COVER SHEET

Posinasetti, Praveen and Kang, Moonjin and Yarlagadda, Prasad KDV (2006) Behaviour Of Metal Transfer Modes In Pulse Gas Metal Arc Welding Of Aluminum. In Gunasekharan, Jay, Eds. *Proceedings of 2006 Advanced Materials Processing Technologies Conference*, pages pp. 1-8, Las Vegas, USA.

BEHAVIOUR OF METAL TRANSFER MODES IN PULSE GAS METAL ARC WELDING OF ALUMINUM

P. Praveen[1], M. J. Kang[1, 2], and Y. K. D. V. Prasad[1]

1. School of Engineering Systems, Queensland University of Technology, 2 George Street, Brisbane, Qld 4001, Australia; email: p.posinaseeti@qut.edu.au, y.prasad@qut.edu.au
2. Production Technology Center, Korea Institute of Industrial Technology, 994-32, Dongchun-dong, Yeonsu-gu Incheon, 406-130, South Korea; email: moonjin@ktiech.re.kr

ABSTRACT

The knowledge of metal transfer mode is important for achieving good quality in thin aluminium sheets welded by pulse gas metal arc welding (GMAW-P). In this study, the effects of various pulsing parameters on metal transfer mode in thin aluminium sheets welded by GMAW-P have been investigated. The pulsing variables namely peak current, base current, peak time, and base time were chosen as variable parameters. The metal transfer mode investigation was based on the synchronization of welding signals and high speed camera to characterize and identify conditions under which different types of metal transfer modes are observed in GMAW-P system. Further investigation involved understanding the effects of the pulsing parameters on different transition region involved in GMAW-P.

Keywords: Aluminum, Metal Transfer Mode, Pulsing Parameters, GMAW-P

1. INTRODUCTION

GMAW-P is widely used in arc welding process for thin sheet metal joining especially with aluminium [1]. In GMAW-P, the welding current is alternatively and periodically varied between background (or base) and peak (or pulse) values as shown in Figure 1. This process uses a consumable metal electrode, which melts due to intense heat of the electric arc surrounded by stream of inert gas.

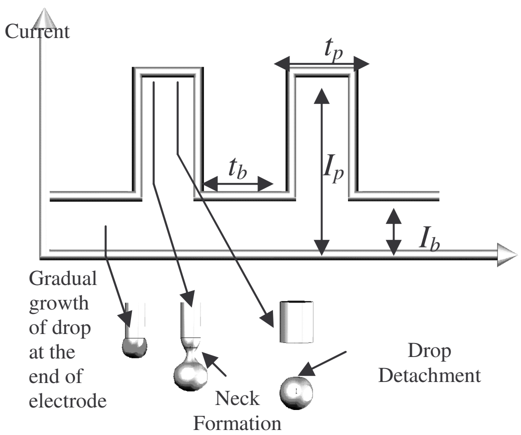

Figure 1. Pulsed current waveform

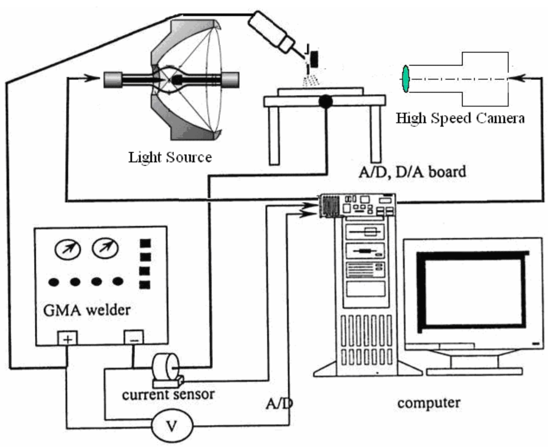

Figure 2: Schematic layout of experimental setup

The main setting parameters which influence weld quality or wire melting are background current I_b, peak current I_p, background time T_b, and peak time T_p. Two additional parameters namely frequency, f = $1/(T_p + T_b)$ and duty cycle, D = $T_p /(T_p + T_b)$ are introduced to simplify parameter setting. In order to obtain proper weld quality, optimal values of these parameters should be set which ensures drop transfer mode.

Weld metal transfer from the electrode tip to the plate has been the subject of research for several years. Due to existence of number of metal transfer modes, the knowledge of the transition current zones between the metal transfer modes has great importance in the GMAW-P process, because it is determines the working conditions which are directly function of pulsing parameters [2]. To optimize and refine the process of metal transfer in GMAW-P, several researchers have studied metal transfer in order to gain fundamental understanding of the dynamics of the process. Quintino et al. [3] found that peak duration is the most important parameter to ensure one drop per pulse (ODPP) mode because neck formation and elongation of the pendant drop occur mostly during this period. If the peak duration is too short, the elongated drop would recoil back to electrode and if it's too long multiple drops detach from the end of the electrode. Allum [4], Amin [5], Smati [6] and Rajasekran et al. [7] used the burn-off criteria, arc stability and weldment quality to determine the suitable range of the pulse parameters. They established that the one drop per pulse is realized when the term $I_p^c T_p$ remains constant. Jacobsen [8] established that for a pendant drop is $t_{dmin} I_p^c$ remains constant. Needham and Carter [9] had taken the pulse amplitude and duration to detach a droplet of size equal to wire diameter, then the background current and duration were adjusted to give the requisite average current and burn-off rate. Kim et al. [10] and Waszink et al. [11] developed theoretical models to predict range of pulsing frequency for ODPP metal transfer. It is reported that the background detachment gives the smoothest metal transfer characteristics. Subramaniam et al. [12] formed a relation between the peak and background conditions by a combination of exponential and Lorentzian function to define the minimum time at peak required for droplet detachment at a desired peak current level. In spite of several researches in this field, still there is a gap in our knowledge preventing us from fully understanding the process due to complexity of the process. Also most of the previous work in GMAW-P has been done on steel. The influence of back ground conditions on metal transfer has been ignored in previous research efforts. This paper reports an experimental study to observe the influence of different pulsing parameters namely peak current, base current, peak time and base time on the metal transfer mode.

2. EXPERIMENTS

In the welding experiments, a 4047 aluminum alloy welding wire with a 1.2-mm diameter was used in the experiments. All experiments were carried out with contact tip to work distance (CTWD) of 20mm, using pure argon as shielding gas at a flow rate of 20 L/min. The workpiece was 6061 aluminum alloy with a thickness of 6 mm. The welding speed was set at 4 mm/s and bead–on-plate was performed for total welding time of 10 secs. Table 1 shows the setting conditions of pulsing parameters used for the experimentation. Factorial design of experiment was selected for the pulsing parameters with the following four levels: (i) I_p : 220, 250, 280, and 310 A, (ii) I_b : 40, 50, 60, and 70 A, (iii) T_p : 2, 4, 6, and 8 ms, and (iv) T_b : 10, 16, 22, and 28 ms. The experimental set-up used in this study is shown in Figure 2. The welding current was measured with a Hall sensor, which was attached to the earth cable, and the arc voltage also was measured between the output terminals. The measured signals were transferred into the computer via an A/D converter with a maximum sampling rate of 10 kHz. The noise on the signals was removed by a digital low pass filter with a 200 Hz cut-off frequency. The waveform signals were collected during a 2 s period after 10 s elapsed from the start of welding. Experiments were carried out using the principle of back-light high speed xenon lamp cinematography which was synchronized with data acquisition system. In this method, a xenon lamp acts as a backlight and is passed through a set of lenses and filters. In the process, almost all of the arc light is eliminated and a shadow of the drop and wire is captured by a high-speed camera.

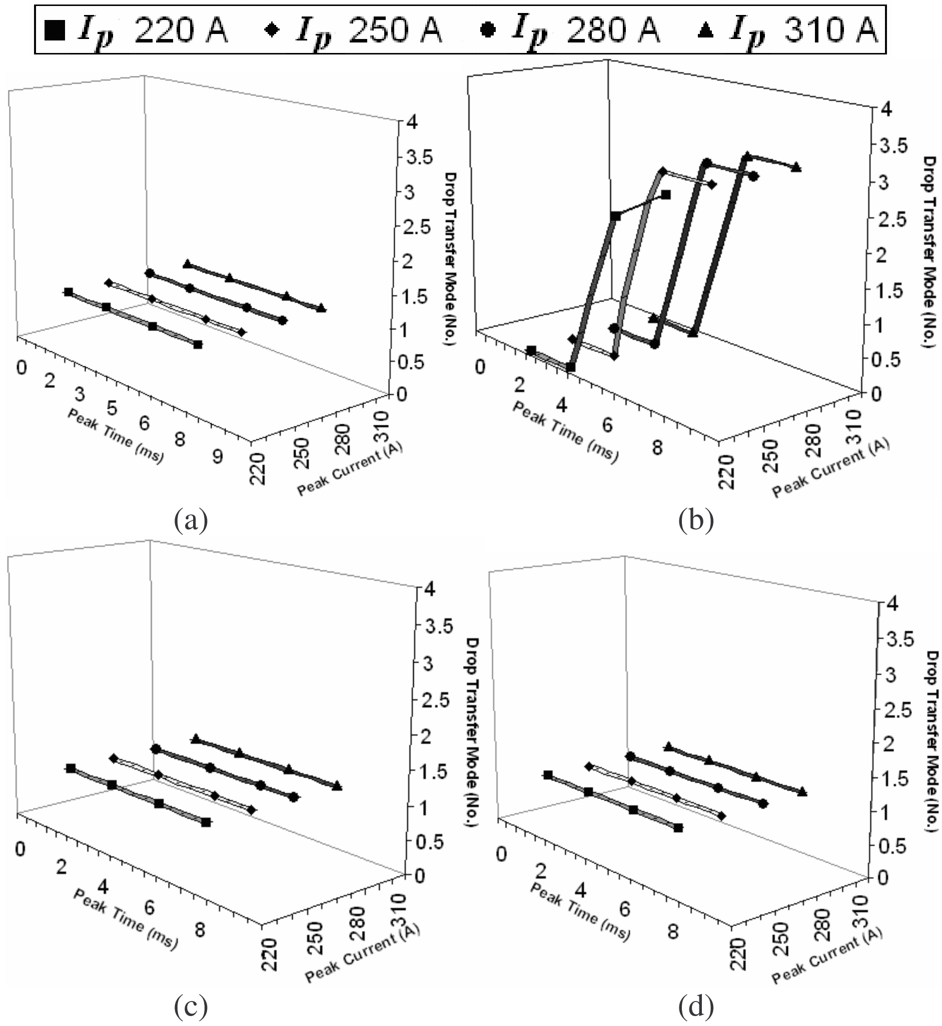

Figure 3. Drop transfer mode vs. peak time for wire feed rate of 4 m/min at (a) I_b = 40A and T_b = 10ms, (b) I_b = 40A and T_b = 28ms, (c) I_b = 70A and T_b = 10ms, and (d) I_b = 70A and T_b = 28ms.

3. RESULTS

When considering metal transfer modes in GMAW-P we can easily identify three categories of metal transfer behaviour: 1. short circuit, 2. one drop per pulse (ODPP), and 3. multiple droplets per pulse (MDPP). The behaviour of different metal transfer modes with different pulsing parameters is shown in Figure 3. The high speed camera images of various metal transfer modes are shown in Figures 4-7.

3.1 Short circuit: Several test conditions resulted in short circuit. Short circuit in GMAW-P is characterized by periodic contacts between the electrode wire and the weld pool. As shown in Figure 4, the electrode wire melts during the base time and the molten droplet is formed at the electrode tip during the arcing period. Longer base time results in melting of the electrode without droplet detachment. Short circuit in GMAW-P generally occurs in two forms: base and peak shorts. Base short are generally characterized by the welding voltage decrease to its minimum value, and the current increases to its maximum value. Peak short, as they occur during the peak time, so current is already higher. They are generally characterized by the welding voltage decrease to its minimum value and the current drops slightly. Both these forms of short circuit can be seen in Figure 4. Short circuit is generally observed at lower base current with lower peak time and higher base time as shown in Figure 3(b).

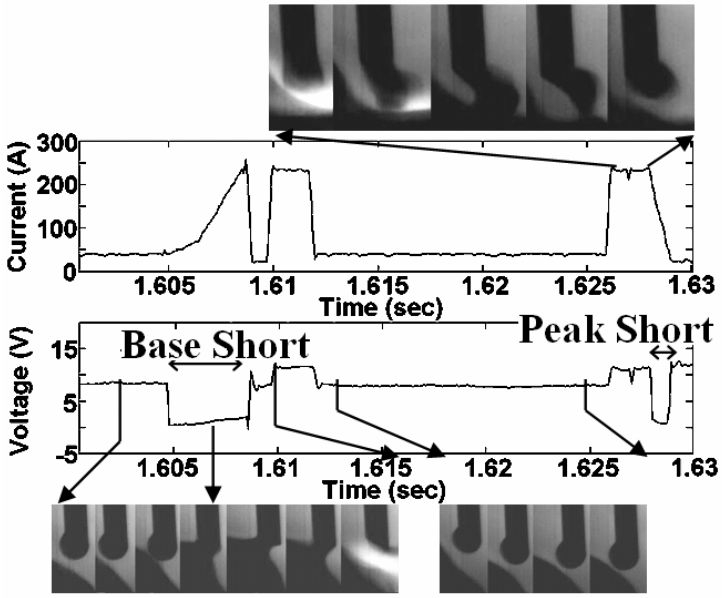

Figure 4. High speed camera pictures of short circuit: I_p = 220A, I_b = 40A, T_p = 2ms, and T_b = 22ms

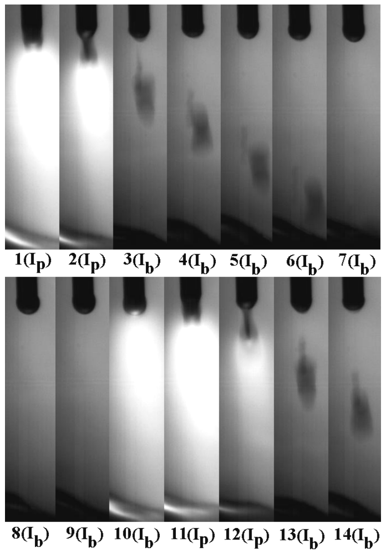

Figure 5. High speed camera pictures of ODPP: I_p = 220A, I_b = 60A, T_p = 2ms, and T_b = 10ms

3.2 One Drop per Pulse: The most desirable form of metal transfer in GMAW-P is ODPP. Several authors in the past have tried to investigate this mode of metal transfer, but the work was done at relatively lower background currents with the assumption that no melting occurs during the background. Figure 5 shows the droplet transfer for ODPP condition with droplet approximately equal to diameter of the wire and with little or no tapering of the electrode observed. Droplet transfer and melting rate are significantly influenced by the magnitude and duration of the base current. Lower base current combined with lower base time and higher base current resulted in ODPP as shown in Figure 3 (a), (c) and (d). This shows that base current and duration are important conditions for achieving ODPP over a wide range of pulsing parameters. Also higher background current generally results in higher deposition rate.

3.3 Multiple Drops per Pulse: Several test conditions resulted in MDPP. Multiple droplet detachments were observed in all cases when peak time and base time are longer as seen in Figure 3(b). Images of multiple droplet detachments without streaming transfer and no significant tapering are shown in are shown in Figure 6(a). The acceleration of the drop detaching during the peak time is much higher compared to the droplets detaching during base time. At higher peak conditions, namely peak current and peak time, there is considerable amount of tapering of the electrode and streaming transfer results. Images of multiple droplet detachments with streaming transfer are shown in Figure 6(b). Streaming transfer is generally undesirable as it results in significant amount of spatters.

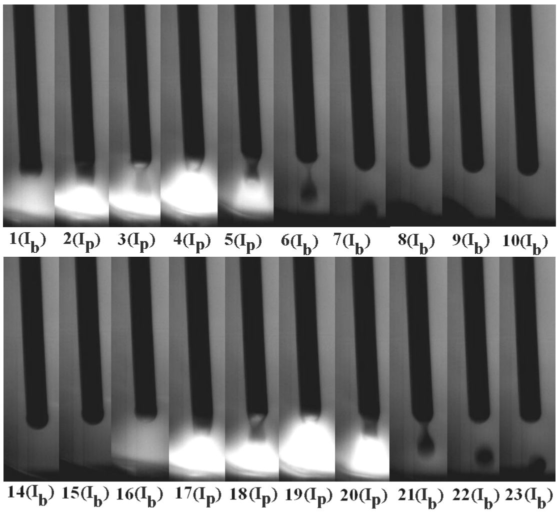

Figure 6 (a). High Speed Camera Pictures of MDPP with no streaming transfer: I_p = 220A, I_b = 40A, T_p PT = 4ms, and T_b = 16ms

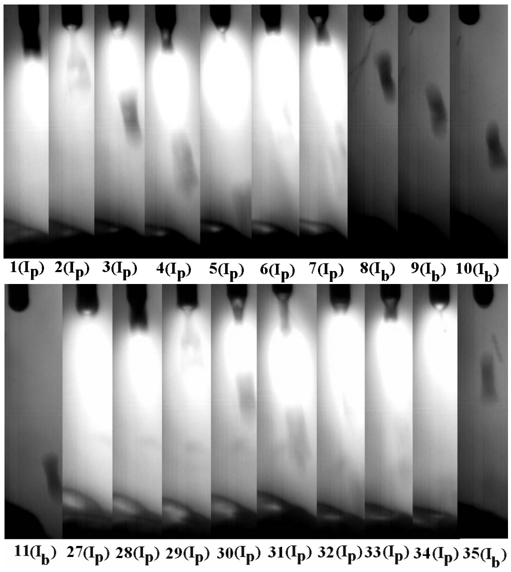

Figure 6 (b). High Speed Camera Pictures of MDPP with streaming transfer: I_p = 220A, I_b = 40A, T_p = 8ms, and T_b = 16ms

3.4 Transition from ODPP to Spray Transfer

This transition is generally more evident at lower values of base currents with higher values of base time and peak time which means lower frequency and higher duty cycle (See Figure 3(b) and 6(a)). If base time is small due to high pulsing frequency lower melting will result in ODPP. With longer base time, assuming the necessary peak time to produce the transition from ODPP to spray transmission only exists and is able to avoid occurrence of short circuit, higher melting of the electrode will result in MDPP. The reason for this behaviour is difference in electrode extension at constant wire feed rate between lower and higher base time which results in higher degree of preheating of wire as well as increase in the fraction of heat in the heat content of droplet [13]. These conditions are ideal for multiple droplet detachments [14]. The absence of transition from ODPP to spray transfer at higher value of base current with lower frequency and higher duty cycle is also due to same reason as electrode extension is much smaller at higher base current even if base time is longer.

3.5 Transition from Spray to Streaming Transfer

This transition is generally more evident at higher values of currents [10] or higher values of peak and base time which means higher values of duty cycle and smaller frequency (See Figure 3(b) and 6(b)). At higher values of currents, electrode tapering begins, increased melting as a result of higher value of current results in the elongation of the taper and a transition to formation of streams of droplets begins to occur [10]. This phenomenon can also be observed under the influence of higher values of duty cycle and smaller frequency. Assuming the necessary peak current to produce the transition from spray to streaming transmission exists, lower peak time will results in spray transfer (See Figure 5(a)). If peak time is maintained long enough, transition from spray to streaming transfer will be observed (See Figure 5(b)) [10].

3.6 Transition from Short Circuit to ODPP

This transition is generally more evident at higher base current or at lower value of base time which means higher frequency (See Figure 3(a), (b) and (c)). If base time is longer electrode extension will be large due to prevalent background conditions and as no droplet detachment will occur during background conditions. As a result chances of occurrence of short circuit are higher with longer base time. At lower base time which means higher frequency, ODPP is observed due to frequent pulsing of the current. At higher base current even with longer value of base time which means lower frequency, ODPP is observed as droplet detachment is more favoured at higher base current due to higher heat input in to the droplet [13].

4. CONCLUSION

Transfer of droplets significantly affects weld quality. Results from the experiment showed that by independently changing the pulse parameters, droplet formation and detachment in GMAW-P can be controlled. The role of frequency and duty cycle in GMAW-P of aluminium is primarily in controlling the droplet transfer mode. Lower frequency characterized by the lower values of peak time and longer base times generally results in short circuit. MDPP is observed with higher values of duty cycle and lower values of frequency which means higher values of peak and base time. ODPP was generally observed at higher base current and at higher frequency with lower base time values.

5. REFERENCES

[1] P. Praveen and P. K. D. V. Yarlagadda, Meeting challenges in welding of aluminum alloys through pulse gas metal arc welding, Journal of Materials Processing Technology, Vol. 164-165 (2005), pp. 1106-1112.

[2] Y. M. Zhang, E. Liguo, and R. Kovacevic, Active metal transfer control by monitoring excited droplet oscillation, Welding Journal, 77(1998), pp 388s-394s.

[3] L. Quintino and C. J. Allum, Pulsed GMAW: interactions between process parameters – part 1, Welding Met. Fabrication, Vol. 85 (1981), pp. 9-12

[4] C.J. Allum, L. Quintino, Control of fusion characteristics in pulsed current MIG welding, Met. Construct., April (1985), 242R–245R.

[5] M. Amin, Synergic pulse MIG welding, Metal Construction, Vol. 13 (1981), pp. 349-353.

[6] Z. Smati, Automated pulsed MIG welding, Metal Construction, Vol. 18 (1985) 38–44.

[7] S. Rajasekaran, Weld bead characteristics in pulse GMAW welding of Al-Mg alloys, Welding Journal, Vol 78 (1999), pp. 397s-407s

[8] N. Jacobsen, Monopulse Investigation of drop detachment in pulsed gas metal arc welding, Journal of Physics D: Applied Physics, Vol. 25 (1992), pp. 783-797.

[9] J.C. Needham, A.W. Carter, Material transfer characteristics with pulsed current, Brit. Weld. J., Vol. 5 (1965), pp. 229–241.

[10] Y. S. Kim, and T. W. Eager, Metal transfer in pulsed gas metal arc welding, Welding Journal, Vol. 72 (1993), pp. 279s-287s.

[11] J. H. Waszink and M. J. Piena, Experimental investigation of drop detachment and drop velocity in GMAW, Welding Journal, Vol. 65 (1986), pp. 289–98s.

[12] S. Subramaniam, D.R. White, J.E. Jones, D.W. Lyons, Experimental approach to selection of pulsing parameters in pulsed GMAW, Weld. J. Vol. 78 (1999) 166s–172s.

[13] V. A. Karkhin, B. V. Fedotov, I. N. Babkin, and S. Subramaniam, Distribution of temperature and voltage drop in the extension of a consumable electrode in welding with constant and pulsed current, Welding International, Vol. 19 (2005), pp. 52-61.

[14] V. A. Nemchinsky, Electrode melting during arc welding with pulsed current, J. Phys. D: Appl. Phys., Vol. 31 (1998), pp. 2797-2802.