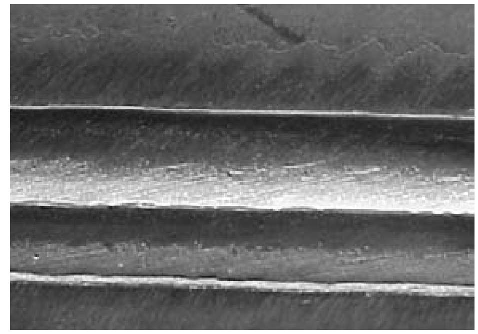

Figure 4. This multiple pass Tandem GMAW weld has a finished appearance that resembles a Submerged Arc Weld.