International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-3, Issue-5,May 2017
ISSN: 2395-3470
www.ijseas.com

PENETRATION MANAGEMENT IN TUNGSTEN INERT GAS (TIG) WELDING OF THIN PLATES BY DETECTING OSCILLATION OF THE MOLTEN POOL

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Abstract

In automatic butt welding of relatively thin plates, it is important to control welding conditions in order to obtain a sound full penetration weld bead. Normally, it is difficult to obtain a full penetration weld, because the optimum welding conditions changes with groove conditions, such as gap of the groove, shape of the groove and so on. Recently, it has been reported that there is an intimate relationship between the oscillation of molten pool and penetration. That is to say, the frequency of a molten pool decreases drastically with transformation from partial penetration to full penetration. Accordingly, estimation of molten pool condition by detecting frequency of the molten pool is tried and furthermore the real–time control for full penetration welding is performed.

In this study the principle of detection of penetration, molten pool oscillation and control system of welding conditions according to the frequency of molten pool oscillation are investigated. As a result of experiment, it was seen that the control system constructed is effective for automatic TIG arc welding of thin plates.

Key words: *Welding, penetration control, Oscillation of molten pool, Frequency analysis*

1.0 Introduction

Recently, research and development for mechanization and robotization of welding processes has been carried out widely, and a number of intelligent welding robots which have sensors, such as arc- sensor and visual sensor, are developed. The adaptive control of welding conditions, in which the welding arc phenomena and the molten pool condition are observed during welding, welding conditions are controlled in real – time. For instance, a method to control the penetration of weld, in which the shape and dimensions of the molten pool are visually detected and welding conditions are controlled so as to keep them optimum, are proposed and the effectiveness is confirmed. However, the vision system in arc welding is not always reliable because of the high intensity light of welding arc. On the other hand, a relationship between the shape of the molten pool in welding and the peculiar frequency of its oscillation has been recently made clear. Accordingly a method to control the penetration in TIG arc welding was developed. In this study, the detection of the oscillation of the molten pool and control of penetration by monitoring the peculiar frequency are discussed.

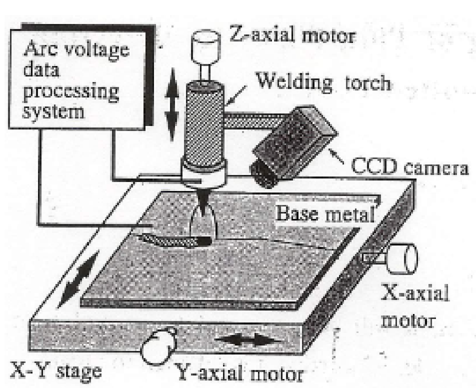


Fig.1: *Experimental arrangement of equipment*

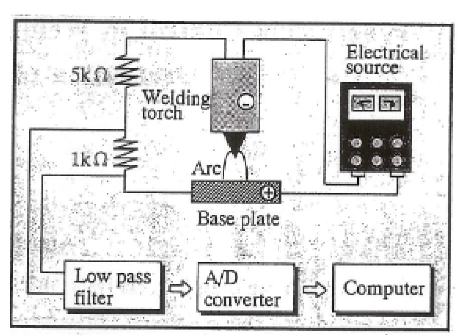


Fig.2: *Processing system of arc voltage data*

2.0 Experimental equipment and robot system

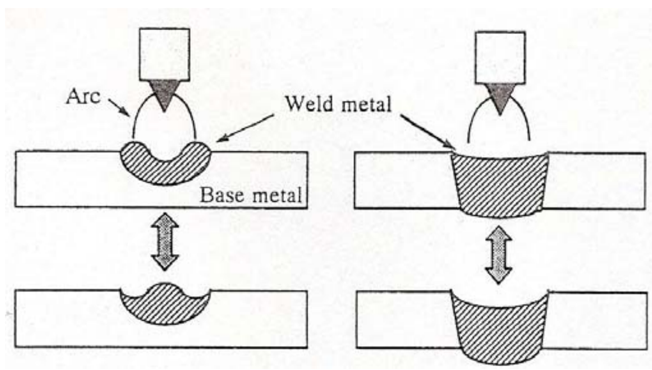
Figure 1: The power source, a pulse current type DC electrical source with drooping characteristics was used. In automatics seam tracking, a vision sensor was used for detecting welding line of joint. Figure 2 shows the arc

voltage detecting equipment by which the oscillation of molten pool is detected during welding. The arc voltage is decreased by a voltage reducer and then signal is taken into personal computer through a low pass filter and A/D converter. In the personal computer the frequency of the voltage oscillation is analyzed and the peculiar frequency of the molten pool is estimated.

3.0 Control of penetration of weld

3.1 Principle to estimate penetration of weld

In the arc welding process of low frequency pulse current, higher current and lower current is applied alternately. Generally, the lower current called base current is kept for relatively long duration after applying higher intensity of peak current in relatively short duration. The weld pool has a tendency to receive higher downward pressure during peak current because of stronger plasma flow. Later after the peak current molten pool returns upward again. As the result of this current change, the molten pool oscillates at the peculiar frequency depending on the shape and size of the pool. Recently, it has been known that, the oscillation mode of the molten pool changes between partial penetrations and full penetration the molten and full penetration as shown in figure 3(a & b).



(a) Partial penetration *(b) Full penetration*

***Figure 3**: Illustration of Oscillation modes of the molten pool*

The change of the oscillation mode and the frequency depends on the penetration of molten pool. Therefore, if the frequency of the molten pool can be detected in welding, it is also possible to detect the conditions of the molten pool during the welding process. Moreover, if the welding conditions can be controlled so as to keep the frequency of the molten pool constant, the stable automatic penetration welding will always be possible. In this study, construction of a welding control system to obtain a sound penetration weld was attempted.

3.2 Detection of arc voltage

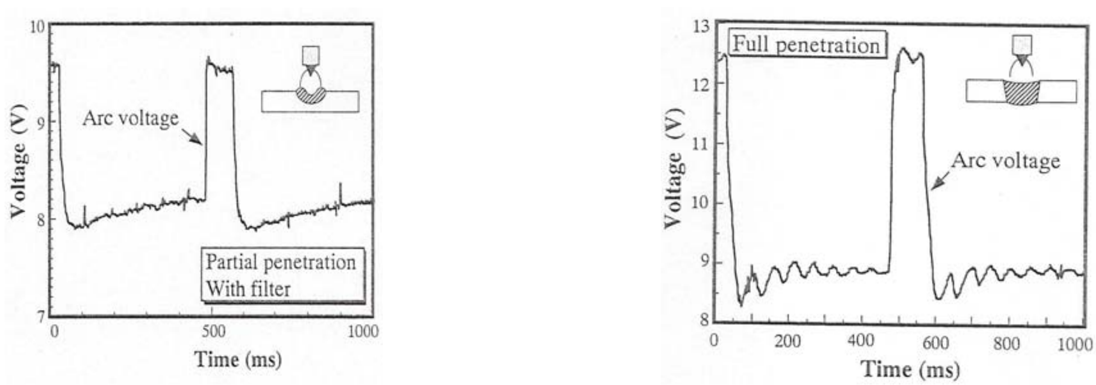
Oscillation of the molten pool was detected by arc voltage. However, the voltage signal obtained in arc welding involves considerable noise, and it is necessary to eliminate them in order to apply the signal to the frequency analysis. Accordingly the voltage detected was taken into computer through the low pass fitter as shown in figure 2. Figure 4 shows an oscillogram which reveals oscillation of arc voltage in partial penetration.

In this case, peak current of 300A, base current of 120A, pulse frequency of 2HZ, peak time of 100 ms and welding speed of 25 cm/min (4.17 mm/s) were used. In this experiment the base metals of stainless steel plates of 3 mm in thickness were used.

3.3 Change of arc voltage oscillation due to penetration mode.

In order to confirm the change of arc voltage oscillation due to the penetration of molten pool the welding speed was decreased to 16.7 cm/min and same experimental states above was performed. Figure 5 shows the experimental results, and it shows that the regular oscillation of arc voltage with frequency of about 30Hz is detected clearly. In this case, the mode of the molten pool was full penetration.

As a result of the welding experiment, a penetration of the weld with back bead width of about 4mm was obtained. From the figure, it is confirmed that the maximum amplitude of the oscillation is shown at the first oscillation just after the drop of peak current and the amplitude decrease gradually with time.



(a) *partial penetration* *(b) Full penetration*

Figure 4: Oscillation of arc Voltage

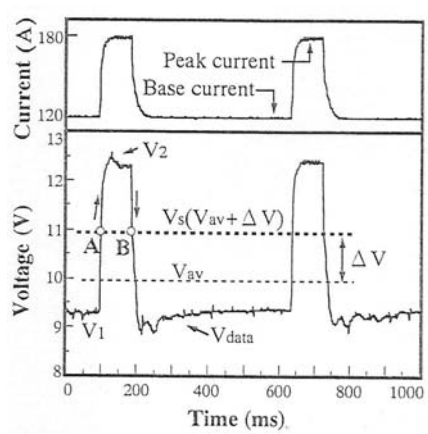


Figure 5*: Oscillation of arc current and voltage*

It shows that, the amplitude of the oscillation of molten pool decreases with time and it reflects to the voltage oscillation. From the experiment, it is confirmed that the method is effective to the monitoring of penetration of weld.

4.0 Arc voltage data processing

The oscillation of the molten pool is observed from voltage oscillation just after peak current. In order to get voltage data stably just after the current drop, the collection of voltage data begins when the arc voltage drops across the threshold value Vs. As shown in figure 6, the threshold voltage was obtained by adding the average voltage, V_{av}, and delta ΔV. The sampling of voltage, V data begins at point A. The number of sampling data was 128 and sampling speed was 500 HZ. An example of voltage data cut off by method mentioned above is shown in *figure 7*. The threshold voltage changes after each sampling.

4.1 Fourier transformation

In order to obtain a spectrum of the frequency of the voltage oscillation, fast Fourier transformation (FFT) method was applied to the voltage data obtained by above-mentioned method. As the data sampling cycle was 500Hz and sampling number 128, the sampling time was 256 ms. The calculated result by FFT is shown in *figure 8*. In this case the SUS304 base metal of 6 mm in thickness was used and welding conditions for full penetration was applied.

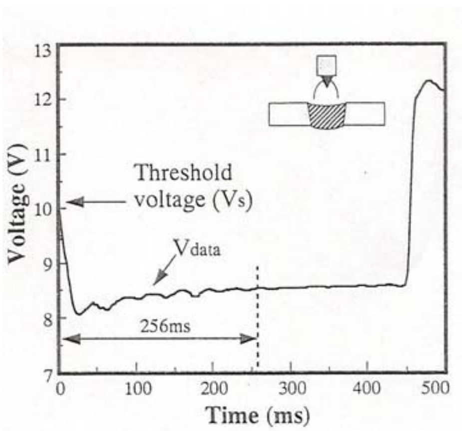


Fig. 7: *Examples of Voltage data*

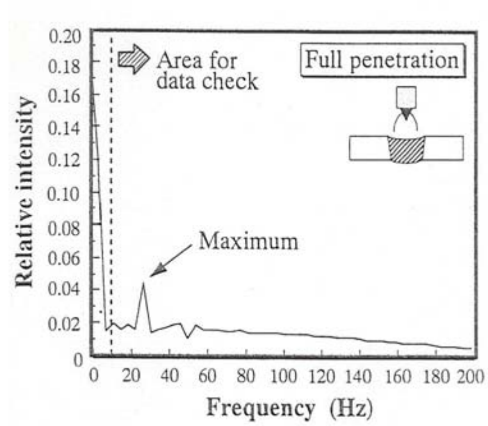


Fig. 8*: Spectrum of Oscillation of molten pool*

From the figure, it's confirmed that the peak value was observed at a frequency which seems to indicate the peculiar frequency of molten pool oscillation. Because the intensity of spectrum at a frequency less than 10HZ sometimes indicates high value, the data in frequency area higher that 10HZ is adopted in control of welding penetration. Therefore, in this case peculiar frequency is estimated to be 30HZ approximately.

In order to make the relationship between peculiar frequency and penetration in TIG welding of stainless steel plates, relationship between peculiar frequency and back bead width was experimentally investigated . The experimental results are shown in figure 9. In the figure the peculiar frequency decreases with increasing back bead width of 4 mm in control of welding penetration.

5.0 Result of penetration control

A control system of penetration based on the principle mentioned above was constructed and automatic TIG arc welding of stainless steel of 3 mm in thickness was performed. In this experiment, Welding speed was used to control the penetration of weld bead. The targeted peculiar frequency of molten pool was selected to 30Hz. As the welding conditions, peak current of 300A, base current of 120A, pulse frequency of 2Hz and peak time of 100ms were used. The initial welding speed was 27.8cm/min (4.6 mm/s).

Figure 10 shows the change of welding speed after beginning of the control. In the figure, the welding speed decreased rapidly with time just after start of welding, because the initial welding speed was too high. As the result of the control, the welding speed was decreased and the penetration increased gradually. After about 15s the welding speed was controlled at about 19cm/min, because the frequency reached to a stationary state of about 30Hz. As a result of this experiment, it is confirmed that the control system is effective in penetration control for welding penetration of thin plates.

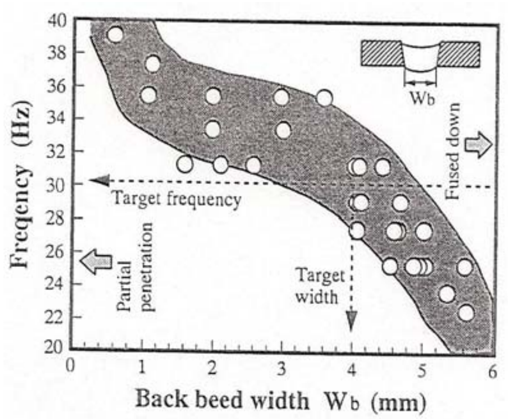


Fig. 9: Relationship back bead width and system frequency

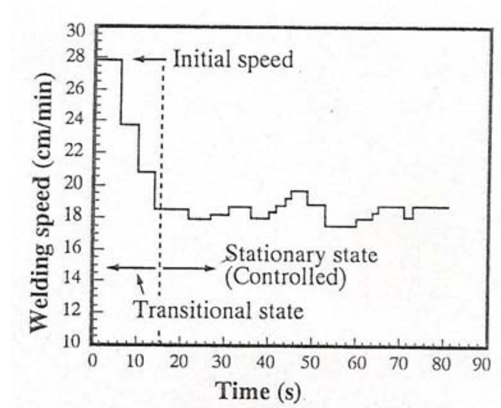


Fig 10: Results of welding experiments by control

6.0 Conclusion

Main results obtained from this experiment are summarized as follows:

- The penetration mode of molten pool can be estimated by detecting its peculiar frequency.
- A method to detect the molten pool oscillation by means of arc voltage oscillation was proposed and its effectiveness was confirmed.
- The spectrum analysis using fast Fourier transformation (FFT) is effective to detect peculiar frequency of molten metal.
- A system to control penetration welding using the principle to detect the peculiar frequency of molten pool was constructed and the effectiveness of the system was shown.

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