Assessing the Effects of GMAW-P Parameters on Arc Power and Weld Heat Input

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Introduction

A review of measurement methods for calculating GMAW-P arc power and heat input revealed disagreement in determining the most appropriate method for such calculations. Literature on the effects of GMAW-P parameters was also reviewed, and revealed that little integrated work has been done showing the effects of pulsing parameters on heat input, dilution, penetration, and bead shape. This project determined the most appropriate method for calculating GMAW-P heat input and the cumulative effects of different pulse parameters on heat input, bead shape, and weld metal dilution.

Measurement of Voltage, Current, Power, and Heat Input - Approach

Three basic types of electrical measurements are readily available for determining arc power, and subsequently estimating weld heat input. In this work, they are referred to as Root Mean Square Power (P_{RMS}), Average Power (P_{AV}), and Average Instantaneous Power (AIP), calculated as shown in Table 1. Typically, constant voltage GMAW power is measured as an average or Root Mean Square quantity. GMAW-P power can be measured using the same methods, but can lead to inaccurate estimations of heat input.

Liquid nitrogen calorimetry was used to determine arc efficiency and the actual heat input for welds made with GMAW-P. Bead on plate welds on mild steel coupons were made using 0.045 in. (1.2 mm) ER 70S-6 wire with 90% Argon – 10% CO_2 shielding gas. Arc voltage and current were measured using high-speed data acquisition, and high-speed video was used to maintain a constant 1/8 in. (0.3 mm) arc length throughout testing. The heat input to the coupons found by calorimetry was compared to the estimated heat input calculated from the three types of arc power (Table 1).

Measurement of Voltage, Current, Power, and Heat Input - Results

At any given productivity level GMAW-P arc power varied up to 22% depending on which type of electrical measurement was used – RMS, average, or AIP. Heat input calculated from electrical measurements was plotted against the measured heat input from calorimetry (Figure 1). Heat input based on average power gave the highest arc efficiency at 85%. This efficiency level is high compared to prior art. Also, the slope of the average power line does not match the slope of the true heat input. Heat input based on RMS power produced a lower arc efficiency of approximately 60%, and again, the slope of the line did not match the true heat input. Previously published arc efficiency data for GMAW-P typically ranged from 70 to 75%.

Heat input for GMAW-P welds based on AIP yielded an arc efficiency of 70.2%. This was in excellent agreement with previously published data. Also, the slope of the AIP curve in Figure 1 was consistent with the slope from the calorimetry based heat input. This indicated that the most appropriate method of estimating heat input for GMAW-P was accomplished through the use of AIP. Modern power supplies typically provide either RMS or average meter readings for

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current and voltage. Heat input calculations using these measurements should be avoided, especially for high integrity applications.

Effects of Pulsing Parameters on Penetration, Dilution and Bead Shape - Approach

Systematic tests were conducted to evaluate the effects of pulse parameter waveform and productivity on heat input, base metal dilution, and weld penetration of constant deposit area, bead on plate welds. In order to eliminate power supply electrical differences as a variable, pulse parameter waveforms from four different commercially available power supplies (called power supply A, B, C, and D) were analyzed and reproduced (simulated) on a Lincoln Powerwave 455 power supply using Waveform Designer software.

Effects of Pulsing Parameters on Penetration, Dilution and Bead Shape - Results

A comparison of the simulated pulsing parameter waveforms (Figure 2) showed that heat input can vary as much as 17% through changes in the waveform. When the pulsed welds were compared to a constant voltage weld, most of the pulsing waveforms produced a lower heat input, which was expected.

The effects of heat input and waveform shape on weld bead shape were evaluated by comparing dilution and penetration (Figure 3). There was an obvious increasing trend as wire feed speed increased, however, waveform shape produced only small changes in dilution, penetration, or bead shape at any one wire feed speed.

Another set of systematic tests were performed with one power supply (E) that offered 3 waveform types at any wire feed speed. The effect of waveform shape was again evaluated by measuring weld bead penetration and dilution. The macro section map (Figure 4) showed the bead shapes were very similar to those seen in the previous experiments. There was an overall increase in finger type penetration and wetting as wire feed speed was increased, but there was very little difference in bead shape for differenct waveform shapes at constant wire feed speed.

Conclusions

1. The most appropriate method to calculate heat input for GMAW-P is through the use of Average Instantaneous Power (AIP), which requires the use of high speed data acquisition.

2. GMAW-P power calculated from RMS measurements of voltage and current provides heat inputs up to 10% higher than actual. Power calculated from average voltage and current yielded heat inputs up to 15% lower than actual.

3. Pulse parameter waveforms changed heat input by as much as 17% for a given wire feed speed, however, the corresponding changes in bead shape, penetration, and dilution were small.

Table 1. Heat Input and Power Equations for the Three Types of Arc Power Calculations

$H_{net} = \frac{P \cdot \eta}{S}$	
$P_{AV} = I_{AV} \cdot V_{AV}$	$V_{AV} = \frac{\sum_{i=1}^{n} V_i}{n}$ $I_{AV} = \frac{\sum_{i=1}^{n} I_i}{n}$
$P_{RMS} = I_{RMS} \cdot V_{RMS}$	$V_{RMS} = \sqrt{\sum_{i=1}^{n} \frac{V_i^2}{n}}$ $I_{RMS} = \sqrt{\sum_{i=1}^{n} \frac{I_i^2}{n}}$
$AIP = \sum_{i=1}^{n} \frac{I_i \cdot V_i}{n}$	
H_{net} = Heat Input P_{AV} = Average Power P_{RMS} =RMS Power AIP=Average Instantaneous Power η = efficiency, S = travel speed, I = current,V = voltage	

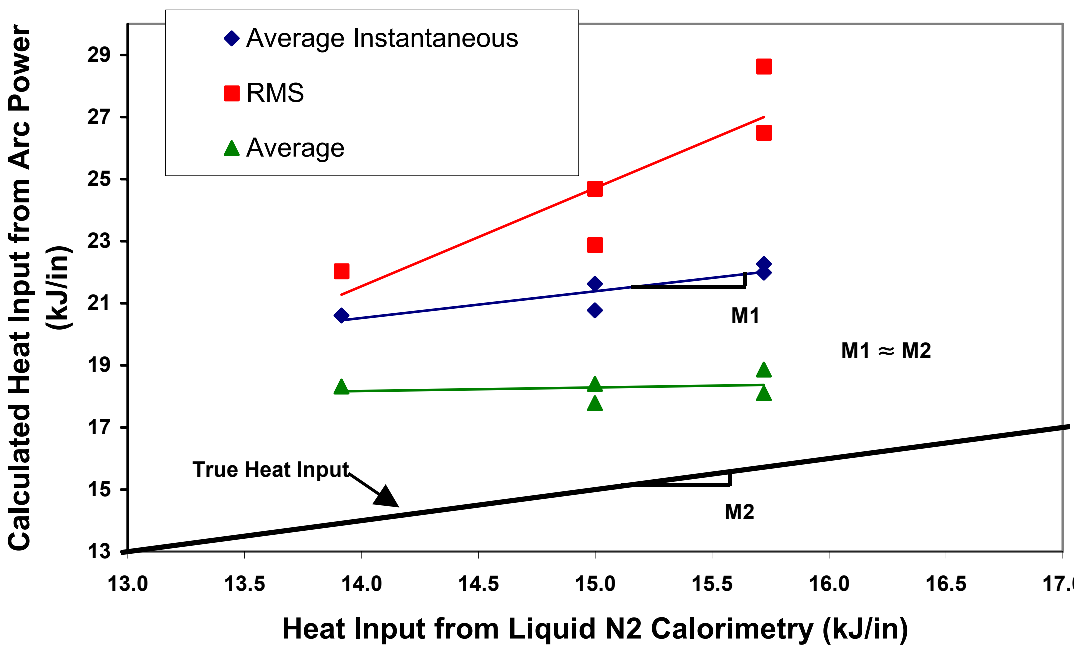


Figure 1. Graph Comparing Calculated Heat Input to Actual Heat Input for GMAW-P

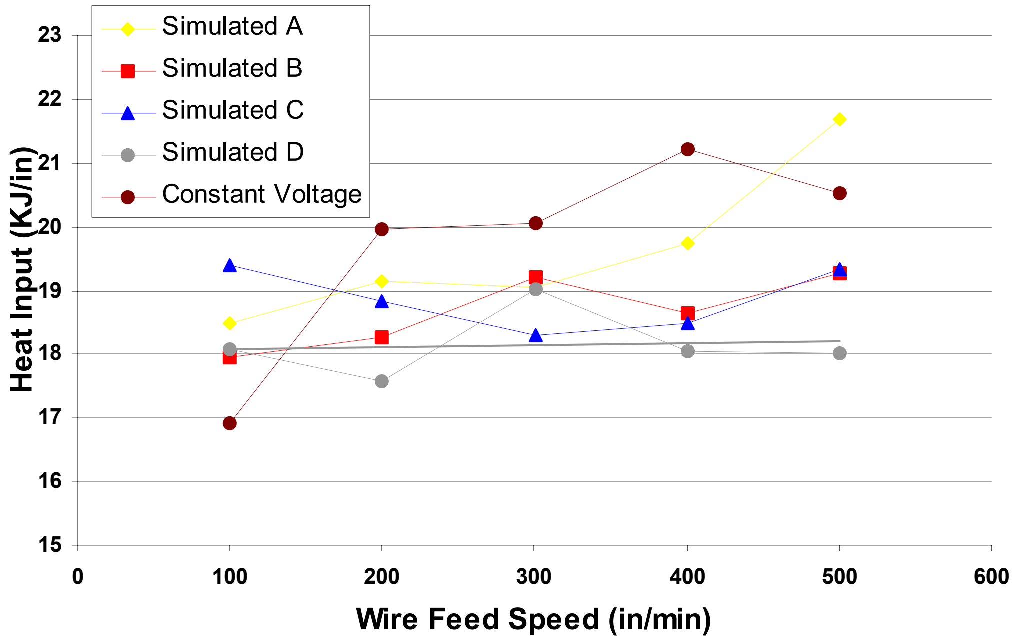


Figure 2. **Heat Input (based on AIP) versus Wire Feed Speed for Simulated GMAW-P Waveforms.**

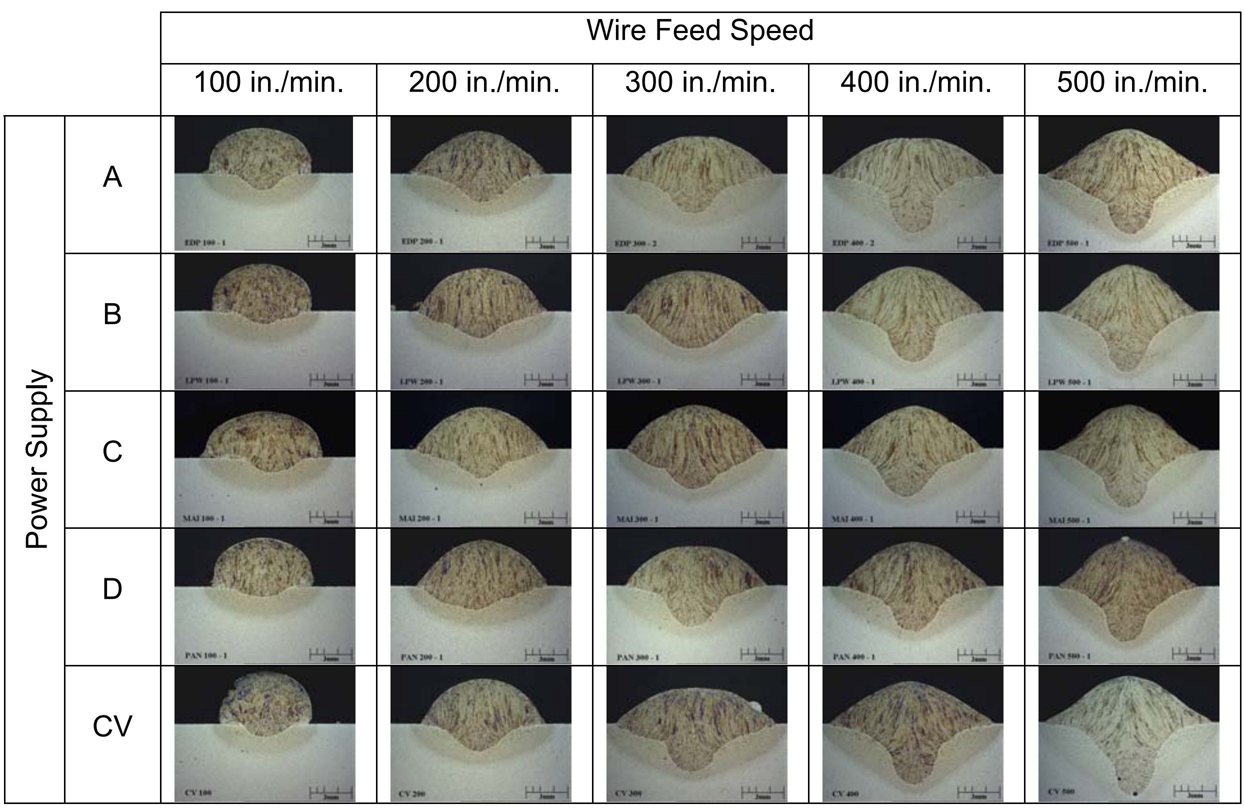


Figure 3. **Macro Section Map for Simulated GMAW-P Waveforms**

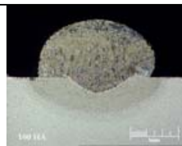
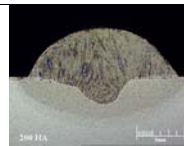
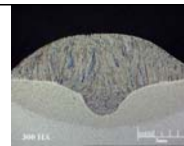
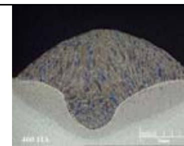
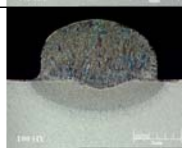
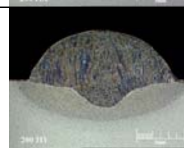
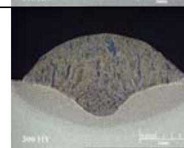
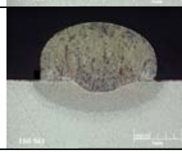
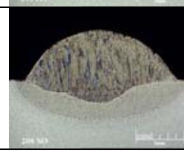
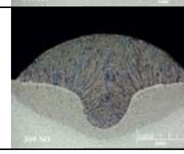
WFS	100	200	300	400	500
Hard					
Hybrid					
Soft					

Figure 4. Macro Section Map for Power Supply E