Proc. of 56th IIW International Conference, Bucharest, Romania, 6–11 July, 2003;
IIW Doc. XII-1779-03.

Variable Polarity (AC) Arc Weld Brazing of Galvanized Sheet

Andy Joseph[1], Chris Webb[2], Mike Haramia[2], and David Yapp[3]

Introduction

Requirements for improved durability in domestic consumer goods have invariably led to the application of more corrosion resistant materials. The basic material used by many industries, including automotive, ventilation and heating, construction, appliances, and furniture is sheet steel. Zinc-coated or galvanized sheet steels are the obvious corrosion resistant material choice for these industries. Steel sheet can be coated with zinc (galvanized) through either electrolytic or hot-dip processes, with coating weight between 30 g/m^2 and 400 g/m^2 (approximately 4 µm to 55 µm thick) depending on the process conditions.

Joining of galvanized materials has proved to be difficult using most arc welding techniques. Many of the problems associated with zinc-coated steels are due to the low melting (420°C) and evaporation (910°C) temperatures of zinc compared to the steel melting temperature (1538°C). Zinc vapors and oxides cause porosity, lack-of-fusion, cracking, spatter, and erratic arc behavior. Process optimization is the best method to prevent welding related discontinuities and defects. Lower melting temperature filler wires offer one process solution when welding galvanized sheet materials. A copper-based filler wire (i.e., silicon bronze) and a standard DC constant voltage welding power source can be used with the gas metal arc welding (GMAW) process to join galvanized steel sheet. GMA brazing filler materials have a low melting temperature and, ideally, no melting of the base metal occurs. Previous research has shown that GMA brazing can overcome the problems posed by coated materials listed above, while maintaining sufficient joint strength (Ref. 1-3).

GMAW-Pulse (GMAW-P) has been used to further reduce heat input and improve process stability of GMA brazing. Current pulsing permits droplet transfer welding at mean currents below the globular-to-spray transition current. Pulse parameters are critical to maintaining a stable arc and a spatter-free process. Robust, spatter-free GMAW-P parameters have been developed that have good aesthetic properties and sufficient joint strength. However, a significant amount of zinc is typically burned off of the backside of most welds. This zinc burn-off is a result of heat input that is still too high despite the lower filler wire melting temperature and use of GMAW-P.

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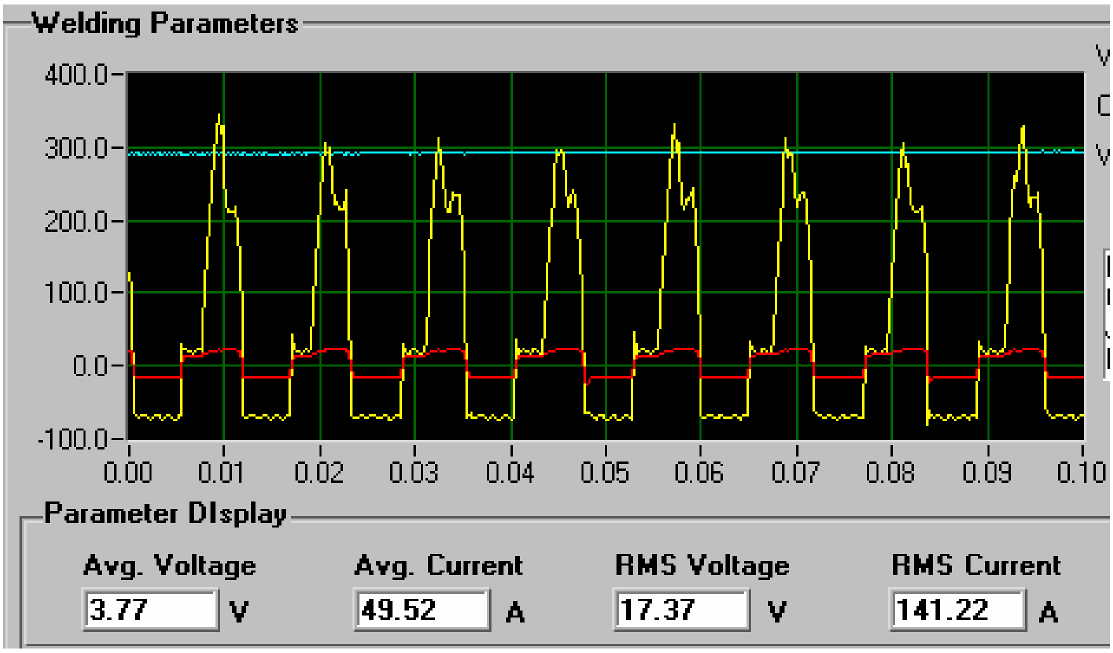
[1] Andy Joseph is in the Arc Welding and Automation group at Edison Welding Institute

[2] Chris Webb and Mike Haramia were with the Ohio State University at the time this work was completed.

[3] David Yapp was with Edison Welding Institute at the time the work was completed, and is now with Cranfield University.

An investigation into the use of variable polarity GMAW (VP-GMAW) with standard weld brazing filler wires was conducted to determine the potential of this process for further reductions in weld heat input. VP-GMAW uses a current waveform that is similar to AC current in that it alternates between positive and negative polarities. It is different from AC because the balance of the two polarities can be varied, hence, the term variable polarity (Figure 1). Variable polarity provides more control of the heat balance in the welding arc by taking advantage of the different arc characteristics obtained with each of the two polarities, DCEP and DCEN. Each polarity has a different heat balance. Variable polarity allows this heat balance to be controlled over a range and thus allows more control of the penetration characteristics and heat input of the process.



Avg. Voltage 3.77 V

Avg. Current 49.52 A

RMS Voltage 17.37 V

RMS Current 141.22 A

Figure 1. Typical Variable Polarity GMAW waveform. Electrode positive is above zero, electrode negative is below zero.

Experimental Procedure

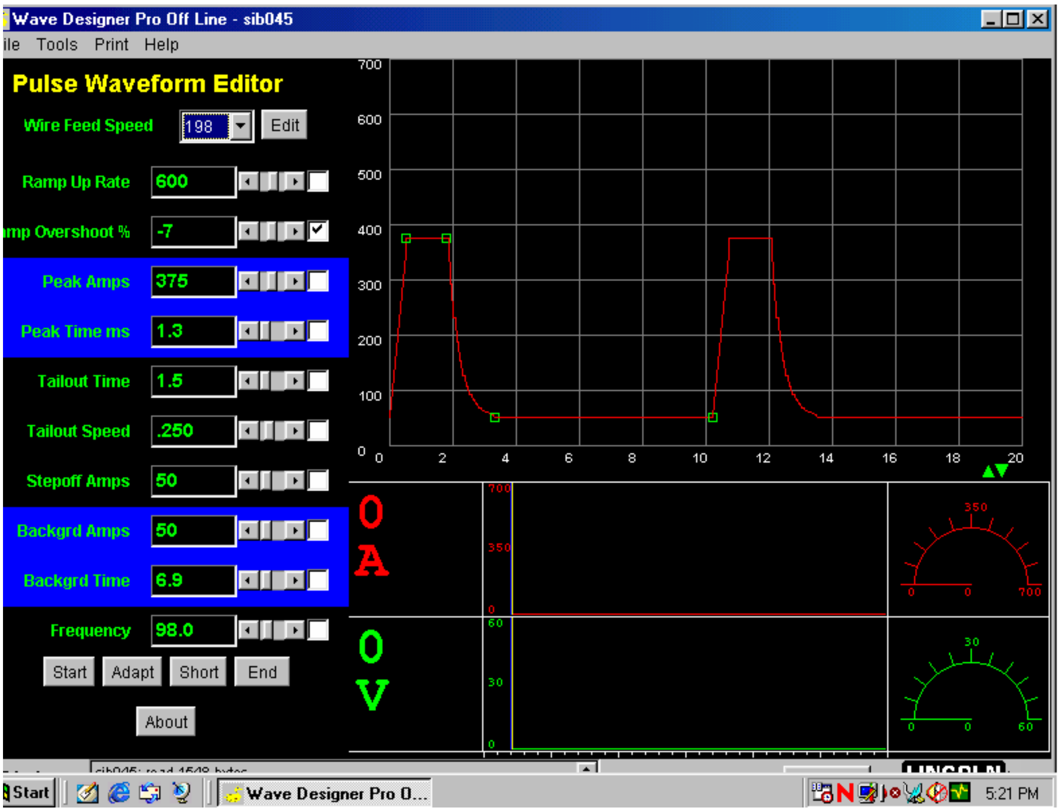
This investigation compared the potential of GMAW-P to VP-GMAW. Lap joint tests were made using a stationary straight machine welding gun and a linear table that moved the base material at a constant speed (Figure 2). This setup allows the High Speed Video (HSV) equipment to be stationary. The lap joints were made using 1.2-mm galvanized sheet with a 1.2-mm gap and were welded in the horizontal (2F) position. Shielding gas was 100% argon at 19 L/min. All hydrocarbons were removed from the material with acetone prior to welding.

Figure 2. Welding table with stationary torch, high speed video, and data acquisition.

The filler wires were silicon bronze (1.14mm diameter, AWS ER CuSi-A) and aluminum bronze (1.14 mm AWS ER CuAl-A2). These two wires are standard wires that are commonly used in industry. U-groove drive rolls and Teflon wire guides were used to prevent wire feed problems such as bird-nesting and unstable arcing.

GMAW-P uses a high current pulse for a finite period of time followed by a low current background period. The low current level background period primarily maintains the arc, while the high current level pulse forms and transfers one or more small drops from the electrode to the weld pool. This pulsing waveform of high and low currents transfers small drops at a mean current level that would normally produce the less desirable globular transfer.

Robust GMAW-P parameters were developed for ER CuSi-A and ER CuAl-A2 electrodes using the Lincoln Powerwave 455 with Waveform Designer Pro software (Figure 3). The power supply and software allowed manipulation of the pulsed current parameters during welding. The main parameters of interest were peak and background current, peak time, and frequency. The software was used to adjust pulse parameters until a consistent one drop-per-pulse was observed on high-speed video, and when the resultant weld exhibited little to no spatter.



Pulse Waveform Editor

Wire Feed Speed 198

Ramp Up Rate 600 ☐

mp Overshoot % -7 ☑

Peak Amps 375 ☐

Peak Time ms 1.3 ☐

Tailout Time 1.5 ☐

Tailout Speed .250 ☐

Stepoff Amps 50 ☐

Backgrd Amps 50 ☐

Backgrd Time 6.9 ☐

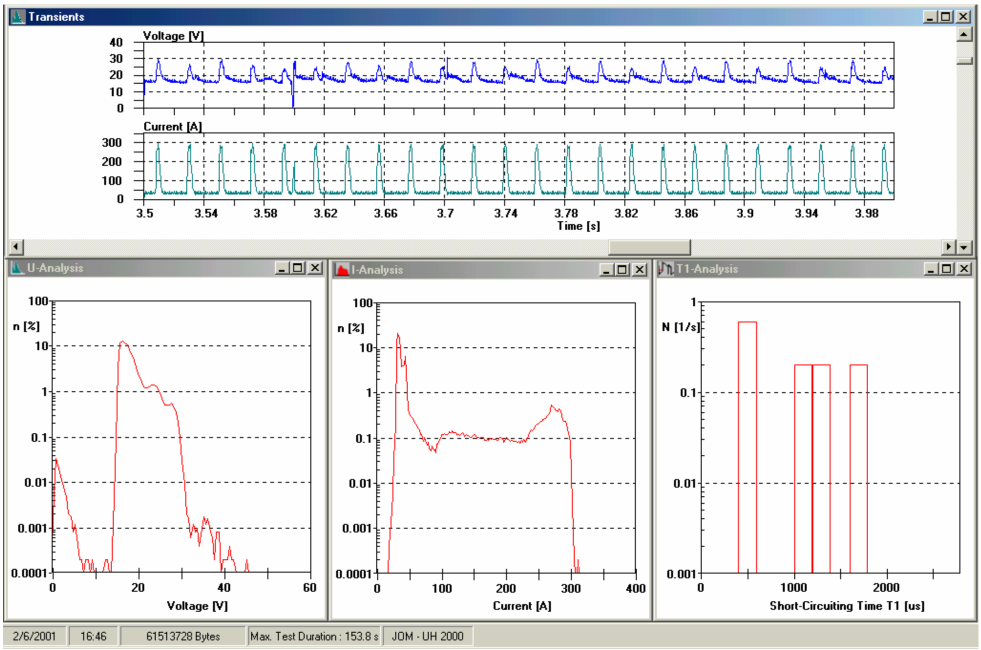
Frequency 98.0 ☐

Figure 3. Waveform Designer Pro software allows manipulation of GMAW-P parameters

Pulse parameters were developed at wire feed speeds of 2.69, 4.24, 5.94, 7.52, and 9.20 m/min. Travel speeds were such that an equal weld size (constant wire feed speed/travel speed ratio) was produced throughout the range of testing. A WFS/TS ratio of 8 was used, and corresponded to travel speeds of 5.61, 8.84, 12.4, 15.7, and 19.2 mm/s.

High speed video was used to observe the metal transfer during the test welds. The HSV camera was set up to allow viewing of both the weld pool and the droplet detachment. A 940 ±5 nm optical filter was used to allow viewing of the metal transfer without using laser back lighting. Sampling rate was 4500 Hz, which is high enough to see the details of the weld transfer.

The Analysator Hannover (AH) data acquisition system (Ref. 4) was used to determine the electrical waveform characteristics (Figure 4). Voltage was measured between the contact tip and the work. These points were considered as close to the arc as possible, and best represent the true arc voltage. Current was measured using a Hall effect current sensor, and the wire feed speed of the electrode was measured using a tachometer. The AH data acquisition system gave waveforms of voltage and current vs. time, as well as statistical histograms of voltage, current, and short-circuiting time. The histogram was essentially a fingerprint of the weld, and quantified repeatability. To determine the repeatability of weld parameters, identical welds were made and the histograms superimposed on top of each other. Any variances from histogram to histogram showed instability, which allowed for fine-tuning of the pulsing parameters.



2/6/2001 | 16:46 | 61513728 Bytes | Max. Test Duration : 153.8 s | JOM - UH 2000

Figure 4. Analysator Hannover data acquisition system with voltage and current waveforms and voltage, current and short circuit histograms for a GMAW-Pulse waveform.

Spatter levels were directly related to the short circuiting time, as well as the percentage of time that the voltage was at zero. Figure 4 represents a weld that had a low amount of short circuiting and spatter - only 0.015% of the sample time was at a voltage of zero.

Variable Polarity GMAW Parameter Development

Identical conditions were used to develop VP-GMAW welding parameters with the exception of the power supply. The Kobelco AL-350 aluminum VP-GMAW power supply was used. The power supply is a constant current inverter type that has a pre-programmed EP/EN ratio control. The Kobelco AL350 power supply was developed for aluminum and provided a pulse globular-free flight transfer mode. The power supply automatically controlled the relationship between the pulse parameters, which included the EN peak current and time, the EP peak current and time, the EP background current, and frequency depending on the wire feed speed and EN setting on the control pendant. The EN setting automatically changed the pulse parameter relationships for each wire feed speed providing a range of arc power. All of the pulsing parameters were controlled synergically via wire feed speed (i.e., one knob controls all pulsing parameters) so the individual pulsing parameters could not be changed.

Mechanical Property Testing

Tensile tests were taken from the weld tests that represented the maximum productivity for each process combination. The tensile tests were made according to ASTM E8. Three specimens were taken transverse to the centerline of the weld. Cross sections of each weld were mounted and polished to ensure proper bead shape and wetting characteristics. Visual inspection of the weld surface and spatter levels were also made.

Experimental Results

GMAW-P Metal Transfer

The GMAW-P welding parameters were adjusted to make “one drop per pulse” transfer (Figure 5a). Each drop was approximately the size of the wire or slightly larger, and detached just after the peak time at the peak current level. The droplet detached cleanly with no spatter. The most common variation during pulsing parameter optimization was that occasionally more than one droplet would detach (Figure 5b). Although most of the time this did not pose a problem in the weld, sometimes the “extra” droplet would miss the weld pool and end up as a large spatter ball on the base material. Pulse parameters were adjusted to eliminate this problem.

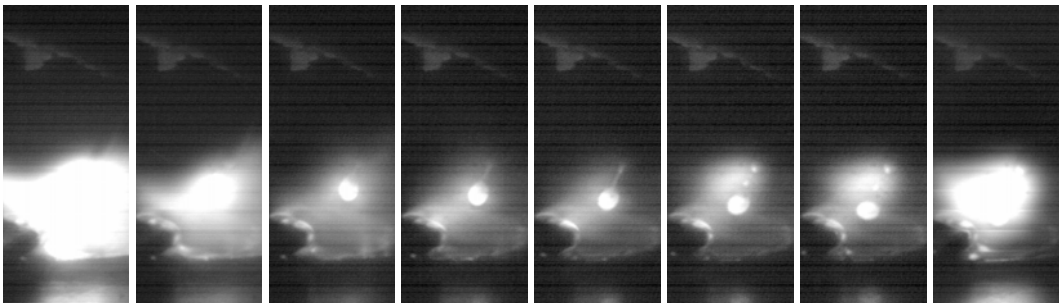


Figure 5a. High speed video of spatter free pulsed GMA brazing metal transfer. Frames are taken at 3ms intervals.

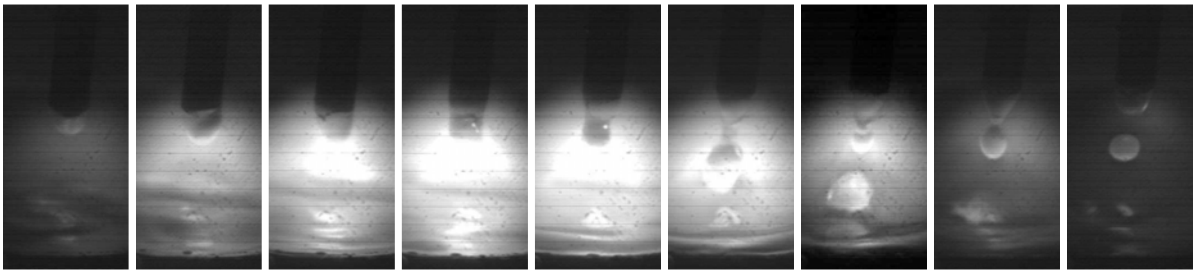


Figure 5b. Pulsed GMA brazing with an “extra” droplet detaching immediately after the primary droplet detachment.

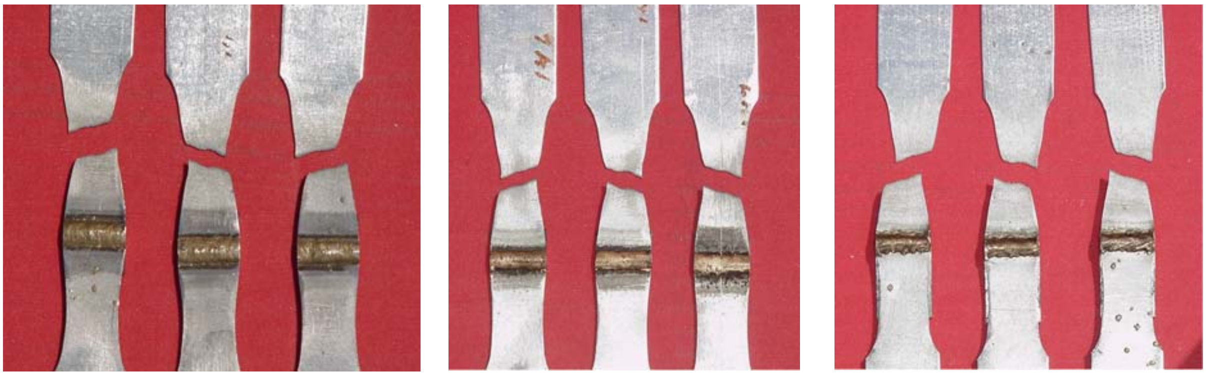
Satisfactory welds were also produced using the ER CuSi-A braze wire in a “two pulses per drop” mode. The first pulse (following a drop detachment) would grow a molten droplet on the end of the wire, and the second pulse detached the molten droplet and transferred it to the weld pool. Although one drop per pulse is sometimes considered optimal, satisfactory welding conditions often utilize multiple drops per pulse. This research found that a two pulses per drop mode of transfer was acceptable at low wire feed speeds (up to approximately 6.5 m/min). At higher wire feed speeds this mode of transfer was unstable, and therefore was not used.

Variable Polarity GMAW Metal Transfer

The VP-GMAW testing began using the ER CuSi-A wire. The metal droplet formation process started with the EN pulse and was completed during the EP peak pulse. It was observed through HSV that the metal drops were formed during the EN polarity pulse. Here, the drops grew rapidly as the arc climbed the tip of the electrode. The drops were typically 1.5 to 2 times the wire diameter, or larger. The arc then switched polarity, becoming dim as the current passed through zero. The EP background current was used to maintain the arc and drop size that was created during the EN pulse. The drop quickly responded to the high current EP pulse where it gained some additional size before being transferred to the weld pool. Since the individual pulsing parameters on the AL-350 power supply could not be adjusted, spatter could not be completely eliminated. This particular power supply was designed specifically for both hard and soft aluminum wires, but not for braze wire. Despite the spatter, the integrity of the joint was still found to be satisfactory for the ER CuSi-A wire. The AL-350 was unable to make a satisfactory weld using the ER-CuAl-A2 braze wire. Refinement of the VP-GMAW parameters is possible with a power supply that has parameter manipulation available, and should make spatter-free welds using both wires possible.

Material Properties

Tensile specimens were tested for each of the wire/power supply combinations. All specimens tested failed in the base material. (Figure 6).



(a) (b) (c)

Figure 6. Tensile Specimens for a) GMAW-Pulse using ER CuAl-A2 filler wire; b) GMAW-Pulse using ER CuSi-A filler wire; c) Variable polarity GMA braze weld using ER CuSi-A.

Weld Quality

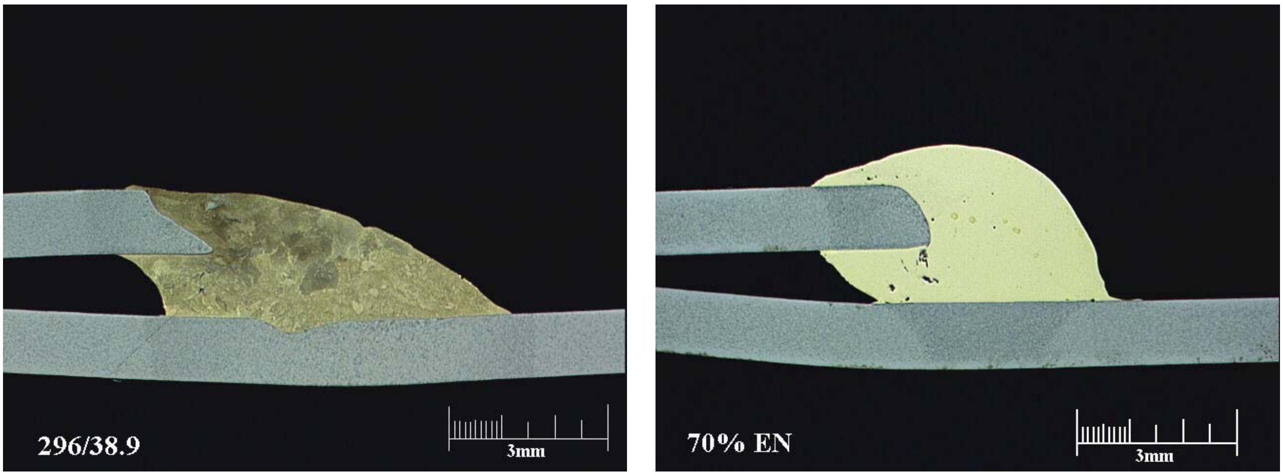
Spatter-free GMAW-P welds (Figure 7) were made throughout the range of wire feed speeds that were tested. The GMAW-P process minimized distortion, however, a heavy black soot was produced by excessive burning of the zinc in the HAZ and on the weld backside. The black soot was an indicator of a loss of zinc and, therefore, a lack of corrosion protection for the HAZ and the back side of the weld.

Figure 7. Spatter free GMAW-Pulse braze weld.

The VP-GMAW process reduced the heat input that resulted in significantly less zinc burn-off on the back side of the weld (Figure 8). The back side of the GMAW-P weld had more soot than the back side of the VP-GMAW weld. The darkest area of the GMAW-P specimen indicated where the weld bead was located, and shows a complete loss of all zinc. The weld made using VP-GMAW showed significantly less zinc burn-off, with almost no dark soot.

Figure 8. Black soot on the back side of the pulsed GMA braze weld caused by excessive heat input (top). Significant reduction in the amount of zinc removed as a result of using variable polarity GMA brazing (bottom).

Another indication of weld quality was found in the macro photographs of the weld cross sections. Figure 9a shows a cross section of the GMAW-P weld at 5.94 m/min wire feed speed. Significant melting of both the top plate and the bottom plate occurred, resulting in base metal dilution of the weld. Figure 9b shows a cross section of the VP-GMAW weld at the same speed. There was very little melting of the top plate, and no melting of the bottom plate, resulting in a low base metal dilution. The low levels of base metal dilution produced a low level of contamination in the weld. The smaller HAZ of the VP-GMAW weld compared to the GMAW-P weld also verifies that the heat input is lower in the VP-GMAW weld. The calculation of true heat input for VP GMAW and GMAW-P is complex, and has not yet been addressed in this work. However, in a detailed examination of VP-GMAW for steel, it was found that the heat input could be up to 50% lower for VP-GMAW compared to an equivalent weld made using GMAW-P (Ref. 5)



(a) (b)

Figure 9. a) Pulsed GMA braze weld where high heat input caused melting of top and bottom plates, and high levels of zinc diluted into the weld metal; b) Variable polarity GMA braze weld with almost no melting of the base material and very little zinc dilution.

Conclusions

The following conclusions were made upon completion of this project:

- The GMAW-P and the VP-GMAW processes were used to produce sound welds with minimal distortion for two standardized braze wires at travel speeds ranging from 5.6 to 19.2 mm/s.

- The VP-GMAW process, when compared to GMAW-P, produced a significant reduction in zinc coating loss.

- Mechanical testing and metallurgical cross sections confirmed that joint integrity, wetting, and gap bridging was acceptable for both GMAW-P and the VP-GMAW processes.

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