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Detection of short circuit in pulse gas metal arc welding process

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Analysis and modelling

ABSTRACT

Purpose: The paper discusses several methods of detecting occurrence of short circuit and short circuit severity in pulse gas metal arc welding process (GMAW-P).
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 the occurrence of short circuit and its severity in GMAW-P process. The investigation is based on the measurement of welding signals specifically current and voltage signals and their synchronization with high speed camera to investigate the short circuit phenomenon in GMAW-P process.
Findings: The results reveal that short circuit can be detected using signal processing techniques and its severity can be predicted by using statistical models and artificial intelligence techniques in GMAW-P process.
Research limitations/implications: Several factors are responsible for short circuit occurrence in GMAW-P process. The results show that voltage and current signal carry rich information about the metal transfer and especially short circuit occurrence in GMAW-P process. Hence it's possible to detect short circuit occurrence in GMAW-P process. Future work should concentrate on development of advance techniques to improve reliability of techniques mentioned in this paper for short circuit detection and prediction in GMAW-P process.
Originality/value: For achieving atomization of the welding processes, implementation of real time monitoring of weld quality is essential. Specifically for GMAW-P process which is widely used for light weight metal which is widely gaining popularity in manufacturing industry. However, in case of GMAW-P process hardly any attempt is made to analyse techniques to detect and predict occurrence of short circuit. This paper analyses different techniques that can be employed for real time monitoring and prediction of short circuit and its severity in the GMAW-P process.
Keywords: Short circuit; Pulse gas metal arc welding

1. Introduction

Achieving good quality with light weight metals like Aluminum is a challenging job [1]. GMAW-P process is widely used in welding of light metal alloys like Aluminum etc. Thus industry has great research interest in automization and robotization of welding processes though implementation of real-time monitoring and control of welding processes especially for light weight metal alloy.

Several sensors like visual imaging, infrared camera, ultrasonic sensing and radiographic sensing methods have been employed for achieing automation [2]. In addition external sensors capable of attaching to welding torch has also been develped. The drawbacks of these sensors are: expensive, reliability, and may cause practical limitation by restricting the motion flexibility and accessibility of the welding torch.

To avoid the above-mentioned drawback, through-the-arc sensing (a sensor that uses the welding voltage and current alone) has been developed and successfully applied in real time monitoring of welding processes. In the experimental work described, several techniques for short circuit analysis based on captured signals of current and voltage have been discussed. To this purpose, a data acquistion system integrated with personal computer was used. The results from signal processing was verfied by using the high speed camera pictures.

2. Material transfer and welding process stability

Pulse mode (or projected spray or drop spray mode), is characterized by pulsing of current between low-level background current and high-level peak current in such a way that mean current is always below the threshold level of spray transfer. It has advantages over the other transfer modes which includes: uniform droplet size closer to electrode diameter, regular detachment, directional droplet transfer, and little spatter. However, this transfer mode can be obtained only in very narrow ranges of current and it is also dependent on other welding parameters such as wire diameter, electrode extension etc.

In order to maintain a stable GMAW-P process following criteria's must be fulfilled: (1) Achieve stable arc, (2) Spray type metal arc transfer (Avoid short circuit), (3) Constant arc length must be maintained, and (4) No spatter (Avoid short circuit)

Occurrence of short circuit in GMAW-P process means arc length does not remain contact and metal transfer through contact with weld pool. Perhaps the most unwanted result of unstable arc in GMAW-P process is the production of large amount of spatter which is unpleasant aesthetically. Hence avoiding short circuit is the most essential condition for achieving the stable welding arc. The easiest method of avoiding short circuit and ensuring stability of GMAW-P process is through control and analysis of captured signals like current and voltage. This is generally followed by statistical and soft computing techniques for extraction of useful information from these signals.

3. Experiments

3.1. Experimental setup

The experimental set-up used in this study is shown in figure 1. Through-the-arc sensing of the welding current, arc voltage and high speed imaging of the droplet transfer are assembled in conjunction with each other to study the influence of the pulse current waveform on the metal transfer process during GMAW-P. Experiments were carried out using the principle of back-light high speed xenon lamp cinematography which was synchronized with data acquisition system.

The arc voltage was measured between the contact tip of the welding gun and the fixture. The welding current was measured with a Hall sensor, which was attached to the earth cable. A data acquisition card in combination with a laptop personal computer was used to acquire voltage and current signals alsong with high speed camera pictures. The sampling rate was 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.

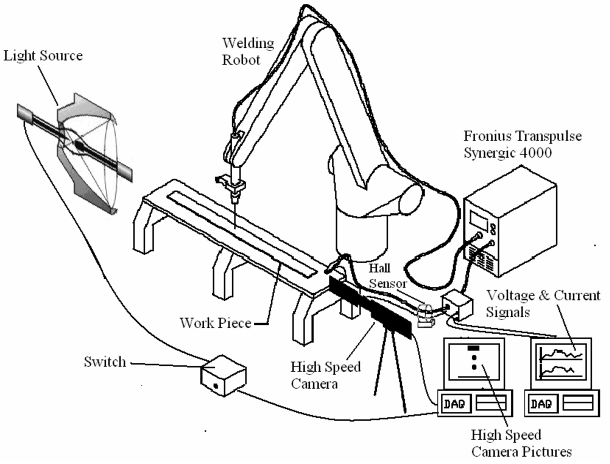


Fig. 1. Schematic diagram of experimental setup

3.2. Welding conditions

Bead on plate welds were made in the flat position using an inverter controlled GMAW power source. Welds were made in the constant current mode. The filler material used was a 4047 aluminum alloy welding wire with a 1.2-mm diameter. The base material was 6061 aluminum alloy with a thickness of 6 mm. The shielding gas used throughout the experiments was pure argon with a gas flow rate of 20 L/min. Contact tip to workpiece distance (CTWD) and speed was kept constant through out the experiments. The values of CTWD and speed used for all the experiments were 20 mm and 4 mm/s. Table 1 shows the setting conditions of pulsing parameters used for the experimentation.

Table 1.
Experimental design plan

Levels	1	2	3	4
I_p (A)	220	250	280	310
I_b (A)	40	50	60	70
T_p (ms)	2	4	6	8
T_b (ms)	10	16	22	28
WFR (m/min)	4	5	6	

4. On-line detection of short circiut

Figure 2 shows the welding current and voltage signal corresponding to short circuit and drop transfer mode respectively. Short circuit waveform is characterized by three regions namely A, B and C which are shown in Figure 2(a).

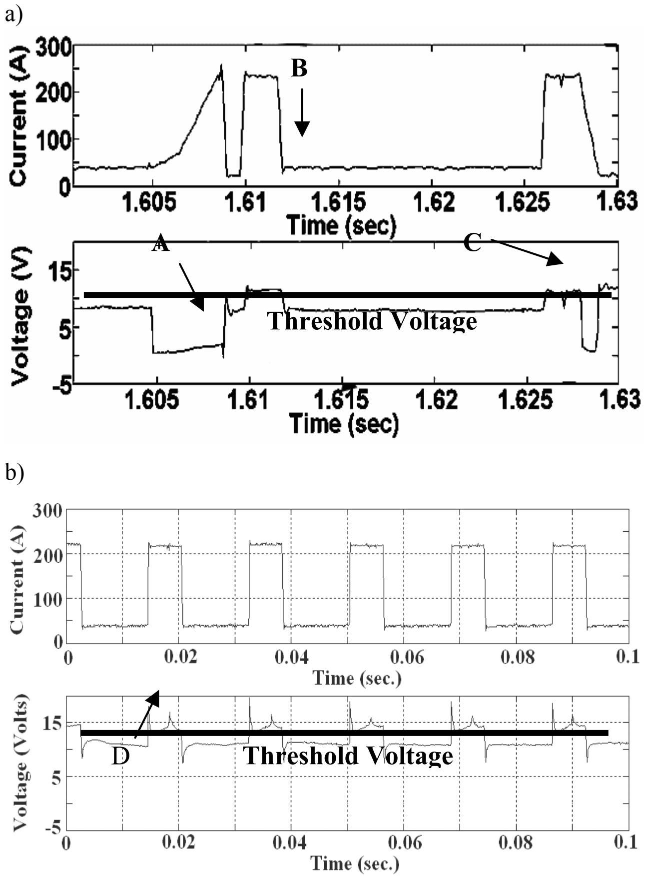


Fig. 2. Typical welding current (top) and voltage (bottom) as functions of time for different metal transfer modes, namely (a) Short circuit, and (b) Drop Transfer

Region A and C is characterized by the drop in voltage below the threshold level (here 5 Volts) where short circuit occurs. While Region B is characterized by voltage well above the threshold voltage when there is no contact between the electrode and workpiece. On the other hand, drop trasnfer mode is characterized by pulses which occur repetitively throughout the voltage waveform and voltage value is well above the threshold value as shown in Figure 2(b). Hence a simple test to detect short circuit is based on voltage magnitude which is shown in equation [1].

$$V_i < V_{\min} \Rightarrow Short \quad Circuit \qquad (1)$$

5. Parametric approach for short circuit severity estimation

Using the signal processing and image processing techniques, short circuit data was separated from the conditions under which drop transfer mode was observed. Total 187 experiments resulted in short circuit out of 786 experiments performed. Further analysis involved quantification of short circuit severity based on signal processing and image processing techniques. Depending upon the pulsing parameters, short circuit occurs with different severities which have been quantified in this work on the basis of number of times short circuit occurs in a single pulse.

Several waveform factors can be extracted from the wire melting rate equation. Waveform factors used in this study are: (1) Pulse characteristics shape factors: Peak Current (I_P), Base Current (I_B), Peak Time (T_P), Base Time (T_B), Unit Peak Current (I_PF), and Unit Base Current (I_BF); (2) Pulse area characteristics shape factors:

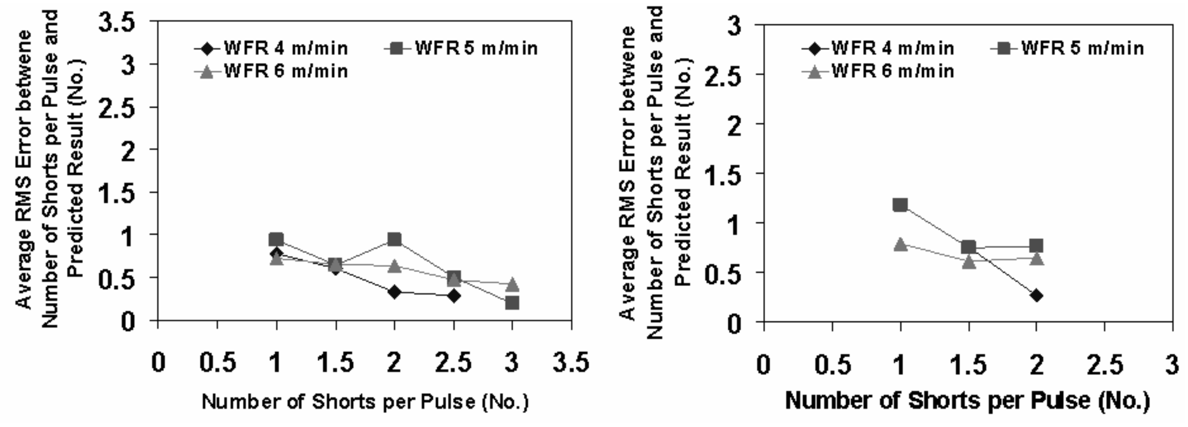
- Peak Time Arc Heating Fraction $(I_P \times T_P)$,
- Base Time Arc Heating Fraction $(I_B \times T_B)$,
- Unit Peak Time Arc Heating Fraction $(I_P \times T_P \times F)$,
- Unit Base Time Arc Heating Fraction $(I_B \times T_B \times F)$,
- Square of Peak Time Arc Heating Fraction $(I_P \times T_P)^2$,
- Square of Base Time Arc Heating Fraction $(I_B \times T_B)^2$,
- Square of Unit Peak Time Arc Heating Fraction $(I_P \times T_P \times F)^2$,
- Square of Unit Base Time Arc Heating Fraction $(I_B \times T_B \times F)^2$,
- Peak Time Resistive Heating Fraction $(I_P^2 \times T_P \times F)$
- Base Time Resistive Heating Fraction $(I_B^2 \times T_B \times F)$.

5.1. Statistical modelling

A linear regression model was composed as shown in Eq. 2, using the 16 factors obtained during two seconds of welding. A correlation and multiple regression analysis were performed to investigate how much influence these factors had on the number of shorts per pulse (Y). The resultant equation can be written as:

$$\begin{aligned} Y &= 0.40359WFR + 0.004492 I_P + 0.1068 I_B + 0.105166 T_B \\ &- 0.00124(I_B \times T_B) - 0.16673(I_B \times T_B \times F) \\ &- 0.00014(I_P^2 \times T_P \times F) + 0.025593\, p(I_B^2 \times T_B \times F) \end{aligned} \qquad (2)$$

The multiple correlation coefficient and standard error between the estimated results and the number of shorts per pulse was found to be 83.9% and 0.35 respectively. This proves that input parameters greatly affect the output and confirms the adequacy of the model in accurately predicting the short circuit severity.



a) b)

Fig. 3. Average rms errors between the predicted results and the number of shorts per pulse at different wire feed rates for: (a) Experimental data from which model is made, and (b) Test data

To ensure the accuracy of the developed model described above and to survey the spread of the values, model results were compared with experimental results. Comparison of average rms error between the experimental observation and results predicted from the model for different wire feed rates are shown in Fig. 3 (a) and (b) respectively. For all shorts per pulses, over estimation of the number of shorts per pulse was found and as number of shorts per pulse increased over estimation decreased. It is also evident from the Fig. 3 (a) and (b) that reasonable agreement between experimental and predicted number of shorts per pulse is shown. Presence of error suggests that developed model should be used with care.

5.2. Fuzzy modelling

In this section, we briefly explain the newly developed fuzzy modeling method for estimating the short circuit severity for GMAW-P process. Sixteen factors representing the characteristics of the pulse waveforms are employed as predictor variables and the short circuit severity (or number of shorts per pulse) is predicted on the basis of a modified exponential membership function fitted to the fuzzy sets derived from predictor variables. The system is trained with means and variances computed from each one of the fuzzy sets and then tested using untrained input predictor variables. The membership function characterising a fuzzy set is chosen as,

$$\mu_{x_i} = e^{\frac{-|x_i - m_i|}{\sigma_i^2}} \tag{4}$$

where: x_i is the i^{th} feature of the unknown state, m_i represents means and $\sigma^2{}_i$ stands for variances for each of the fuzzy sets

It is observed that some of the fuzzy sets have a very small variance and others, a large variance. This spurred the choice of a new membership function in [3] involving the structural parameters *s* and *t* given by,

$$\mu_{xi} = e^{-\Delta x'_i / \sigma_i^{2'}} \tag{5}$$

where, $\sigma_i^{2'} = (1+t) + t^2\sigma_i^2$

$\Delta x_i' = |(1-s) + s^2 \Delta x_i|$

$\Delta x_i = |x_i - m_i|$

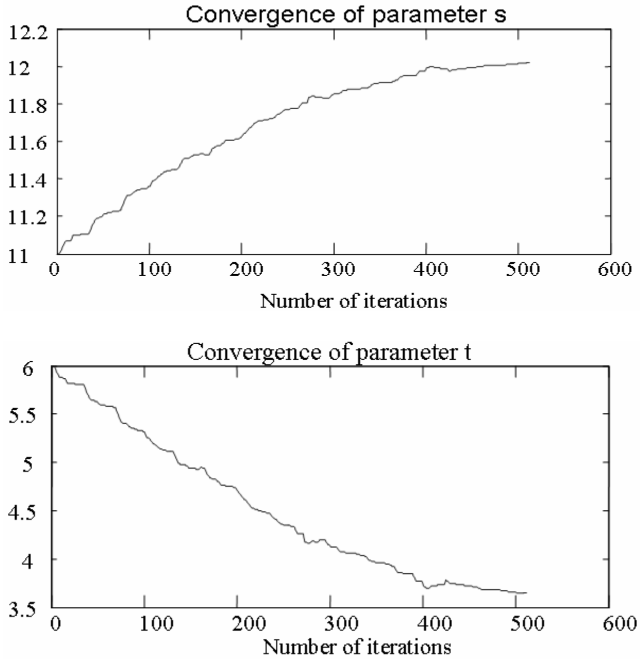


Fig. 4. Convergence of parameter ‘s’ and ‘t’ with number of iterations on X-axis and time taken (secs) on Y-axis.

The new mean and the new variance are functions of the mean and variance of the reference fuzzy set. Thus the structural parameters- *s*, *t* model the variations in the mean and variance. The choice of these parameters has reasoning. That is, if *s*=1, $\Delta x_i' = \Delta x_i$. Thus, *s* would be perturbed around 1 to reflect changes in the means. Similarly, if *t*=-1, then $\sigma_i^{2'}$ = σ_i^2 thus, *t* would reflect the changes in the variances. The initial values of *s* and *t* are taken as 11 and 6 respectively and are later updated using the gradient descent technique.

The above mdoeling strategy was applied on a dataset consisting on a subset of 256 experiments conducted at a wire feed rate of 4 m/min (as shwon in Table 1). The convergence of structural parameters s and t for constant ε is shown in below given figure. The final values of s & t were found to be 12.0152 and 3.6459 respectively. We obtained a recognition rate of 100% with a smaller dataset of 64 experiments and 94.5% with a second test data set consisting of 256 experiments.

6. Conclusions

This paper presents various methods by which short circuit occurrence and its severity can be predicted in GMAW-P during real time operation. To this end various experiments were performed to find the pulsing conditions under which short circuit occurs and their characteristic influence on current and voltage signal was characterized for detecting short circuit in GMAW-P process. Further work involved identification of waveform factors and their influence on short circuit severity. Through arc sensing was found to be reliable for detection of short circuit and for prediction of short circuit severity.

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