SUPPLEMENT TO THE *WELDING JOURNAL,* APRIL 2012
Sponsored by the American Welding Society and the Welding Research Council

Arc Characteristics in Pulse-GMA Welding with Acute Groove Angles

An arc sensor system was investigated for welding a V-groove joint with acute groove angles of 45 and 60 deg by considering the arc characteristics in pulsed GMA welding

BY R-H. KIM, G-D. CHOI, C-H. KIM, D-W. CHO, AND S-J. NA

ABSTRACT

This paper presents the experimental results of arc characteristics in pulsed GMA welding with acute groove angles of 45 and 60 deg. Electrical signals of current and voltage were measured, while the arc behavior was observed by using a high-speed camera, and their relations were investigated and analyzed to provide data that may be used for automatic joint tracking in future research. By understanding the arc characteristics, appropriate threshold current could be determined for electrode turning in a weaving-type arc sensor for pulsed GMA welding in acute groove angles.

Introduction

With automation of the welding process, a wide variety of sensors are used to detect and track the weld joint, and to monitor the welding phenomena. In particular, tactile, vision, and arc sensors are widely used for automatic weld joint tracking (Ref. 1). Among these sensors, the arc sensor is utilized in measuring the voltage and current of welding arcs and coaxially tracking the joints and monitoring weld quality. Various studies have been carried out, primarily on a DC welding power source for gas metal arc welding (GMAW) (Refs. 2–5). In more recent studies, a new algorithm has been applied to existing arc sensors. Ahn et al. utilized the changes in welding current by the contact tip-to-workpiece distance (CTWD) to more closely examine the arc sensors that are free from weaving (Ref. 4). Kim et al. tracked the weld joints by comparing the changing patterns of welding current, observed in weave welding, thereby obtaining the information on weld joints (Ref. 5).

Pulsed GMA welding was developed in 1960 to address the disadvantages of globular transfer and to take advantage of spray transfer. The most distinctive feature of this method is that it takes the form of a pulse that has the welding current consisting of peak and base current, and thus its average current has a lower value than the transition current of spray transfer. In this case, the base current retains the welding arc while the peak current is maintained for a sufficient period of time so that droplets can be transferred (Ref. 6). Each time the pulse current is applied, one droplet is transferred from the welding electrode to the base metal to maintain the control of metal transfer. Compared to the DC GMA welding power source, less heat input is applied to the base metal, and regular metal transfer enhances the quality of the weld joint (Ref. 7). Welding current values measured in the form of continuous wave (CW) are primarily used in the conventional, constant voltage type of DC GMA welding. Pulsed GMA welding, meanwhile, has a greater number of current-waveform parameters as it involves the peak current and base current (Ref. 8). The power source of pulsed GMAW is widely used in the form of constant current, constant voltage, and a combination of these two forms, while a synergic control and other methods are utilized to control the pulse waveform. For this reason, the use of an arc sensor is not feasible in the existing normal context. Previous studies have applied the arc sensors to certain types of welding power sources, capitalizing on the feature that the peak current or pulse period changes linearly with CTWD. However, little research has been done on the application of the arc sensor to various types of weld joint shapes (Ref. 9).

In order to achieve complete penetration of a thick plate, the root opening and groove angle must be adequately selected in the process of welding a butt joint. The deposited metal decreases and productivity increases when the groove angle becomes smaller, but the preceding of the weld pool results in weld defects such as incomplete penetration at the groove face. For this reason, a wide range of groove shapes is tailored to different welding conditions. When the groove joint is welded by weaving, the arc shape differs according to the groove angle and the self-regulation effect of the welding arc by the weaving speed and groove angle, thereby affecting the patterns of the welding signal.

Therefore, in an endeavor to identify the arc sensor characteristics for tracking weld joints in pulsed GMA welding, the groove angle and root opening for a V-groove joint were varied to perform weave welding, and the characteristics of the arc shape and current waveform were examined.

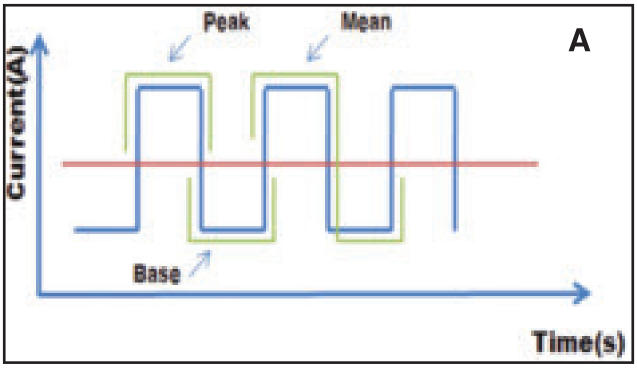
Experimental Setup

This study utilizes a biaxial stage to move the electrode and an inverter-type synergic pulse-type welding power source, for which an embedded microprocessor controls the pulse parameters. A hall sen-

R-H. KIM and G-D. CHOI are with Department of Welding Research, Industrial Research Institute, R&D division, Hyundai Heavy Industries, Jeonha-Dong, Dong-Gu, Ulsan, Republic of Korea. C-H. KIM is with Advanced Joining Technology Team, Songdo-Dong, Yeonsu-Gu, Incheon, Republic of Korea. D-W. CHO and S-J. NA (sjoona@kaist.ac.kr) *are with Department of Mechanical Engineering, KAIST, Daehak-ro, Yuseong-gu, Daejeon, Republic of Korea.*

KEYWORDS

GMAW-P
Acute Groove Angle
Arc Characteristics
Arc Sensor
V-Groove Joint



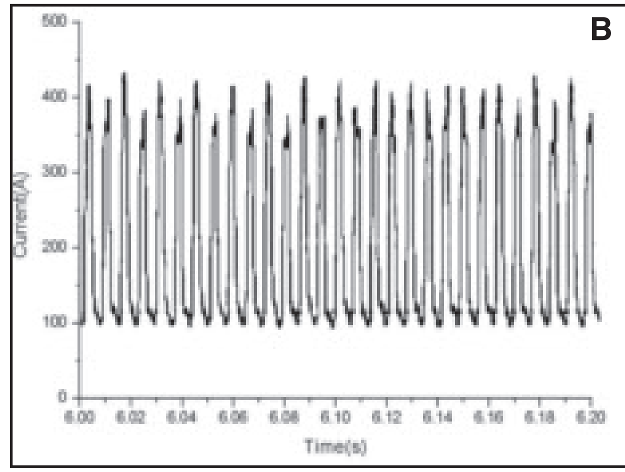


Fig. 1 — Typical shape of pulse signal. A — Types of welding current; B — measured pulse signal.

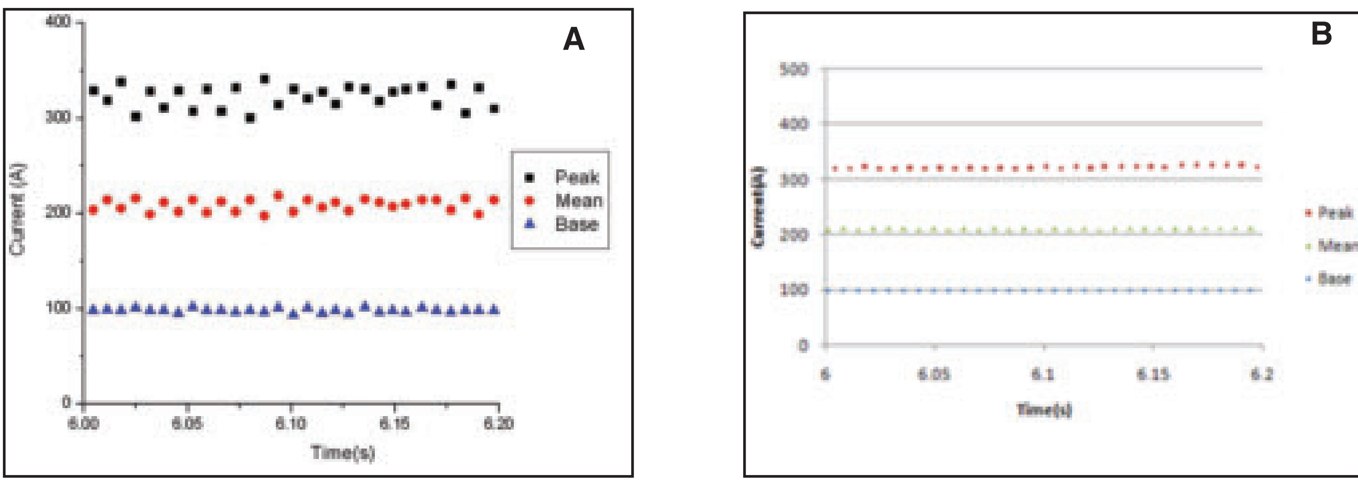


Fig. 2 — Various current signals of pulse GMAW. A — Separated pulse signal; B — moving averaged signal.

Table 1 — Welding Condition for Single-Sided Asymmetric Workpiece

Electrode	1.2 mm Diameter, YGW15
Shielding gas	100% argon, 30 L /min
Wire feed rate	6 m/min
Welding speed	8 mm/s

sor was used to measure the welding current, and an A/D converter was employed for data acquisition at 8 kHz. This study used a low-pass filter of 1 kHz, and mild steel as a specimen for the experiment. Images from a high-speed camera, obtained at 1000 frames per second, were synchronized with the welding current.

Signal Processing

As illustrated in Fig. 1, the measured welding current is classified into peak current if it is above the threshold current and base current if it is below the threshold current. Thus, the measured current waveforms, described in Fig. 1B, are divided into peak, average, and base current, as shown in Fig. 2A. The divided current signals, however, fluctuate considerably in each period, and therefore the moving average is used to stabilize them, as suggested in Fig. 2B. The moving average is obtained by putting the weight factor on 15 data. The equation for this calculation is provided as follows:

$$I_{wk} = \frac{\sum_{i=1}^{n}\left(w_i \times I_{k-i+1}\right)}{\sum_{i=1}^{n} w_i} \qquad (1)$$

where I_{wk} is the moving averaged welding current, w_i is a weight factor, n is the number of data, and I is the welding current.

Arc Characteristics on Single Bevel

Experimental Procedure

Before examining the arc characteristics in a V-groove joint, which is equivalent to an actual weld joint, various experiments on a single-bevel joint (Fig. 3A) were carried out under the welding conditions described in Table 1. This shape refers to a weld joint where the size of the root opening is sufficiently large, that is, where the size of the root opening does not affect the welding signals.

Arc Characteristics on Single Bevel

Figure 4 shows the changes in the peak, average, and base current that occur by increasing CTWD, and where the slope of straight lines denotes the sensitivity of the arc sensor. The level of sensitivity is the highest when the peak current is applied, and consequently, the peak current is utilized in identifying the arc characteristics. The shapes of the peak current — measured by the relative position of the welding electrode and the base metal — at a bevel angle of 22.5 deg are illustrated in Fig. 5. Here, the x-axis coordinate is defined such that it sets the edge of the root and groove surface at the reference point of 0 mm.

During the welding process, the peak current remains stable in the root area (Sec. I) and declines as the welding electrode approaches the edge (Sec. II); it subsequently increases severely (Sec. III) before its slope of augmentation decreases (Sec. IV). In order to carefully examine

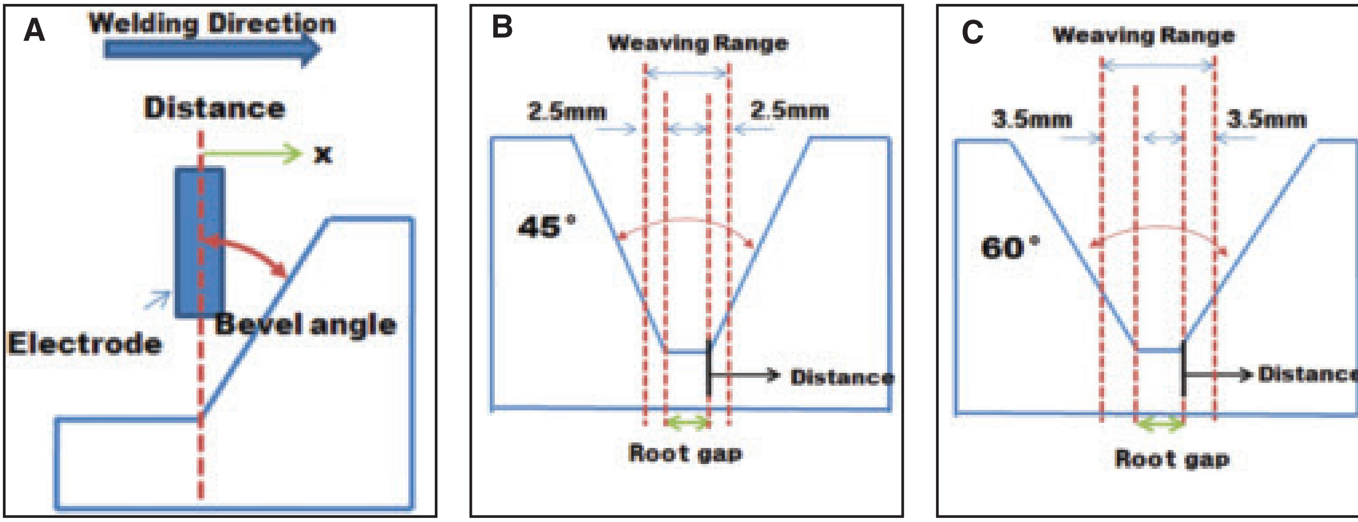


Fig. 3 — Configuration of single bevel and V-groove workpiece. A — Single bevel; B — groove angle of 45 deg; C — groove angle of 60 deg.

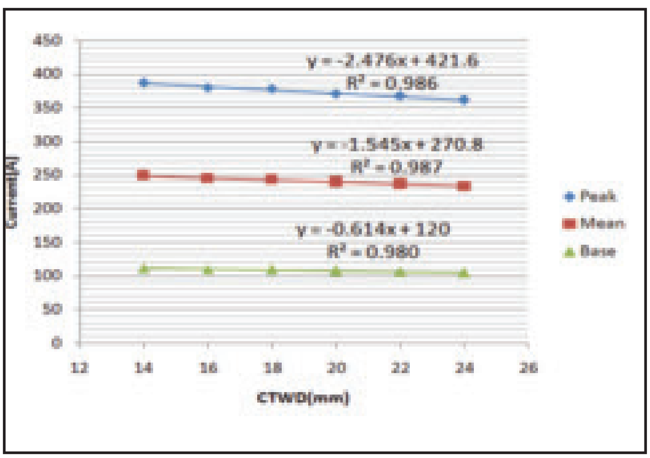


Fig. 4 — Arc sensor sensitivities for pulse parameters.

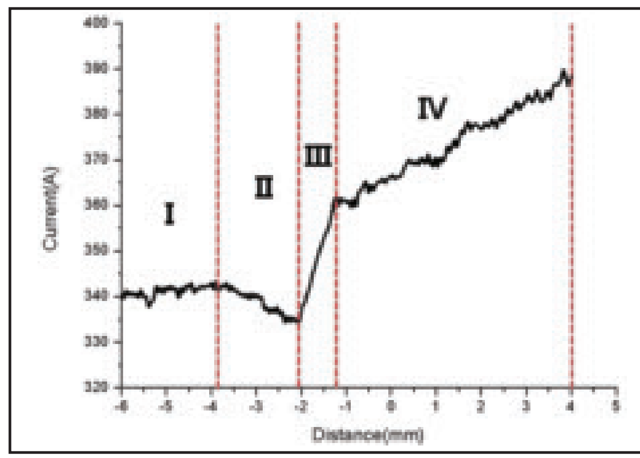


Fig. 5 — Peak currents for the bevel angle of 22.5 deg.

Table 2 — Welding Conditions for V-Groove

Electrode	1.2 mm Diameter, YGW15
Shielding gas	100% argon, 30 L/min
Wire feed rate	6 m/min
Weaving speed	8 mm/s
Welding speed	4 mm/s

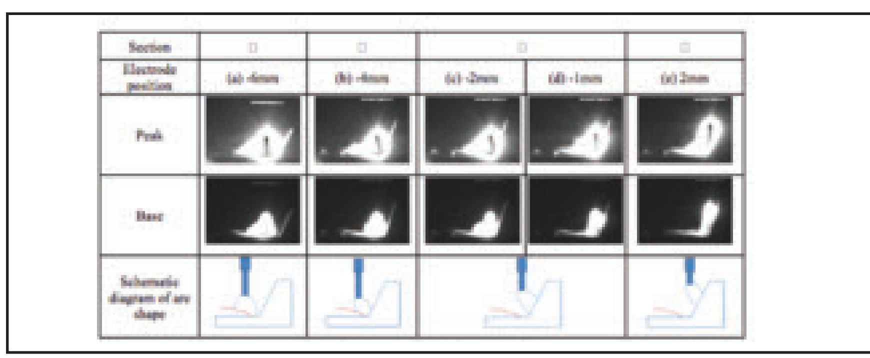


Fig. 6 — Arc shape and its schematic diagram for the bevel angle of 22. 5 deg. A — Section I, –6 mm; B — Section II, –4 mm; C — Section III, –2 mm; D — Section III, –1 mm; E — Section IV, 2 mm.

these phenomena, the peak current is divided into four sections, with the arc shapes of each interval obtained through high-speed imaging. Images from the positions of the peak current and base current are obtained through the touch position-synchronized imaging technique.

In Section I, the almost constant welding current is maintained in the root area, as in the case of bead-on-plate welding. This is due to the fact that the arc shape is hardly affected by the bevel, as shown in Fig. 6A. In Section II, the arc is slanted to the bevel face — as illustrated in Fig. 6B — as it nears the edge, increasing the CTWD and thereby reducing the welding current. With the movement of the welding electrode in Section III, the welding arc moves rapidly from the edge to the groove face, as shown in Fig. 6C and D. Thus, CTWD decreases drastically while the welding current increases rapidly. In the last section, Section IV, the position of the arc moves constantly alongside the groove face, and thus CTWD decreases and the welding current increases. For a bevel angle of 30 deg, the shape of the peak current measured for various positions of the welding electrode is shown in Fig. 7. As described in the picture, the welding current at a bevel angle of 30 deg demonstrates the similar interval-specific characteristics to those found at a bevel angle of 22.5 deg.

Figure 8 represents the variation of

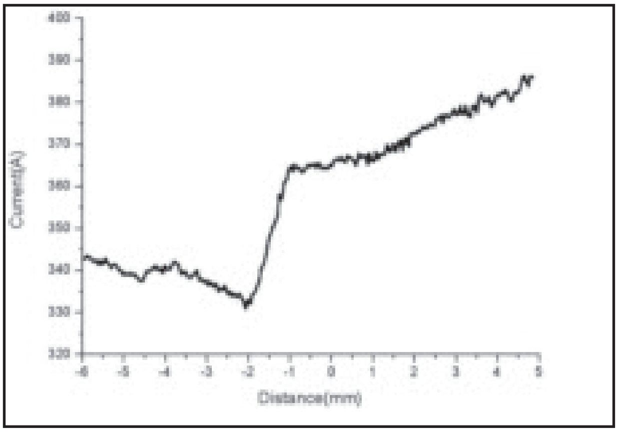


Fig. 7 — Peak currents for the bevel angle of 30 deg.

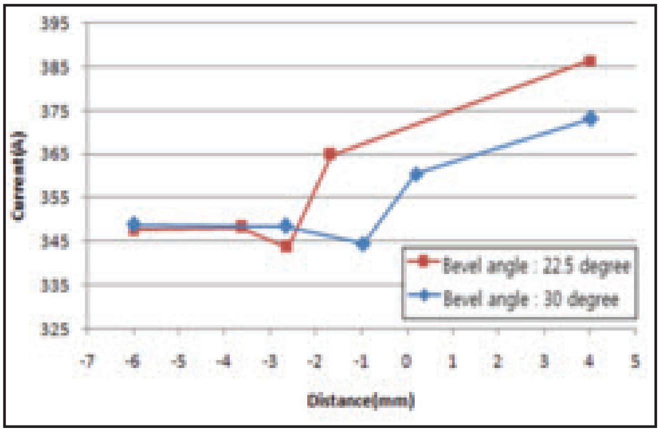
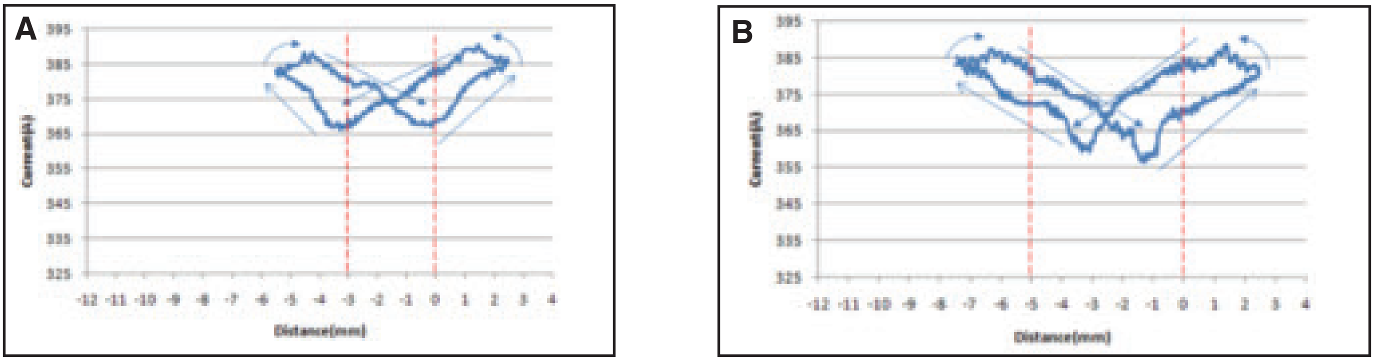


Fig. 8 — Characteristic peak current at various electrode positions for the bevel angles of 22.5 and 30 deg.



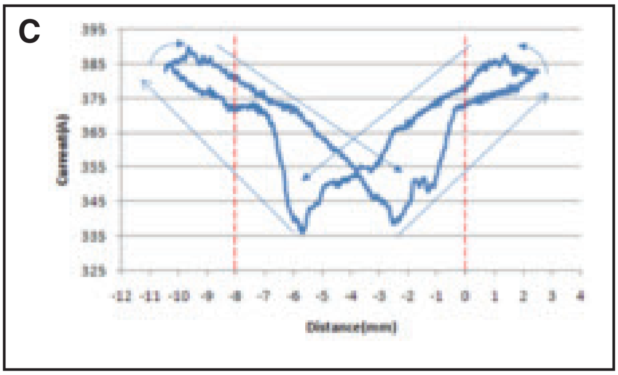


Fig. 9 — Peak current waveforms for 45-deg groove angle. A — 3-mm root opening; B — 5-mm root opening; C — 8-mm root opening.

average current values obtained through 10 experiments at bevel angles of 22.5 and 30 deg. At the bevel angle of 22.5 deg, the arc jumps to the groove face from a point of –2.5 mm from the edge, while at 30 deg, the arc jumps to the groove face from a point of –1 mm. Regarding the starting positions of Sections II and III, the position is closer to the edge at the bevel angle of 22.5 deg than that at 30 deg. In other words, the position of the arc's movement to the groove face is closer to the edge at the bevel angle of 30 deg. The reason for this is that the distance between the end of the welding electrode and groove face is larger at the bevel angle of 30 deg. The welding current remains almost unchanged and decreases slightly while the arc moves on the root opening to the corner between the root face and groove face, but increases drastically as the arc jumps to the groove face. After that, it increases rather gradually as the welding arc moves on the groove face.

Arc Characteristics of a V-Groove Joint

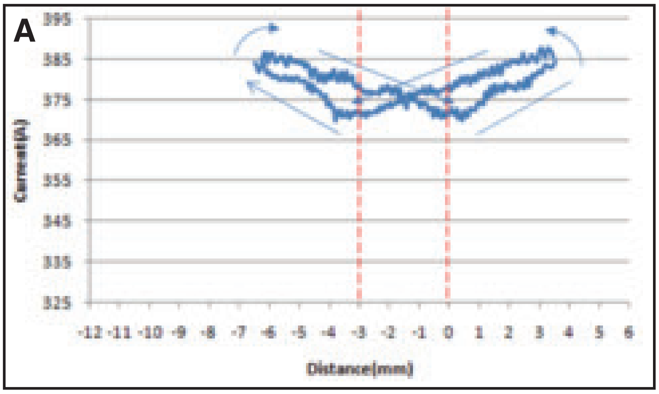
Experimental Procedure

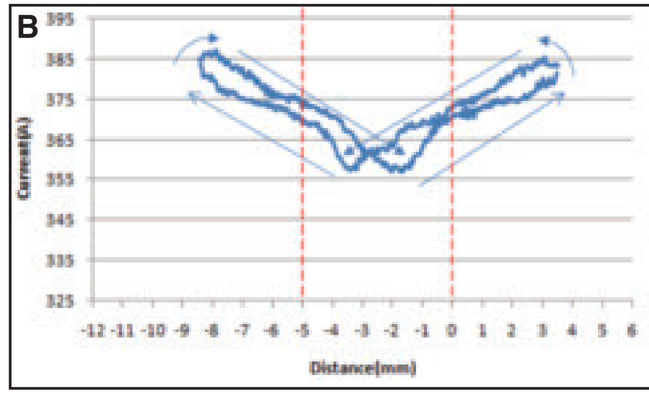
A V-groove joint with a root opening as specified in Fig. 3B and C was welded under the welding conditions described in Table 2 in order to measure the welding current. Experiments were conducted for each groove shape at root openings of 3, 5, and 8 mm. In order to establish the difference between the center and the end of weaving (i.e., CTWD) at 6 mm, the weaving was performed to where the welding electrode was at a distance of 2.5 mm from each edge for the groove angle of 45 deg, and the weaving was performed to where the welding electrode was 3.5 mm off each edge for the 60-deg groove angle.

Arc Characteristics at Groove Angles of 45 and 60 Deg

Figure 9 shows the results obtained with root openings of 3, 5, and 8 mm at a V-groove angle of 45 deg. Compared to the single bevel of Fig. 8, a rapid increase in welding current was not observed as the welding arc moved to the groove face in the V-groove joint. The welding current decreased and increased rather gradually. This is probably due to the fact that the transferred droplets flow into the root from the groove face as the welding proceeds, especially for a small root opening — Fig. 9A. For the large root opening, this effect disappeared, and the rapid change of welding current appeared again, as shown in Fig. 9B and C. This root filling with molten droplets decreased the average current value on the root face as the root opening increased.

The results of the current waveform obtained with root openings of 3, 5, and 8 mm for a groove angle of 60 deg are shown in Fig. 10. As the arc proceeded alongside the groove face, no rapid decrease in welding current was found, similar to the 45-deg groove angle. When the root opening was sufficiently large, as illustrated in Figs. 9C and 10C, different results were





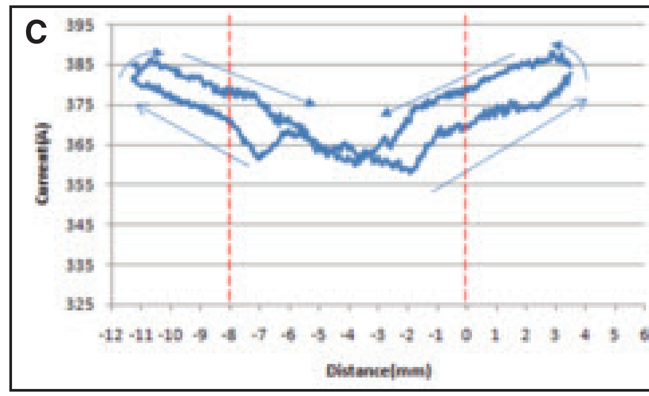


Fig. 10 — Peak current waveforms for 60-deg groove angle. A — 3-mm root opening; B — 5-mm root opening; C — 8-mm root opening.

found in terms of the amplitude of the current waveform. This can be explained in-conjunction with the position of the characteristic point by the bevel angle, as mentioned in Fig. 8. In other words, the position of the characteristic point nears the edge when the bevel angle or the groove angle is greater, lessening the previously sharp change in arc length, and thereby reducing the extent of welding current change.

The welding current waveforms observed when the arc moved up along the groove face are quite different from those observed when it moved down along the groove face for all the cases treated. This is probably due to the fact that the transfer of filler metal during the moving up process of the arc has made the groove face higher than when the arc moved down along the groove face.

The arc characteristics on the V groove can be applied to the joint tracking algorithm in future works. The first characteristic is when the section where the welding current sharply increases because of the arc jumping to the groove face, which should be ignored by setting a proper threshold current. The second is when the welding gun turns back at the highest point to the opposite groove face, the welding current increases for a short period from the groove face heightening effect where the nominal CTWD is getting longer, as both ends of the waveforms in Figs. 9 and 10 show. The third is the welding current waveforms observed as the arc moved up along the groove face are quite different from those observed when it moved down along the groove face. The threshold current for electrode turning in automatic joint tracking is chosen as 380 A in all cases in Figs. 9 and 10.

Conclusions

The goal of this investigation was to identify the arc characteristics at a V-groove joint with acute groove angles, which may be utilized as basic data for automatic weld joint tracking. The following phenomena were observed in the welding arc depending on the type of joint geometry:

1) As the welding proceeds from the root to the groove face, the welding arc moves toward the edge of the V groove and reduces the welding current. With the welding arc moving to the groove face, a sharp increase in welding current is observed. The arc then moves alongside the groove face and the welding current increases gradually.

2) As the welding progresses from the groove face to the root, no rapid movement of the welding arc is observed, owing to the consequence of the molten pool in the root opening.

3) A rapid movement of the arc is observed at a small groove angle where the distance between the welding electrode and the groove face is relatively small.

4) By understanding the arc characteristics, an adaptive algorithm for weld weaving may be successfully applied to automatic joint tracking in future works.

Acknowledgment

Support by the Brain Korea 21 Project and the Ministry of Knowledge and Economy is gratefully acknowledged.

References

1. Nomura, H. 1994. *Sensors and Control Systems in Arc Welding*. pp. 1–7, London, Champman & Hall, Inc.

2. Kim, J. W., and Na, S. J. 1991. A study on an arc sensor for gas metal arc welding of horizontal fillets. *Welding Journal* 70(8): 216-s to 221-s.

3. Kim, J. W. 1991. A study on the analysis of weld pool convection and seam tracking by considering the arc length characteristics in GMA welding, KAIST, doctoral thesis.

4. Ahn, J. H., and Kim, J. W. 1998. A study on the weavingless arc sensor system in GMA welding (1) — Implementation of weld seam tracking algorithm. *Journal of the Korean Welding and Joining Society*. 16(3): 44–54.

5. Kim, Y. J., Rhee, S. H., and Um, K. W. 1998. A study of seam tracking by arc sensor using current area difference method. *Journal of the Korean Welding and Joining Society* 6(3): 44–54.

6. Wu, C. S., Chen, M. A., and Lu, Y. F. 2005. Effect of current waveforms on metal transfer in pulsed gas metal arc welding. *Measurement Science & Technology* 16(12): 2459 to 2465.

7. Norrish, J. 1992. *Advanced Welding Processes*. Bristol, Institute of Physics Publishing.

8. Palani, P. K., and Murugan, N. 2006. Selection of parameters of pulsed current gas metal arc welding. *Journal of Materials Processing Technology* 172(1): 1–10.

9. Shen, H. 2003. Seam position detection in pulsed gas metal arc welding. University of Wollongong, Master's thesis.