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Arc voltage behavior of one drop per pulse mode in GMAW-P

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ABSTRACT

Purpose: Experimental measurements have been made to investigate the meaning of the change in voltage for the pulse gas metal arc welding process through one drop per pulse mode (ODPP).

Design/methodology/approach: Welding experiments with different values of pulsing parameter and simultaneous recording of high speed camera pictures and welding signals (such as current and voltage) were used to identify ODPP drop transfer mode in pulse gas metal arc welding. The investigation is based on the synchronization of welding signals and high speed camera to study the behaviour of voltage signal under ODPP.

Findings: The results reveal that the welding arc is significantly affected by the molten droplet detachment. In fact, sudden increase and drop in voltage just before and after the drop detachment characterizes the voltage behaviour of ODPP drop transfer mode in pulse gas metal arc welding.

Research limitations/implications: The results show that voltage signal carry rich information about different drop transfer occurring in pulse gas metal arc welding. Hence it's possible to detect different drop transfer modes. Future work should concentrate on development of filters for detection of different drop transfer modes.

Originality/value: Determination of drop transfer mode with pulse gas metal arc welding is crucial for the appropriate selection of pulse welding parameters. As change in drop transfer mode results in poor weld quality in pulse gas metal arc welding, so in order to estimate the working parameters and ensure stable pulse gas metal arc welding understanding the voltage behaviour of different drop transfer modes in pulse gas metal arc welding will be useful. However, in case of pulse gas metal arc welding hardly any attempt is made to analyse the behaviour of voltage signal for different drop transfer modes. This paper analyses the voltage signal behaviour of ODPP mode for pulse gas metal arc welding. ODPP mode widely used to achieve best quality weld.

Keywords: Welding; Arc voltage; One drop per pulse

1. Introduction

Pulse gas metal arc welding (GMAW-P) is widely used arc welding process for thin sheet metal joining especially with aluminium [1-5]. 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. The main setting parameters which influence weld quality or wire melting are background current I_b, peak current I_p, background time T_b, peak time T_p and wire feed rate. In order to obtain proper weld quality, optimal values of these parameters should be set which ensures drop transfer mode.

Several researchers studied the various aspects of GMAW-P [6]. Quintino et al. [7] and Ueguri et al. [8] found that peak duration is the most important parameter to ensure 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. Smati [9] showed that ODPP is realized when the term $I_p^2 T_p$ remains constant. It is reported that the background detachment gives the smoothest metal transfer characteristics. Kim et al. [10] and Waszink et al. [11] developed theoretical models to predict range of pulsing frequency for ODPP metal transfer. Despite extensive attempts at analytical and numerical modelling, discrepancies still exist between predicted and experimental results. Hence there is still gap in our knowledge preventing us from fully understanding droplet dynamics especially for newer materials like Aluminum.

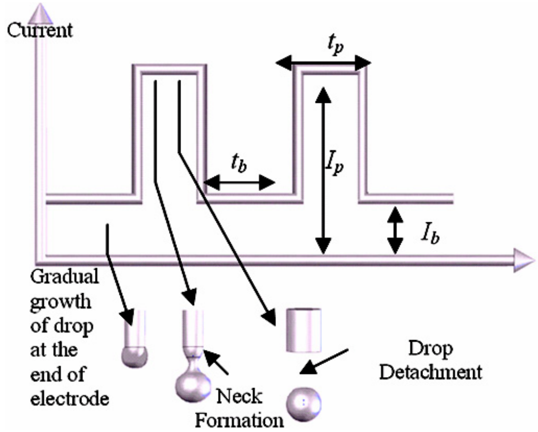

Fig. 1. Parameters of pulsed current waveform

The most popular method to identify the type of drop transfer and the moment at which the drop transfer occurs is based on an oscillographical analysis of voltage (voltage versus time). The knowledge of this interaction between the drop transfer and voltage signal becomes important when the target is the optimization and control of welding process. It is only recently that attempts have been made to understand the physical basis for the dynamics of droplet transfer. Hence there is still gap in our knowledge preventing us from fully understanding the interaction between the voltage signal and droplet dynamics. This paper reports an experimental study to observe the overall impact of droplet dynamics on welding arc characteristics. The possible influence of the arc voltage and current fluctuations on the formation and detachment of the droplet was observed. This was achieved by correlating precisely the welding arc electrical signals (arc current and voltage) with the droplet images recorded simultaneously in real time.

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. The experimental set-up used in this study is shown in Figure 2.

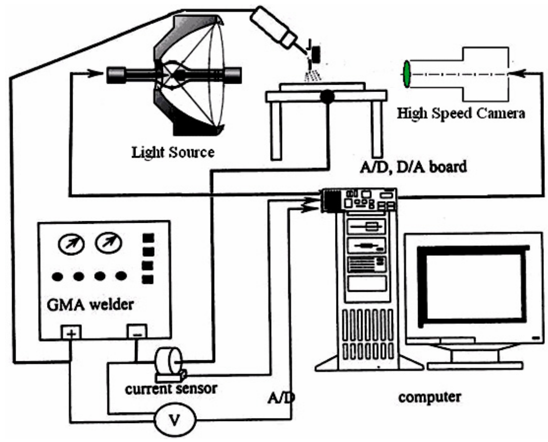

Fig. 2. Schematic diagram of experimental setup

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 data sampling rate for the signals was 10000 samples/s. 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 shows typical waveforms of welding current and voltage for ODPP mode of metal transfer.

Table 1.
Experimental design plan

Levels	1	2	3	4
Peak Current (A)	220	250	280	310
Base Current (A)	40	50	60	70
Peak Time (ms)	2	4	6	8
Base Time (ms)	10	16	22	28

3. Results and discussions

It can be seen from Fig. 3 that these electrical signals are fluctuating and noisy in general, but have a regular pulsing structure constantly varying between background (or minimum) and peak (or maximum) values and differ in a very different manner for ODPP drop transfer mode. At first glance, it seems difficult to interpret the exact meaning of these electrical signal characteristics of ODPP drop transfer mode. But careful correlation by synchronization of welding signals and high speed camera reveal rich information to characterize ODPP drop transfer mode occurring in GMAW-P system.

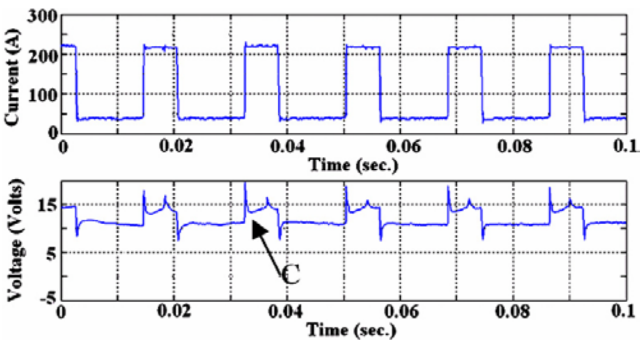

Fig. 3. Typical welding current (top) and voltage (bottom) as functions of time for ODPP drop transfer mode

For all the drop transfer modes, current waveform shows very low frequency components, indicating that the inductance of the power supply has limited and smoothed the change in the current with different drop transfer modes, reducing the high frequency component. Also arc length under different metal transfer modes was found to be fairly constant expect for just before and after the droplet detachment when the arc length is longest and shortest.

3.1. Drop transfer characteristics in ODPP online signal

ODPP mode has certain characteristics features in the region C, and this region has same frequency as that of the pulse waveform and droplet detachment. Synchronized images of high speed camera pictures with voltage and current waveform during ODPP mode and region C represented in Figure 3(b) is shown in Figure 4. Carefully correlating the welding arc signals (arc current and voltage) with high speed camera pictures reveal that one droplet detaches in region C which has same frequency as pulse waveform. The regular occurrence of Region C through out the pulse suggests that the droplets are all transferred in a very similar fashion. The influence of droplet formation, necking, detachment and travel on the welding arc can be investigated by assessing the droplet images together with arc voltage signal at corresponding times. Figure 4 shows details of the electrical signals for one period of fluctuation together with high speed camera pictures. The images selected give a generalised picture of the ODPP phenomenon in GMAW-P. Generally ODPP is achieved at lower peak time. As a result often droplet detachment occurs right at the end of the peak time and as a result it was difficult to explain the influence of droplet travel on welding arc. Hence, the region C was particularly selected during the base phase with the purpose of properly explaining the influence of droplet travel on the welding arc.

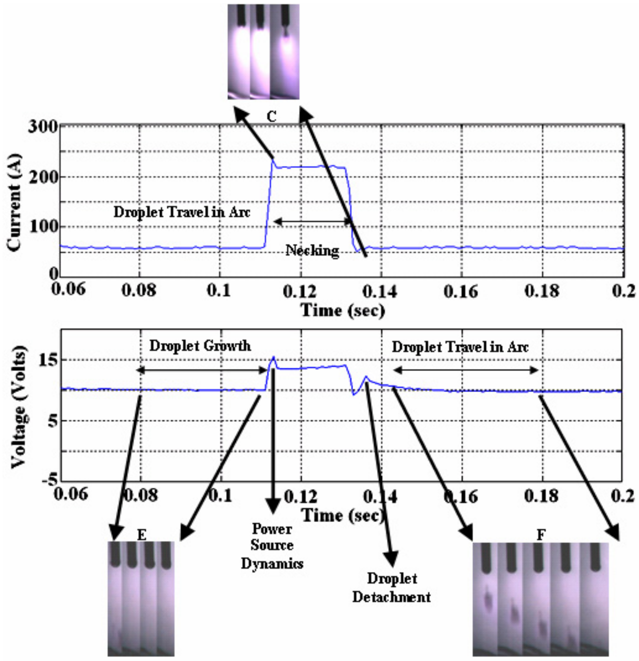

Fig. 4. Synchronized images of high speed camera pictures with arc current and voltage waveform for ODPP

By pulsing the welding current, electromagnetic forces may be used to detach drops from the electrode. When the radius of the droplet reaches close to the electrode wire or if current is switched to sufficiently higher values, the current density in the region of the droplet near the solid–liquid interface has a component that is directed radially downwards in to the droplet. As a result electromagnetic force acts as a detaching force which removes liquid metal away from the neck region of the droplet promoting droplet detachment [12]. Second sudden increase in voltage corresponds to the necking at the solid-liquid interface just before the droplet detachment event which can be confirmed by correlation with high speed camera pictures of region C is shown in Figure 4. Sudden increase in voltage probably corresponds to the increased electrical resistance of the droplet neck just before separation [13] and sudden reduction in arc length due to elongation of the droplet.

Droplet detachment event can be seen on voltage curve by sudden drop in voltage as shown in Figure 4. The voltage drop may be equal or exceed the rise of voltage due to necking in the opposite direction. Drop in voltage nearly equal to the rise in voltage due to necking in the opposite direction can be simply explained by the simple recovery from the necking effect. However higher drop in voltage during the droplet detachment which is observed sometimes can be explained by the geometry of the welding wire which experiences dynamic variations during a metal transfer period. Just after the droplet has detached, small amount of liquid metal still remains at the tip of the wire, and unbalanced surface tension force causes the remaining liquid to recoil and oscillate on the wire tip causing small additional voltage drop [14].

Droplet travel in the welding arc is characterized by small drop and almost constant voltage. General current flow pattern within the welding arc originates from the electrode tip following a fan like distribution and converges in the form of a circle on the base metal. In presence of droplet in the welding arc, the current flow pattern is first in to the droplet and then from droplet in to the base metal in the form of fan distribution again. So if the current density distributions at the start of metal droplet formation are compared with droplet inside the welding arc, it can be 'observed that the distributions inside the arc plasma are very different but the outer shapes of the arc plasma are identical [15]. As outer shape of the arc plasma is not much influenced by the droplet travel, and it is understandable that arc voltage remains constant. Also the electrical field gradient in the arc column is much lower with constant electric field and straight line voltage characteristics. In addition, the electric potential difference is a function of the cathode spot radius. So there is always a minimum in the electric potential in different cathode sport curves which corresponds to the lowest energy consumption by the system as the optimum value [16].

4. Summary and conclusions

Experimental investigation has been made to correlate precisely visually and to assort with precision the behaviour of the welding electrical signals during the several phases of the metal transfer for correlating drop dynamics and electrical characteristics.

The results indicate that it is feasible to use voltage signal for detecting ODPP drop transfer mode observed in GMAW-P. The characteristic shape of the voltage waveform and its fluctuations with ODPP mode follow a regular pattern.

The results suggest that the welding arc voltage can be significantly affected by the drop dynamics in GMAW-P. Sudden rise in voltage was observed just before the detachment because of the necking. Sudden drop in voltage was observed just after the detachment due to sudden change in arc length and dynamics of solid-liquid interface because of predominant surface tension. Voltage was found to be fairly constant during the drop travel within the welding arc.

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