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Original Article

Analysis of short circuit transfer behavior using acoustic signal detection

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Abstract

The stability of a short circuiting period is important to obtain the desired weld quality. The objective of this research is to analyze the uniformity of liquid bridge disruption period during short circuit mode affected by various shielding gas compositions. The shielding gas compositions of 100% CO_2 and 84%Ar+2%O_2+14%CO_2 were used in this study. Short circuiting period was detected by using acoustic signals emitting from the arc. Acoustic data were recorded by using multimedia function of XP windows audio card through a high sensitivity microphone. The results of short circuit acoustic data were analyzed by using continuous wavelet transformation for classifying the difference of acoustic emitting mechanism of electrode tip touching with base metal and pinching cut-off. For 84%Ar+2%O_2+14%CO_2 shielding gas, it clearly showed smoother short circuit transfer than that of CO_2 shielding gas. CO_2 shielding gas gave large variation in disruption period comparing with that of 84%Ar+2%O_2+14%CO_2 gas mixture.

Keywords: GMAW, short-circuit transfer, shielding gas compositions, liquid bridge disruption period, continuous wavelet transformation

1. Introduction

The short circuit transfer mode is one of the metal transfer modes in gas metal arc welding (GMAW) and useful in many welding applications (Pomaska, 1991). This mode transfer is suitable for welding of thin sheet materials. Due to low heat input, it can minimize distortion of welded products and give good controlling of bridge welding on root pass. The mechanism of the short circuit mode is that liquid droplet accumulating at the electrode tip touches the weld pool and creates a liquid bridge between electrode tip and the weld pool (short circuit). While the droplet bridges the weld pool, current density increases significantly resulting in strong magnetic pinching force acting on hot liquid droplet. Once magnetic pinching force overcomes the surface tension of the molten liquid, the pinching cutoff of molten tip (detachment) occurs. Then re-ignition of the arc starts again. The short circuit transfer mode has been known to be occurred at low welding current and voltage range. Therefore heat input is quite low comparing with globular and spray transfer mode. The benefits of using low heat input are welding distortion minimization and out-of-position weld. Until now most welding industries have chosen carbon dioxide (CO_2) gas as a shielding gas due to price benefit. However, CO_2 promotes many spatters and, at some welding current ranges, gives irregular weld appearance (Chu *et al.*, 2004). Ushio *et al.* (1998) developed pulse current control welding machine for reducing spatters during weld. Although novel welding machines could be used to solve the problem, the cost of welding machines is high comparing to conventional machines. Mixed gases, such as argon plus CO_2, argon plus helium, or argon plus oxygen plus CO_2 and others, have been known by welding industries for many years that they can

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improve arc stability, deposition rate, welding speed and metal transfer quality. Wang and Li (1997); Jones *et al.* (1998), and Lin and Simpson (2001) have investigated various techniques for monitoring of metal transfer modes. Acoustic data evaluation has been developed by Grad *et al.* (2004) and Cayo *et al.* (2008) to carry out the analysis of sound pressure level (SPL) during welding. Warinsiriruk and Poopat (2006) have used many techniques for characterizations on acoustic signal detection and studied the effect of shielding gas compositions on metal transfer behavior, such as transfer rate, droplet velocity in the arc, transition current boundary, and dynamic behavior. Metal transfer behavior can be evaluated in millisecond scale giving high precision GMAW process monitoring. For present work, the objective of this research is to analyze the uniformity of liquid bridge disruption period during short circuit transfer mode affected by various shielding gas compositions. Continuous wavelet transformation technique was used for signal analysis. In this study, through-arc sensing technique by using high fidelity microphone was used as an acoustic sensor.

2. Research Methodology

Figure 1 shows the experimental setup and flow diagram. A Fronius series Transpulse Synergic 4000 welding machine for GMAW system was used. Welding consumable used in this study was ER70S-6 wire with a diameter of 1.2 mm. Welding was done on 6 mm carbon steel plate. The shielding gases used were 84%Ar+2%O_2+14%CO_2 and 100% CO_2 with a constant gas flow rate of 15 l/min (LPM). Welding currents and arc voltages were set at 120 A-19.8 Volt, 140 A-20.6 Volt, 160 A-21.4 Volt and 180 A- 22.2 Volt. Contact tube-to-work distance (CTWD) were set constant at 15 mm. A dynamic microphone was used as a acoustic sensor placing at the distance of 200 mm from welding arc. Therefore the effect of magnetic field that can cause electrical noise can be minimized. The acoustic waves emitted from short circuit transfer phenomenon were recorded and transferred to digital signal processing with 44 kHz/16 Bits sampling rate. Acoustic signal characteristics of short circuit mode were classified by

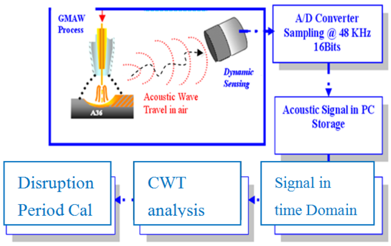


Figure 1. Equipment setup and procedure

using continuous wavelet transformation (CWT). MATLAB software having a package for transforming the time domain signals to wavelet window signal was used in this work. The short circuiting period or liquid bridge disruption period was analyzed as a function of welding currents and gas compositions.

3. Experimental Results of Continuous Wavelet Transformation

Acoustic data in time domain for 100% CO_2 and 84% Ar+2%O_2+14%CO_2 shielding gases are shown in Figure 2 and 3, respectively. It can be seen that each shielding gas could affect acoustic signals and its characteristics differently. Moreover these characteristics were changed when welding currents were changed. Continuous wavelet transformation (CWT) can be used as a classification technique as shown in Figure 4. Since CWT was used to analyze the signal (S) as a function of time and Ψ. The wavelet coefficient (Dunn, 2008) of S at scale *a* and position *b* is defined by equation 1.

$$C_{a,b} = \int_R s(t) \frac{1}{\sqrt{a}} \psi\left[\frac{t-b}{b}\right] dt \qquad (1)$$

Figure 4 shows the results of continuous wavelet transformation for acoustic signal in case of 100% CO_2 shielding gas. Acoustic data of 400 samples (9 ms) were analyzed. In the time scale view, x-axis represents the position along the signal (time), and y-axis represents scale. The colors at each x-y point represent the magnitude of the wavelet coefficient *C*. Red color represents high magnitude scale and blue color

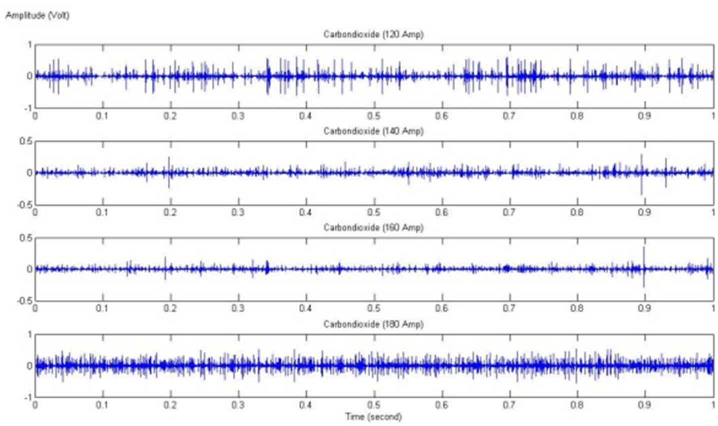


Figure 2. Acoustic signals obtained from welding by using CO_2 shielding gas.

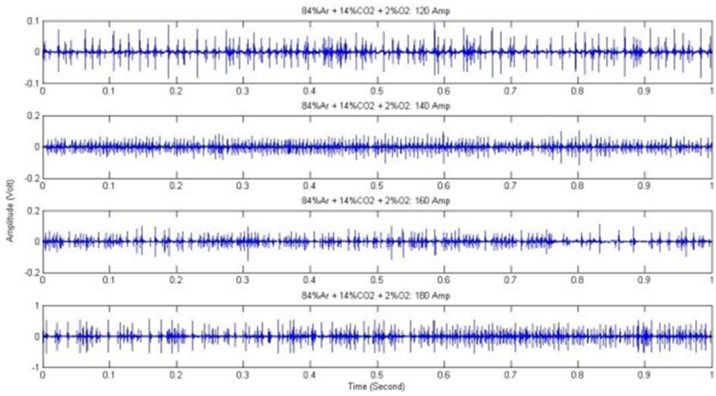


Figure 3. Acoustic signals obtained from welding by using 84%Ar+2%O_2+14%CO_2 shielding gas.

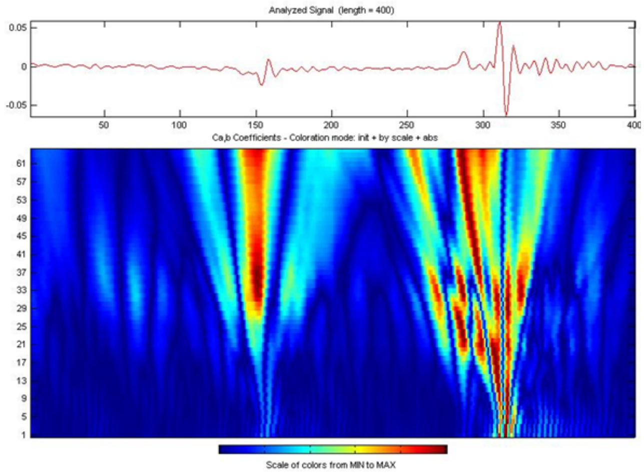


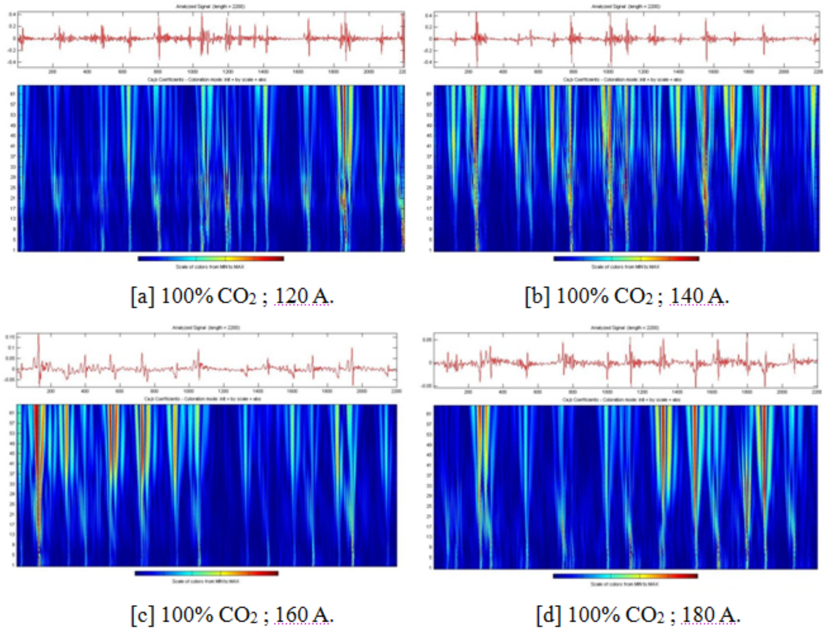
Figure 4. Acoustic data of short circuit transfer in 9 millisecond (above) and CWT time– scale view (below) obtained from welding by using 100% CO_2 and welding current of 120 A.

represents low magnitude scale. In this study, the phenomena of *C* magnitude relating with scale *a* and position *b* was analyzed. The signals *s(t)* in time domain as shown in Figure 4 shows two acoustic pulses where each pulse had different magnitude along scale axis. This type of acoustic wave represented short circuit metal transfer mode. The first small amplitude of the acoustic wave represented the possibility of electrode tip dipping into the weld pool and the arc was extinguished. The second higher amplitude of the acoustic signal represented the break-up of the molten electrode tip due to electromagnetic pinching force. Droplet transferred to weld pool and the arc re-ignited. This phenomenon has been confirmed by many previous studies. Usage of CWT analysis could give clearly view for metal transfer behavior.

Continuous wavelet transformation analysis in the time interval of 5 millisecond showing the uniformity visualization of short circuit transfer for 100% CO_2 and 84%Ar+2%O_2+14%CO_2 shielding gas were displayed in Figure 5 and 6, respectively. It can be clearly seen that color scales representing the transfer characteristic of 84%Ar+2%O_2+14%CO_2 shield gas gave clearly more uniform than that of 100% CO_2 shielding gas. This behavior was also affected significantly as welding current increased. It has been known and studied by many researchers that the rate of metal transfer increased as welding current increased. Graphical views of CWT analysis could give a clear view of the short circuit transfer behavior.

4. Experiment Results of Liquid Bridge Disruption Period

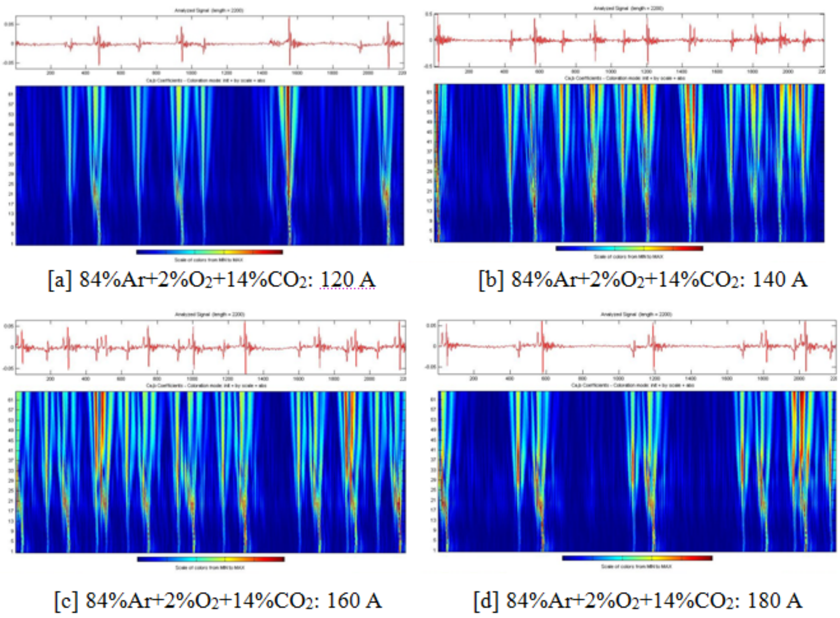
Acoustic data in time domain as shown in Figure 2 can also be used to measure the liquid bridge disruption period. The time between peak amplitude of electrode dipping to the weld pool and the peak amplitude of pinching of acoustic signal can be measured. Table 1 shows the results of liquid bridge disruption period by using a mean value and standard deviation. Shorter liquid bridge disruption period meant increasing of the number of droplet transfer as it was observed in CO_2 shielding gas. Larger standard deviation for CO_2 shield gas could be explained that the uniformity of short circuit transfer was not quite as stable as those of 84%Ar+2%O_2+14%CO_2 shielding gas. The liquid bridge disruption period of 84%Ar+2%O_2+14%CO_2 shielding gas was quite uniform although welding currents were increased. The effect of



[a] 100% CO_2 ; 120 A. [b] 100% CO_2 ; 140 A.

[c] 100% CO_2 ; 160 A. [d] 100% CO_2 ; 180 A.

Figure 5. Time-scale view of CWT for 100% CO_2 shielding gas with the electrode wire diameter of 1.2 mm carbon steel wire.



[a] 84%Ar+2%O_2+14%CO_2: 120 A [b] 84%Ar+2%O_2+14%CO_2: 140 A

[c] 84%Ar+2%O_2+14%CO_2: 160 A [d] 84%Ar+2%O_2+14%CO_2: 180 A

Figure 6. Time-scale view of CWT for 84%Ar+2%O_2+14%CO_2 shielding gas with the electrode wire diameter of 1.2 mm carbon steel wire.

liquid bridge disruption period at various welding currents and shielding gases of 100% CO_2 and 84%Ar+2%O_2+14%CO_2 was shown in Figure 7. It can be seen that welding currents significantly affected liquid bridge disruption period and its period variation. Increasing welding current resulted in decreasing of liquid bridge disruption period. For 100% CO_2, liquid bridge disruption period decreased as a function of welding current more rapidly than that of 84%Ar+2%O_2+14%CO_2 shielding gas. Since CO_2 shielding gas is an active gas, it violently decomposes in plasma regime resulting in a irregular metal transfer giving a lot of spatters. On the other hand, mixed shielding gases with argon rich can give more stable arc and generate much less spatters. Mixing of oxygen and carbon dioxide in argon gas could improve arc stability and promote more stable metal transfer due to the reduction of the surface tension of the molten tips. For 84%Ar+2%O_2+14%CO_2 shielding gas at high welding currents of 160 A and 180 A, short circuit transfer started having higher variation since it started going to transition area between short circuit mode and globular transfer mode. In this transition, both

Table 1. Mean and standard deviation of liquid bridge disruption period (unit in millisecond).

Welding Current (Amp)	100% CO_2		84%Ar+2%O_2+14%CO_2	
	Mean	Standard Deviation	Mean	Standard Deviation
120	3.016	0.679	2.509	0.248
140	2.298	0.706	2.353	0.350
160	2.055	0.628	2.242	0.497
180	1.405	0.467	2.295	0.523

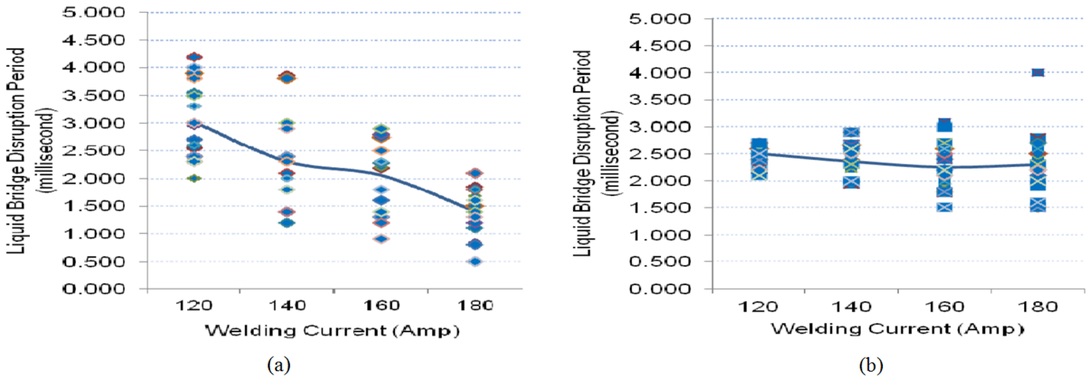


Figure 7. Liquid bridge disruption period (millisecond) of (a) 100%CO_2 shielding gas and (b) 84%Ar+2%O_2+14%CO_2 shielding gas as a function of welding currents.

short circuit and globular transfer might occur. Overall results from 84%Ar+2%O_2+14%CO_2 shielding gas could give much more stable short circuit transfer than that of 100% CO_2 shielding gas resulting in better control of short circuit transfer mode.

5. Conclusion

In this research, the effect of shielding gas composition on liquid bridge disruption period of short circuit transfer mode by using acoustic signal detection and wavelet transformation analysis was studied. Different shielding gases of 100% CO_2 and 84%Ar+2%O_2+14%CO_2 were chosen for studying of their characteristics. Contact tube-to-work distances (CTWD) was set at 15 mm. Carbon steel electrode, ER70S-6 (AWS A 5.18), with the diameter of 1.2 mm was used in this study. Acoustic signals obtained from the arc were used as a monitoring technique. Acoustic data of short circuit transfer was measured at various welding currents. The periods of liquid bridge disruption were observed and measured. It can be concluded that:

1) Liquid bridge disruption periods were observed from time domain and graphical plots obtained from wavelet transformation analysis can give clear understanding of short circuit transfer behavior. Larger standard deviation of disruption period in CO_2 shield gas than those of 84%Ar+2%O_2+14%CO_2 shielding gas could be explained that CO_2 is active gas which decomposed and ionized violently in the plasma arc and give less uniformity of short circuit transfer. Liquid bridge disruption period of 84%Ar+2%O_2+14%CO_2 shielding gas was quite uniform although welding currents were increased.

2) Uniformity of short circuit transfer can be visualized in time-scale view by using continuous wavelet transform.

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