Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 29 ISSUE 2 August 2008

Relationship between wire feed speed and metal transfer in GMAW

M.St. Węglowski [*,a], Y. Huang [b], Y.M. Zhang [b]
[a] Welding Department, ul. Bł. Czesława 16/18, 44-100 Gliwice, Poland
[b] University of Kentucky, Lexington KY 40506, USA
* Corresponding author: E-mail address: marek.weglowski@is.gliwice.pl

Received 23.03.2008; published in revised form 01.08.2008

Manufacturing and processing

ABSTRACT

Purpose: This paper presents the results of an investigation of the metal transfer. The main goal of the investigation was to check that using narrow band filter and high speed digital video camera can be used, without a back-lighting laser, to observe the metal transfer process. Presented are the influence of wire feed rate (welding current) on droplet diameter, droplet trajectory and velocity.
Design/methodology/approach: The experiments were carried out on an automated welding table. A high speed video camera "Olympus i-SPEED" was used. For each welding wire feed speed the image of metal transfer and welding parameters (welding current, arc voltage and wire feed rate) were recorded.
Findings: Results presented in this paper indicate that the wire feed has a significant influence on droplet diameter, droplet trajectory and droplet velocity. That method based on digital high speed camera and narrow band filter is very sensitive to the changes of welding conditions and should be used as a tool for monitoring of the GMAW process.
Research limitations/implications: The high speed video camera is an expensive instrument and it can be used only as a laboratory tool in monitoring and optimizing of welding processes.
Practical implications: The achieved experience allows directing further research on the metal transfer in GMAW and studying the possibilities of using this method in other welding processes.
Originality/value: The new method for monitoring metal transfer based on narrow band filter and high speed digital camera does not require He-Ne laser to provide the back-lighting in order to observe the metal transfer process. This method is cheaper and easier to use. The original results of these investigations are mathematic descriptions of droplet flight trajectory and droplet velocity.
Keywords: Welding; Metal transfer; High speed camera; Sensing

1. Introduction

Gas Metal Arc Welding (GMAW) is a welding process where the heat is generated by an electric arc incorporating a continuously-fed consumable electrode that is shielded by an externally supplied gas. The metal transfer modes during the GMAW process are described by the following categories: short circuit, globular, spray and streaming [1].

The physics of metal transfer is not yet well understand, due to the facts that the arcs are too small, the temperatures are too high, and the metal transfer is at too high rate. Thus, many mechanisms affecting metal transfer have been suggested [1]. To better understand the dynamics of the metal transfer in GMAW, authors [2] have studied the dynamic modeling of metal transfer process in GMAW. Since the stable metal transfer mode is usually associated with a good quality weld, Quantino [3] has investigated the control of metal transfer in GMAW using neural networks. This has been done through the use of sensors, control algorithms, and neural networks. Extensive studies have been done on the metal transfer. In [2] the metal transfer was controlled and its mode was detected by monitoring current and voltage [4], and analysis of the formation of metal droplets in GMAW [5]. In order to determine the dominant factors, which affect the metal

© Copyright by International OCSCO World Press. All rights reserved. 2008

transfer mode, a dimensional analysis has been conducted in previous studies [6]. Most of recent investigations focused on studying the effect of waveform parameters on the mode of metal transfer in pulsed gas metal arc welding (GMAW-P) Al–Zn–Mg alloy [7] and aluminium [8]. The numerical analysis of metal transfer in GMAW-P were carried out and selection of parameters of pulsed current gas metal arc welding were used to optimization of welding process [9]. Many investigations were carried out up to date have covered subject matter of dynamic analysis of metal transfer [10]. The metal transfer mode is also an interesting subject matter for newly developed welding methods for example double electrode gas metal arc welding (DE-GMAW) developed at the University of Kentucky [11]. Some studies focused on detailed analysis of droplet velocity and developed model based only on the electromagnetic pinch force [12]. Further, a non-isothermal numerical model has been developed to simulate the metal transfer process in GMAW. Short circuit gas metal arc welding process also cover the subject matter of studies [13]. The melting of the wire which is fundamental and influences process stability and productivity, has been a main topic of some investigations [14]. The hybrid laser-MIG welding methods have also been studied by many researchers [15].

However, the investigations that were carried out up to date have not covered subject matter of mathematic description of droplet flight trajectory and droplet velocity. This paper describes a mathematical analysis of droplet flight trajectory and droplet velocity based on polynomial regression of experimental data. In previous investigations, the shadowgraph technique has been used to image the metal transfer process using He-Ne laser as a back-lighting [16]. In this paper an easier method which is only based on a narrowband filter and high speed camera is used.

2. Experimental setup and procedure

The experiments were carried out on an automated welding table for GMAW. The experimental platform is shown in Fig. 1. The Olympus i-SPEED high speed video camera (HSVC) was used during experiments to image and record the metal transfer process. The HSVC used a sampling speed of 3000 frame per second (fps). A narrowband filter (central wavelength 940 nm) was used to reduce the welding arc light brightness. All welds were made with a welding gun Miller Roughneck C 4015, using 1,2 mm (0.045 inch) diameter Quantum ARC 6 (Hobart Brothers) - carbon steel wire (AWS A5.18, ER70S-6) equivalent to SG2. The chemical composition of the welding wire is given in Table 1. Pure argon and flow rate of 16 L/min were used for shielding. The base metal was mild steel S255 (EN 10025) of 10 mm thickness.The torch was moved at the travel speed 250 mm/min (10 inch/min) to make bead-on-plate welds. The work-piece was fixed to the table. Direct current levels in the range of 178 - 246 A were examined, all at an operating voltage of 32 V. The change of the wire feed rate in the range of 3.81 m/min to 6.1m/min (150 to 240 inch/min) causes changes in the welding current in the range 178 - 246 A. The three-phase welding machine Hobart EXCEL – ARC 8065 CC/CV was used. The wire feeder was Miller R-115.

During welding the arc voltage, welding current and wire feed speed were continuously measured. The closedloop Hall effect current sensor Model CLN-500 was used to measure welding current. This sensor provides electrical isolation between the current carrying conductor and the output of the sensor. The voltage was measured by a resistance bridge directly in the output of power supply. The wire feed rate was measured directly in the wire feeder Miller R-115. Signals from the welding circuit were recorded on the PC through the data acquisition card NI DAQ 6036E. The signals were recorded at a sampling rate of 40 kHz. Signals were analysis in Matlab software in time domain.

Table 1
Chemical composition of base metal and welding wire

Element	C	Mn	Si	P	S	Cu
Base material	<0.16	0.40-1,20	<0.35	<0.03	<0.025	-
Filler material	0.06-0.15	1.40-1.85	0.8-1.15	<0.025	<0.025	<0.05

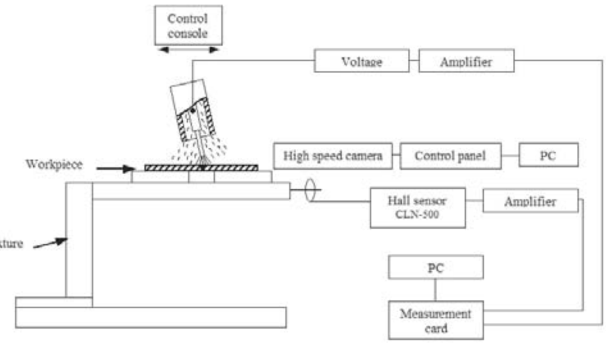

Fig. 1. Experimental platform

3. Results and discussion

3.1. Droplet diameter

One of the main goals was to calculate droplet diameter. To this end, it was necessary to measure horizontal and vertical diameters for each droplet in graphical software Corel. The diameter D of the droplet is calculated in two directions (horizontal d_h and vertical d_v diameter) as $D=(d_h + d_v)/2$ when the droplet to be analyzed reaches a particular location in the image. The average diameter was calculated for each set of welding parameters using seven image sequences. The lowest and highest diameters were not used in the calculation. If the difference between horizontal and vertical diameter was higher than 20%, next sequence of images was used. The standard error of droplet diameter was calculated according to formula 1:

$$S_D = \sqrt{S_d^2 + S_i^2} \qquad (1)$$

where:
S_D – standard error of droplet diameter,
S_d – standard deviation ,
S_i - measurement resolution. S_i = 0,1 mm.

The relationship between droplet diameter with standard error in dependence of wire feed rate (welding current) is shown in Figure 2. As can be seen, the changes in the wire feed speed did cause changes in droplet diameter. The diameter decreases when the wire feed speed (welding current) increases. The changes average 50 % of initial value.

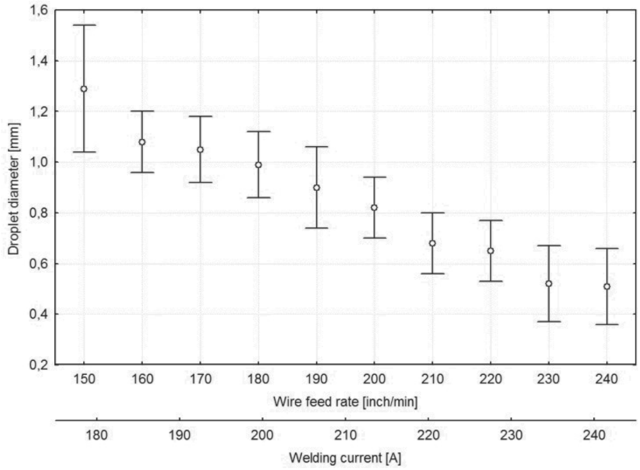

Fig. 2. Influence of wire speed rate (welding current) on droplet diameter

3.2. Droplet velocity

To estimate the tracking equation of single droplet, a 3rd degree of polynomial regression was used. After fitting the coefficients in the formula of polynomial obtained for wire speed 200 inch/min (welding current 216 A):

$$y_{200} = -0.00651 + 0.20726 \cdot t + 0.06304 \cdot t^2 - 0.00115 \cdot t^3 \text{ [mm]} \quad (2)$$

where:
t – time [ms],
y – distance along the arc axis from detachment,

Comparison between measurements (from high speed video) and mathematical description is shown in Figure 3 for welding wire speed 200 inch/min (5.08 m/min) that corresponds to welding current 216 A. As shown in Fig. 3 the mathematical formula 3 has a good agreement with the experimental data in the whole range. The distance from detachment was measure in graphical software Corel based on images of droplets. To estimate the velocity of droplet v_{200} for wire feed speed 200 inch/min, the derivative of movement equation 2 can be calculated. To achieve the velocity of droplet in mm/s, the formula 2 was multiply 1000 times. The mathematical description of droplet velocity for wire feed speed 200 inch/min is:

$$v_{200} = \frac{dy_{200}}{dt} \quad \text{- derivative of movement equation} \quad (3)$$

then for welding current 216 A,

$$v_{200} = 207.26 + 128.8 \cdot t - 3.45 \cdot t^2 \text{ [mm/s]} \quad (4)$$

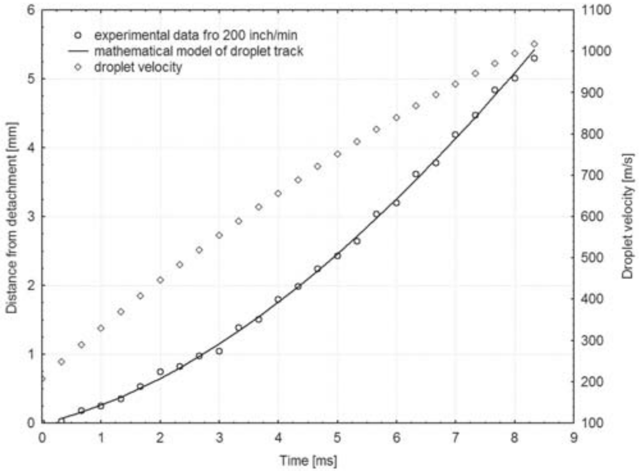

Fig. 3. The droplet flight trajectory and droplet velocity for wire feed speed 200 inch/min, comparison experimental data with mathematical model based on formula 2 and 4

As shown in Fig. 3 the maximum velocity 1018 mm/s the droplet achieve for t=8.3 ms. The average velocity of droplet is 660.64 mm/s.

4. Conclusions

The metal transfer in the GMAW has been analyzed. The measurement system was based on a high speed camera which is capable of measuring the metal transfer at 3000 frames per second. In the paper there were presented influence of wire feed rate (welding current) on droplet diameter.

The following conclusions can be drawn from the investigation:

- measurements of the droplet size have shown that average diameter of droplet in the range of wire feed rate from 150 to 240 inch/min varies in the range of 1,29±0,25 to 0,51±0,15 for pure argon shielding gas,
- to calculate the droplet flight trajectory a 3rd degree polynomial regression was used, equation 2 and 3 are valid for argon as shielding gas
- to calculate the changes in droplet velocity the derivative of movement equation is derived.

The gained experience allows directing further research on the metal transfer and exploring the possibilities of using this simple method for on-line monitoring of the welding process on automated and robotized stands. Improved algorithm based on brightness-based separation method can automatically locate the droplets and compute the droplet size with an adequate accuracy. The investigations that were carried out up to date by Lin [12] indicated that the average velocity of droplet is 650 mm/s for wire 1,2 mm at welding current 210 A. The results of present work indicate that average velocity of droplet is 660.64 mm/s at welding current 216 A.

Acknowledgements

The authors would like to thank The Fulbright Commission for financing this research, which was done within the framework of the research project Young Advanced Research Grant – University of Kentucky Centre for Manufacturing, Welding Research and Development Laboratory and the Applied Machine Vision Laboratory 2007-2008. This research is also supported in part by the National Science Foundation under grant CMMI-0726123.

References

[1] R.L. O'Brein 1991. Welding Handbook, American Welding Society.

[2] I. Kim, A Basu, A mathematical model of heat transfer and fluid flow in the gas metal arc welding process, Journal of Materials Processing Technology 77 (1998) 17-24.

[3] L. Quintino, R. Riberio, J. Faira, Classification of GMAW transfer using neural networks, International Journal for the Joining of Materials 11 (1999) 6-8.

[4] K. Luksa, Z. Rymarski Collection of arc welding process data, Proceedings of the 12th International Scientific Conference "Achievements in Mechanical and Materials Engineering"AMME'2003, Gliwice-Zakopane, 377-380.

[5] F.L. Zhu, H.L. Tsai, S.P. Marin, P.C. Wang, A comprehensive model on the transport phenomena during gas metal arc welding process, Progress in Computational Fluid Dynamiccs 4 (2004) 99-117.

[6] S.K. Choi, Y.S. Kim, C.D. Yoo, Dimensional analysis of metal transfer in GMA welding, Journal of Physics D: Applied Physics 32 (1999) 326-334.

[7] G. Fu, F. Tian, H. Wang, Studies on softening of heat-affected zone of pulsed-current GMA welded Al–Zn–Mg alloy, Journal of Materials Processing Technology 180 (2006) 216-220.

[8] P.K. Ghosh, L. Dorn, M. Hübner, V.K. Goyal, Arc characteristics and behaviour of metal transfer in pulsed current GMA welding of aluminium alloy, Journal of Materials Processing Technology 194 (2007) 163-175.

[9] P.K. Palani, N. Murugan, Selection of parameters of pulsed current gas metal arc welding, Journal of Materials Processing Technology 172 (2006) 1-10.

[10] S.K. Choi, C.D. Yoo, Y.S. Kim, The dynamic analysis of metal transfer in pulsed current gas metal arc welding, Journal of Physics D: Applied Physics 31 (1998) 207-215.

[11] K. Li, Y.M. Zhang, Metal Transfer in Double-Electrode Gas Metal Arc Welding, Journal of Manufacturing Science and Engineering-Transactions of the ASME (in print).

[12] Q. Lin, X. Li, S.W. Simpson, Metal transfer measurements in gas metal arc welding, Journal of Physics D: Applied Physics 34 (2001) 347-353.

[13] K. Luksa, Diagnosing of short circuit gas metal arc welding process, Proceedings of the 3rd Scientific Conference "Materials, Mechanical and Manufacturing Engineering", M3E'2005, Gliwice – Wisla, 2005, 977-984.

[14] P.J. Modenesi, R.I. Reis, A model for melting rate phenomena in GMA welding, Journal of Materials Processing Technology 189 (2007) 199-205.

[15] G. Campana, A. Fortunato, A. Ascari, G. Tani, L. Tomesani, The influence of arc transfer mode in hybrid laser-MIG welding, Journal of Materials Processing Technology 191 (2007) 111-113.

[16] C.D. Allemand, R. Schoeder, D.E. Ries, T. W. Eager, A method of filming metal transfer in welding arcs, Welding Journal 64 (1985) 45-47.