366 Journal of Electrical Engineering & Technology, Vol. 2, No. 3, pp. 366~372, 2007

Characteristics of Pulse MIG Arc Welding with a Wire Melting Rate Change by Current Polarity Effect

Tae-Jin Kim†, Jong-Pil Lee*, Byung-Duk Min*, Dong-Wook Yoo* and Cheul-U Kim**

Abstract – Joining thin aluminum alloy is difficult using most welding techniques. Many of the problems are associated with burn-through by the high heat input. Common welding techniques are TIG (Tungsten Inert Gas), MIG (Metal Inert Gas), and PULSE-MIG welding. The method provides more control of the heat balance in the welding arc by taking advantage of the different arc characteristics obtained with each of the two polarities. In this paper, we proposed a new welding method by control DSP 320C32, and the characteristic and experiment result-voltage, current, welding bead, and penetrations by this method are presented.

Keywoods: Pulse MIG, Arc welding, Current polarity, Thin aluminum welding, Penetration

1. Introduction

Aluminum and its alloy possess many beneficial characteristics such as lightweight, high strength, corrosion- resistance, and good recycling properties, all of which allows them to be widely used in related fields. Especially, they have been widely applied not only in the fields of high-speed railway, subway, tanks of LNG vessels, and architecture, but also those automotive industries that are aimed at reducing weight by developing an aluminum engine and chassis.

Aluminum welding, such as shown in Fig. 1, is the main current of TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas) welding that use an inert gas to prevent oxidation in welding.

In the case of the TIG welding, the arc is very stable, and it shows a good aesthetic weld bead because the melted metal is not directly interacted with the welding rod. However, it has a problem of low productivity due to the difficulties of the increment of traveling speed and automation of the welding process.

In the case of a high current, MIG welding is mainly applied to the welding of a semi-infinite thick plate with the thickness over 5mm due to the deep penetration that is caused by the welding of DCEP (Direct Current Electrode Positive) polarity in the case of the high current MIG welding. However, a burn-through is caused by the extremely deep penetration if this welding is applied immediately for the thin aluminum plate having a thickness of about 1~2mm.

Furthermore, there are frequent short-circuits between the wire, the base material, and the unstable arc when the low current and voltage are applied to prevent the burn-through due to the shortened length of the arc. It becomes too difficult for the practical uses of the welding.

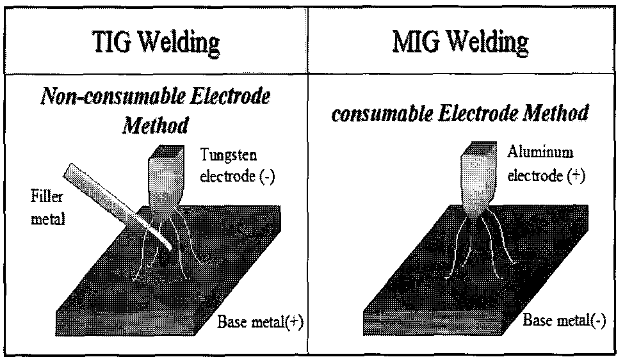


Fig. 1. Comparison between TIG and MIG welding

This study proposes a technology to accomplish the minimization of burn-through for the thin plate welding having thickness of about 1~2mm by controlling the depth of penetration with the DCEN (Direct Current Electrode Negative) polarity variable ratio of 0~60% of the output. This not only permits the utmost possible assembly tolerance but also performs low spatter and rapid welding by implementing the pulse MIG welding algorithm using the method of one pulse-one droplet that allows exact metal transfer by the synchronization of the instant pulse current as the control of the output waveform of a welding machine.

---

† Corresponding Author: Power Conversion & System for RES Group, Korea Electro- technology Research Institute, Changwon, 641-600, Korea (tjkim@keri.re.kr)

* Power Conversion & System for RES Group, Korea Electro- technology Research Institute, Changwon, 641-600, Korea (jplee@keri.re.kr, bdmin@keri.re.kr, dwryoo@keri.re.kr)

** Dept. of Elec. Eng., Pusan Nat. Univ., Pusan 609-735, Korea (e-mail: kimcu@pusan.ac.kr)

Received 22 December, 2006 ; Accepted 10 April, 2007

2. Pulse mig welding for thin aluminum

2.1 Problems with Al welding

The high current MIG welding, which works very simply for automation and for increasing the quality while productivity is increased, is applied for the welding of an Al semi-infinite thick plate. However, the TIG welding has been used for the welding of Al thin plates and it has demonstrated the following problems.

① At the commencement of the arc emission of TIG welding, the high frequency radiation noise is quite severe and will affect the adjacent devices frequently and fatally, such as in the case of a computer or robot.
② In the case of high speed welding with high current, it essentially demonstrates very low productivity due to the production of humping bead.
③ Automatic production is difficult because the tungsten electrode will be continually controlled during the welding, and the workers will have to make an effort to change the electrode.

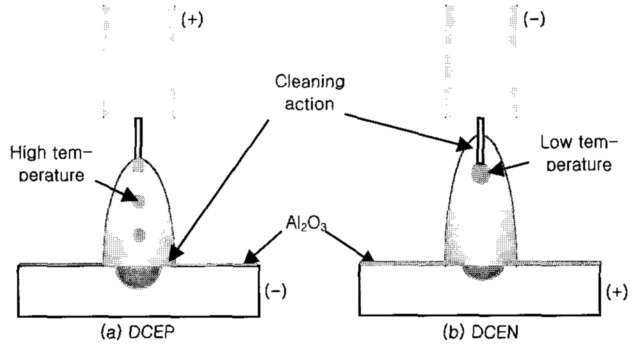
In addition, it is required to develop an AC pulse MIG welding machine by controlling the polarity ratio that presents the arc stability and reduces the spatter while it controls the penetration in order to permit the large assembly tolerance as well as solving the problem of penetration for the thin plate. Here, the required conditions for the welding are summarized as follows.

① A spray transfer mode to prevent spatter production.
② A reduction of heat input to prevent penetration of the thin plate.
③ The elimination of oxidation coating using the arc of reverse current in the welding of metals, which includes an oxidation coating, such as aluminum, magnesium, or other metals.

2.2 Definition of the characteristics of polarity and polarity ratio

Fig. 2 presents welding drop characteristics DCEP and DCEN. As indicated in Table 1, the polarity effect in gas metal arc welding of DCEP and DCEN is different.

The voltage drop of the arc can be categorized by three large parts, which are the positive, negative, and arc voltage drop. Here, the positive voltage drop is about 1 ~ 10 volts, and the negative voltage drop is about 10 ~ 20 volts. In addition, the current density shows the difference followed by the levels of voltage drop, and the general current densities for each polarity are as follows.



(a) DCEP (b) DCEN

Fig. 2. Welding Drop Characteristics of DCEP and DCEN

Table 1. Polarity effect in Gas metal arc welding

Polarity	DCEP	DCEN
Current density	10^2 ~ 10^5 A/cm$_2$	10^6 ~ 4×10^8A/cm^2
Voltage drop	1 ~ 10V	10 ~ 20V
Arc stability	Stable	Unstable
Melting rate	Low	High
Temperature	High	Low
Penetration	Deep	Shallow

Moreover, the negative spot is not fixed as the positive spot and shows a property that is irregularly and rapidly moved through the surface of a negative plate. In addition, the arc cannot be focused at the end of the wire and is moved to the far back of the wire from the end of the wire. Therefore, it is demonstrated that a part of the end of the wire can be surrounded by the arc as an outward look, so that the melting speed of the wire is faster than that of DCEP. However, the arc is unstable, and as a result, the temperature of the metal is lowered.

As presented in Fig. 3, the waveform of AC pulse is periodically repeated by DCEP and DCEN, and the wire melting speed and heat input can be controlled by applying the En-polarity ratio defined as expressed in Eq. (1).

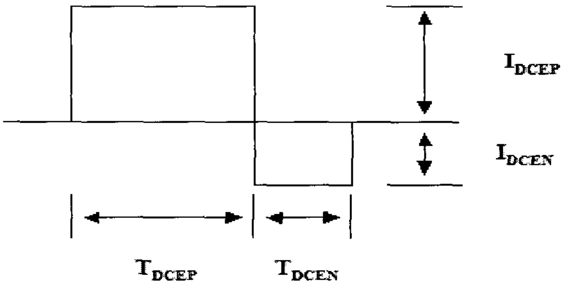


Fig. 3. Definition of the En-ratio

I_{DCEN}: average current of the DCEN
I_{DCEP}: average current of the DCEP
T_{DCEN}: time for the DCEN
T_{DCEP}: time for the DCEP

$$EN-ratio=\frac{I_{DCEN}\times T_{DCEN}}{I_{DCEP}\times T_{DCEP}+I_{DCEN}\times T_{DCEN}}\times 100(\%) \quad (1)$$

2.3 Welding algorithms for the patterns of welding current

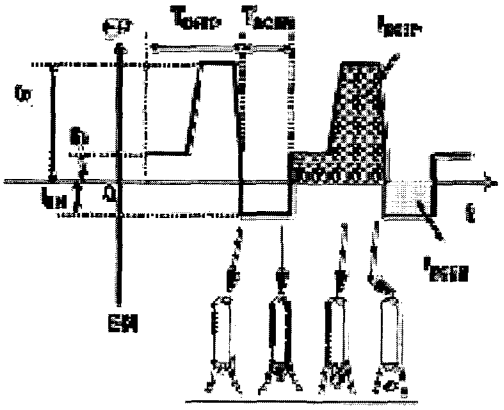


Fig. 4. Proposed algorithm of the pulse MIG welding

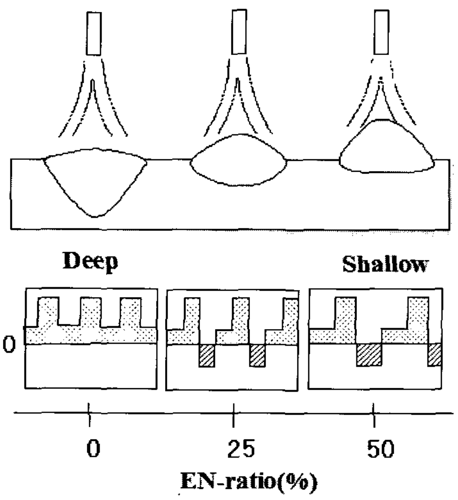


Fig. 5. Relationship between the shape penetration and the En-ratio

Fig. 4 shows pulse MIG welding algorithm using the method of one pulse-one droplet that makes an exact metal transfer by the synchronization of the instant pulse current as the output waveform control of the welding machine in order to perform the high speed welding of a thin Al plate. It also presents the implementation of low spatter and high speed welding by using the constant metal transfer.

Fig. 5 presents an outline of the technology that attempts to accomplish the minimization of burn-through for the thin plate welding with thickness of about 1~2mm by controlling the depth of penetration with the DCEN (Direct Current Electrode Negative) polarity variable ratio of 0~60% of the output and permits the utmost possible assembly tolerance of the base material.

3. Welding system for thin aluminum

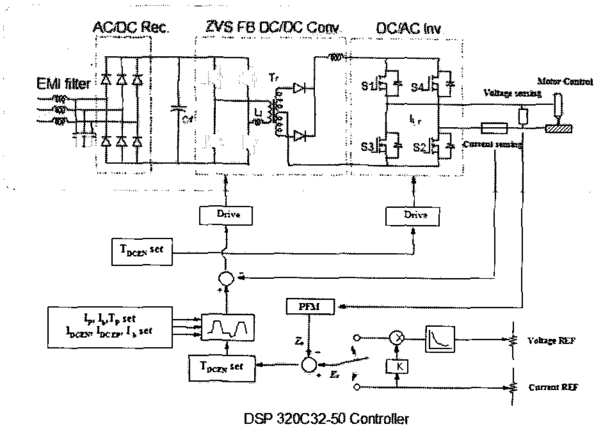


Fig. 6. The pulse MIG welding system for thin Al

The main and control circuits for the high speed welding of a thin Al plate are illustrated in Fig. 6. The input voltage of 3-phase AC 220V, 60Hz can be converted into the smooth DC voltage of 300V through a diode rectifier, and then the DC voltage is transferred to the insulated secondary side of the high-frequency transformer followed by the 20kHz switching full bridge DC/DC converter. At this time, the magnetic flux of the coil can be increased by the alternative coiling of the primary and secondary side of the transformer during transformer production in order to maximize the efficiency of energy transmission. In addition, the output of the secondary side of the transformer is formed as a kind of center tap and is rectified by using a diode, allowing it to become a low-frequency inverter (10Hz~200Hz).

Fig. 7 is the current waveform control for constant arc length L. In the case of A welding bead shape and penetration depth, spatter is not independent of arc length L. If arc length L is not constant during arc welding, the welding is not good. In this study, the arc length L is controlled base current (I_b), but pulsed current waveform is fixed (about 300A, 1~2ms). In this welding, the DCEN period T_{EN} is constant and so is the En-ratio. Thus, I_{EN} cannot be constant in this welding droplet for a pulsed period.

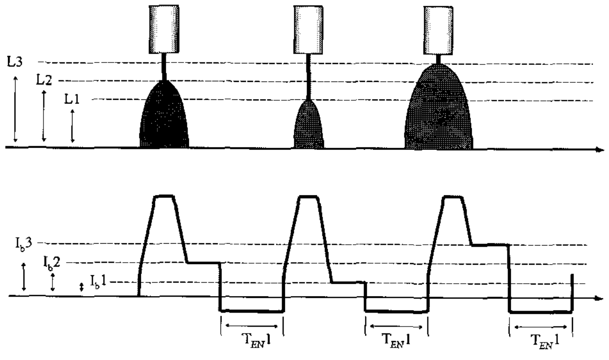
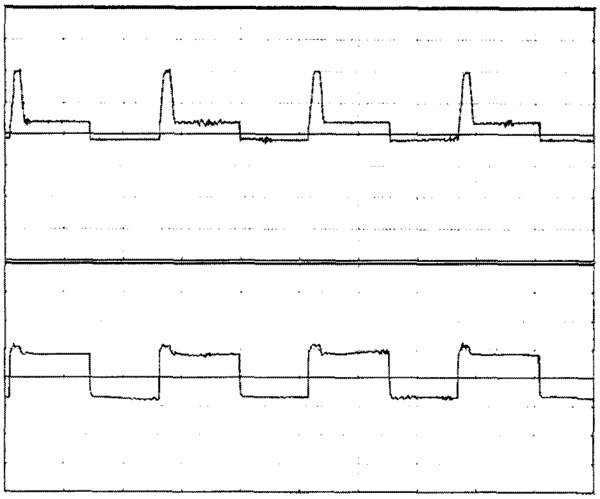
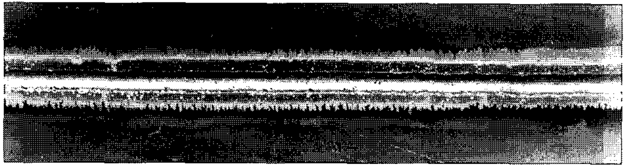


Fig. 7. Current waveform control for constant arc length

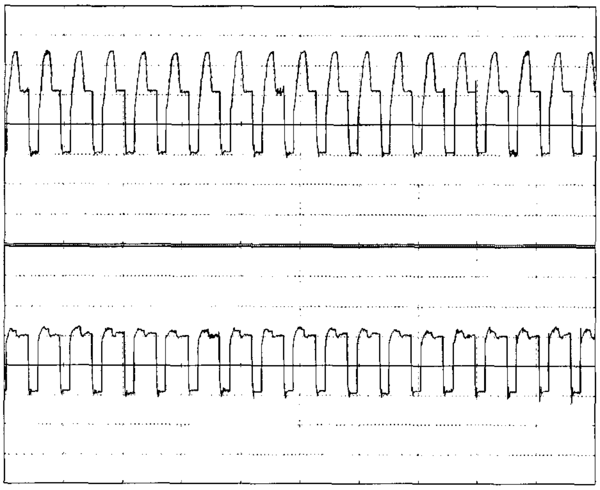


Welding current (up: 150A/div, 10msec/div), voltage (down: 20V/div, 10msec/div)

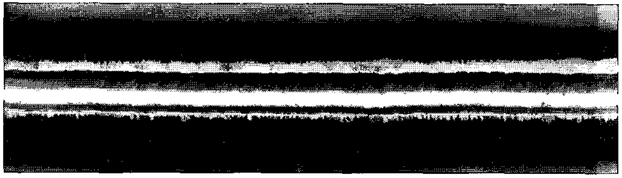


b) Bead shape on the top view

Fig. 8. Waveform of the voltage & current of average welding voltage, current: 15.5V, 56.5A, En-ratio 20%, traveling speed: 120cm/min



Welding current (up: 150A/div, 10msec/div), voltage (down: 20V/div, 10msec/div)



b) Bead shape on the top view

Fig. 9. Waveform of the voltage & current of average welding voltage, current: 20.5V, 202.5A, En-ratio: 20%, traveling speed: 120cm/min

4. Evaluation of the output characteristics of developed pulse MIG welding machine

The welding machine with the designed AC pulsed waveform is used to evaluate the output characteristics of the waveform where the Al plate (Al 5052, Length: 300mm, Width: 50mm, Thickness: 1.2mm, 3mm, 5mm) and shield gas (100% Ar) are used in the test, and the traveling speed is 120cm/min with the wire of A5356 (φ1.2). The welding is evaluated by the bead on the plate and lap-joint welding. The currents are applied by the step of 20A up to 50 ˜ 150A, and the En-ratios are increased by the step of 10% up to 10 ˜ 40%. In addition, the root gaps are 0mm, 0.5mm, 1mm, and 1.5mm. The applied current is 60A, and the En-ratio is 20% in the case of the lap-joint welding.

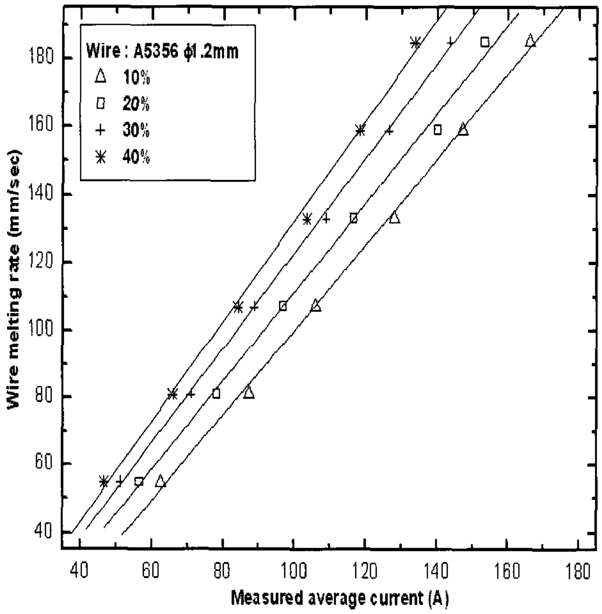


Fig. 10. Relationship between the wire melting rate and the En-ratio

5. Results and evaluations

Fig. 8 depicts the waveforms and bead shape on the top view average welding voltage and current of 15.5V, 56.5A, En-ratio of 20%, and traveling speed of 120cm/min. Fig. 9 shows waveforms and bead shape on the top view average welding voltage and current of 20.5V, 202.5A, En-ratio of 20%, and traveling speed of 120cm/min. Fig. 10 presents the wire melting speed for the En-ratio. It is shown that the wire melting speed is increased by the increment of the En-ratio under the same measurement current. Fig. 11 presents the relationship between the En-ratio and penetration depth, bead width, and bead height. It can be seen that the higher the En-ratio is, the narrower and higher the shape of the bead is. Fig. 12 shows a microscopic picture of the cross-section of the welding sample (3mm) that is welded by the bead on plate method using the developed welding machine. Fig. 13 illustrates shapes of the bead on the top view by the En-ratio. As a result, the penetration is shallow, the width of the bead is narrowed, and the height of reinforcement is increased by the increment of the En-ratio at the same current and traveling speed. Fig. 14 presents a microscopic picture of the cross-section of lap-joint welding used by the base metal with a thickness of 1.2mm. The burn-through does not occur at the gap of 0mm for both En-ratios 0% and 20% but occurs at the gap of 0.5mm, 1mm, and 1.5mm for the En-ratio of 0% That is, the burn-through occurs for the DCEP, and good welding is acquired at the En-ratio of 20% without any penetration. Fig. 15 is a picture of the prototype for the designed system.

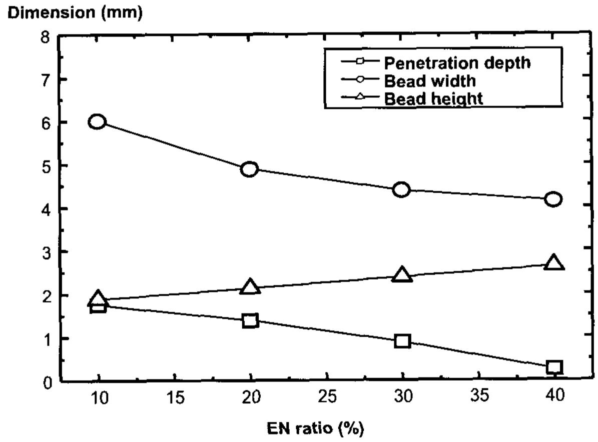
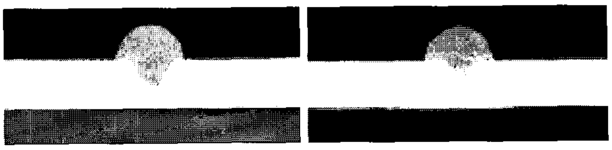


Fig. 11. Relationship between the En-ratio and bead shape

Table 2. DEVICES FOR THE WELDING SYSTEM

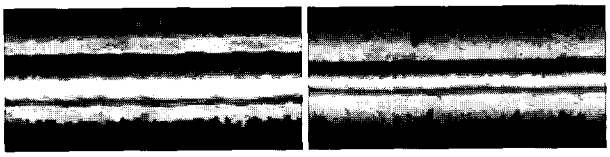
Items	Welding power supply
Input Voltage	AC 220V 3-phase 60Hz
Device	Primary converter: IGBT(2NBI300N-60) : 600V, 300A Secondary converter: IGBT(CM600-HA-5F):250V, 600A
Switching Fr.	20kHz
Transformer	Ferrite core, EEtype 1set 14 : 4
Leak Inductance	4.5μH (20kHz)
Output Current (Peak Current)	60-250A(320A)
Output Voltage (No-Load)	16-40V(100V)
Output Diode	FRD (MEO 500-06 DA) : 600V, 500A

a) En-ratio = 10% b) En-ratio =20%



c) En-ratio = 30% d) En-ratio =40%

Fig. 12. Shapes of the bead cross section by the En-ratio



a) En-ratio =10% b) En-ratio =20%

Fig. 13. Shapes of the bead on the top view by the En-ratio

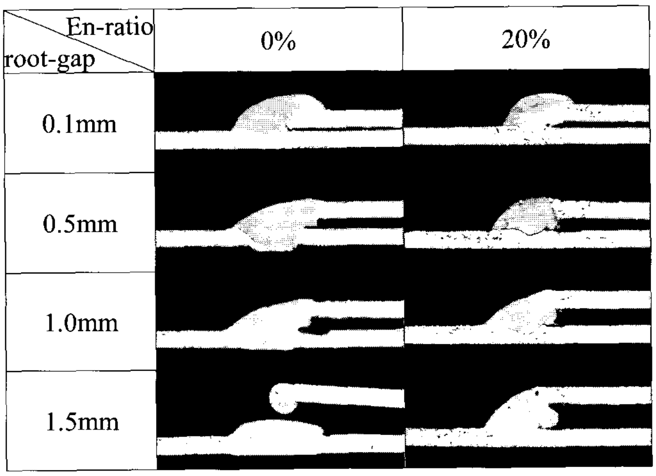


Fig. 14. Shapes of the lap-joint bead cross section by the root-gap changes

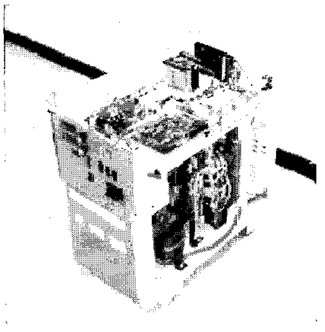


Fig. 15. Prototype of pulse MIG welding power supply

6. Conclusions

This study shows the results according to the test of the characteristics of pulse MIG welding waveform that is periodically repeated by DCEP and DCEN to control the wire melting speed and heat input for the changes of polarity in order to apply for the thin Al plate welding as follows.

1) A good bead appearance of welding is acquired for the high speed welding of a thin Al plate without any penetration.

2) The wire melting speed is increased and the heat input is decreased by the increment of the En-ratio at the same current settings. It can be verified by the cross-section shapes of the bead of welding.

3) In case of the gap existing for the lap-joint welding of thin plate, good welding can be acquired by the increment of En-ratio without any penetration.

References

[1] B. Altshuller, “A guide to GMA welding of aluminum”, Welding Journal, vol. 77, no. 9, pp. 83-90, Aug. 1998.

[2] H. Ohada, C. Ueha and K. Agatsuma, “Innovative Vehicle - the train Hitachi review”, Hitachi review, vol. 50, no. 4, pp. 130-133, Apr. 2001.

[3] L. A. Guitterez, G. Neye and E. Zschech, “Microstructure hardness profile and tensile strength in welds of aa6013 T6 extrusion”, Welding Journal, vol. 75, no. 3, pp. 115-121, Mar. 1996.

[4] U. Tomoyuki, “MIG welding machine of aluminum and its Alloy”, Journal of the Japan Welding Society, vol. 30, no. 3, pp. 39-44, Mar. 2001.

[5] J. H. Choi, Y. S. Kim, and H. J. Kim, “Characteristics of Metal Transfer of GMAW shielded by CO2 gas”, Journal of Korea Welding Society, vol. 16, no. 3, pp. 9-17, Mar. 1998.

[6] J. A. Johnson, N. M. Carlson, H. B. Smartt and D. E. Clark, “ Process control of GMAW”, Welding Journal, vol. 70, no. 4, pp. 91-99, Apr. 1991.

[7] J. H. Waszink and M. J. Piena, “Experimental investigation of drop detachment and drop velocity in GMAW”, Welding Journal, vol. 65, no. 11, pp. 289-298, Nov. 1986

[8] T. Mita, A. Sakabe and T. Yokoo, “Quantitative estimates of Arc stability for CO2 gas shielded arc welding”, Welding Journal, vol. 67, no. 2, pp. 152-159, Feb. 1988.

[9] S. Ueguri, K. Hara and H. Komura, “Study of metal transfer in pulsed GMA welding”, Welding Journal, vol. 64, no. 8, pp 242-250, Aug. 1985.

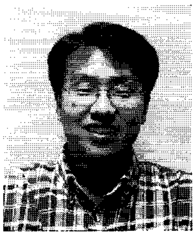
[10] B. Ogunbiyi and J. norrish, “GMAW metal transfer and arc stability assessment using monitoring index”, in Proc. Computer Technology in Welding, vol. 2, pp. 103-108, Feb. 1996.

[11] Masao Ushio: “Improve Sheet Metal Welding Quality & Productivity with AC Pulsed MIG Welding System” IIW Doc.XII-1629-00.

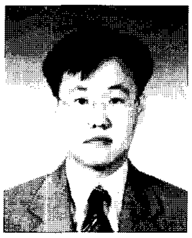
[12] T. J. Kim, C. U. Kim, R. H. Rim, “Development of a power supply for the Pulse MIG arc welding with the changes of output current polarity”, in Proc. IEEE IECON'04, vol 1., pp. 203-206, Nov. 2004.

[13] T. J. Kim, J. P. Lee, H. U. Park, C. U. Kim, “Development of a power supply for the pulse MIG arc welding with a wire melting rate change”, in Proc. IEEE PESC'06, vol 2., pp. 1108-1111, Jun. 2006.

Tae-Jin Kim
He received his B.S., M.S. and Ph.D degrees in Electrical Engineering from Pusan National University, Korea in 1994, 1997 and 2007 respectively. From 1995 to 1996, he was a Researcher at the Superconductor Research Center in OSAKA University, Japan. From 1997 to 1999, he was a Researcher in the Power Electronics Research Team at KERI. Since 2007, he has been with the Power Conversion & System for RES Group at KERI, where he is currently a Senior Researcher. His research interests are design of the DC/DC Converter and ARC controlled welding machine. He is a member of the Korean Institute of Electrical Engineers (KIEE).



Jong-Pil Lee
He received his B.S., M.S. in Control and Instrumentation of Engineering and Electrical Engineering from Korea University, Korea in 1997 and 1999 respectively. From 1999 to 2005, he was a Researcher at Hyundai Heavy Industries co. Ltd. From 2005 to 2006, he was a Researcher in the Power Electronics Research Team at KERI. Since 2007, he has been with the Power Conversion & System for RES Group at KERI, where he is currently a Senior Researcher. His research interests are design of the Power Converter for Photovoltaic Power Conditioning System and Hybrid Electrical Vehicle.



Byung-Duk Min
He received the B.S. degree in electrical Engineering at Kyungbook National University in 1990 and received the M.C. and Ph.D. degrees in electronic and electrical Engineering at POSTECH in 1992, 1997, respectively.

He worked for Hyundai Electronics Industries and Hyundai Heavy Industries from 1997 to 2004.

His main research intrests are Photovoltaic PCS, photovoltaic simulator, UPS, induction & PMSM Motor driver, and hybrid electric vehicle driver.

He is currently a senior researcher in Power Conversion & System for RES Group, KERI.

Dong-Wook Yoo
He received in the B.S. degree from Sung Kyun Kwan University in 1983, and the M. S. degree from Yonsei University in 1985, and the Ph. D. degree from Sung Kyun Kwan University in 1997, all in electrical engineering. He joined Power Conversion & System for RES Group in Korean Electro-technology Research Institute(KERI), Changwon, in 1985, where he is a Principal Researcher. His research interests are induction heating, X-ray generator, high voltage power supplies, and power conversion for renewable energy.

Cheul-U Kim
He was born in Kyungnam, Korea in 1942. He received the B.S in electrical engineering from Pusan National University, Korea, in 1969. He received the M.S in electronic engineering from University of electro-communications, Japan, in 1974. In 1982, He was a Visiting Professor in Tokyo Institute of Technology, Japan. He received the Ph.D. in electronic engineering from Jung-Ang University, Korea, in 1986. He has been with Pusan National University, Korea, as a professor in Departure of Electrical Engineering.