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Back Bead Width Control in One Side SAW using Flux Copper Backing*

—Correlation between Back Bead Width and the Voltage as measured between Base Plate and Copper Backing (Report 1)—

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Abstract

A back bead width control system has been proposed to stabilize the process of one side FCB SAW in which a stationary copper backing plate covered with a flux layer of several milimeters thickness is used as backing.

When a stable welding process is maintained under an adequate welding condition, a signal voltage between the backing copper plate and the plate being welded is detected. The polarity and phase of the detected voltage having a few volts level well correspond to those of the arc voltage in case of AC current welding.

In a stable FCB SAW process, the back side bead is usually formed by a key-hole action of the arc. The reason is probably that the arc penetrates the welding groove and the flux layer, then it contacts the copper plate and is reflected to the welding plate. A correlation between the detected voltage level and the back side bead width is recognized.

A similar phenomenon is observed in a key-hole welding using a transfer type plasma arc.

In order to maintain a constant back bead width the detected voltage is compared with a reference voltage, and then the welding current is controlled by the difference between the above voltages.

Key Words: One-side welding, SAW, FCB process, Key-hole welding, Back bead width, Feed-back control, Arc welding phenomenon, Bead formation

1. Introduction

It is more than 20 years since a one side submerged arc welding (hereinafter called SAW for short) has been developed and put into practical application in Japan.

During those 20 years, the one side welding technique has been applied not only to SAW but also to manual welding and semi-automatic welding such as SMAW, MAG or TIG.

Recently, this technique is also applied to narrow gap arc welding.

However, concerning the welding phenomena in one side welding, only a few studies have been reported.[1] Therefore there are many points which must be solved.

Since 1978, the authors have developed and applied the automated back bead control systems for one side SAW in which the back bead is formed by key-hole action of the arc, and for one side TIG in which the back bead is formed by heat convection and/or heat conduction action of weld pool.

The feature in these control systems is that an arc light intensity or a light intensity emitted from weld pool is detected from the back of a base plate, then the welding current is controlled to maintain the intensity at a required level which corresponds to the back bead width.

Although these control systems have been successfully applied, they have some limitations in practical use as follows;

(a) A backing apparatus which has photo sensors detecting the light intensity must be arranged on the back of base plates to be welded and be traversed synchronously with the progress of welding.

(b) Backing consumables must transmit a light.

To overcome these drawbacks, the authors have investigated a new back bead control system in a one side SAW using Flux and Copper Backing method (FCB) which is a typical backing method for stationary use.

In this investigation, it is found out that when a stable back bead is maintained by key-hole action, a signal voltage which is a few volts level occurs between the copper backing plate and the base plate being welded.

It is recognized that a correlation exists between the detected voltage (hereinafter called Vd for short) and the back bead width, and there are interesting correlations between Vd and main welding parameters.

Then some attempts have been made to examine the possibility of executing the back bead width control using Vd.

2. Experimental method

The backing flux is laid on a copper plate 20 mm thick., 110 mm wide as shown in Fig. 1 (a).

The copper plate is pressed against the back of the base plate by compressed air hose. The pressure to the copper plate is 0.3∼0.4 bar assuming that the pressure to the copper plate is even everywhere.

Welding equipment, consumables and main welding

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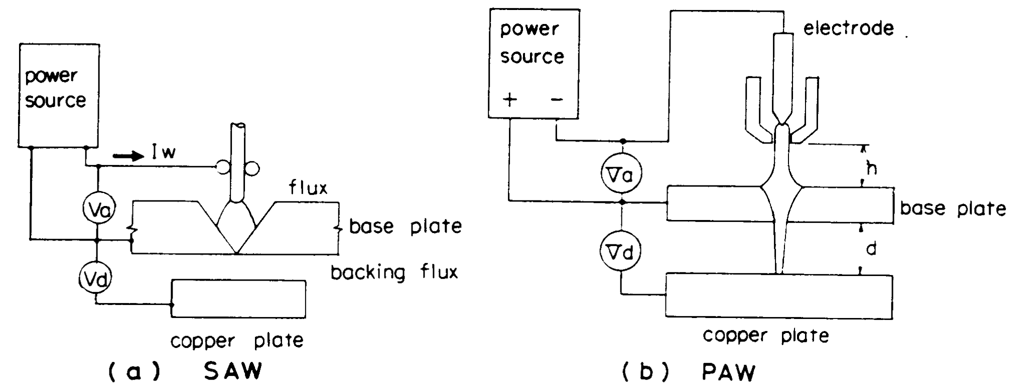

Fig. 1 Measurement of the voltage between base plate and backing copper plate (Vd) and the arc voltage (Va).

Table 1 Fluxes used as backing flux for the test.

trade name	composition system	type	containing thermosetting resin	viscosity	bulk density (g/cm^3)	manufacturer
PFH - 45	$MgO-CaO-SiO_2$	bonded	no	high	1.070	Kobe Steel
PFI - 50	$MgO-CaO-SiO_2-Fe$	do	no	do	1.292	do
PFI - 50R	$MgO-CaO-SiO_2$	do	yes	do	1.176	do
MF - 1R	$SiO_2-MgO-ZrO_2$	fused	yes	medium	1.584	do
KB - 50	$MgO-CaO-SiO_2-Al_2O_3$	bonded	no	unknown	1.070	Kawasaki Steel

parameters used for this work are as follows unless otherwise specified.

Welding method : Flux-Copper Backing (FCB)-SAW (single electrode)
Welding machine : type SWT-24NT (manufacturer: OTC)
AC power source : type KF-2000 (mfr: OTC)
DC power source : type CPMR-1000 (mfr: OTC)
Flux : type PFI-50 (mfr: Kobe Steel)
Wire : type US-43 4.8 mm dia. (mfr: Kobe Steel)
Backing flux : type PFI-50R (mfr: Kobe steel)
Steel plate : grade A steel for shipbuilding, thickness 12 mm
Groove : 50°V groove, gap 0 mm
Main welding parameters: welding current 800A
arc voltage 35V
welding speed 30 cm/min.
wire extension 30 mm
Thickness of backing flux: before pressed 5 mm
after pressed 4 mm

The fluxes shown in Table 1 are used to examine the influence of fluxes.

The voltage (Vd) between copper plate and base plate being welded as shown in Fig. 1 (a) is recorded by an oscillograph (input impendance: 1.5 kΩ) and/or an oscilloscope (input impedance: 1 MΩ).

The arc voltage (Va) and welding current (Iw) are also recorded.

In order to confirm that Vd will be detected in plasma arc welding, Vd is recorded in a similar procedure shown in Fig. 1 (b).

In this case, a recorder having an input impedance of 1MΩ is used.

The welding equipment and welding conditions for the plasma arc welding test are as follows;

DC power source : UR-F (mfr: Hitachi)
Plasma torch : UW-51 (mfr: Hitachi)
Plate : stainless steel, thickness 6 mm, mild steel, thickness 6 mm
Groove : I groove, gap 0 mm

3. Test result and discussion

3.1 *Feature of the detected voltage (Vd)*

A typical waveform of Vd is shown in Fig. 2. In Fig. 2, a waveform of the arc voltage is also shown. Both waveforms are recorded with the common cable connected to the base plate (hereinafter the common cable is connected to the base plate).

From Fig. 2, the feature of Vd is such that the polarity and the phase of Vd are the same as those of the arc voltage (Va).

In a waveform of arc voltage, the waveform on plus side is almost symmetric with respect to that on minus side except re-striking voltage appearing on plus side. But in the waveform of Vd, the amplitude on minus

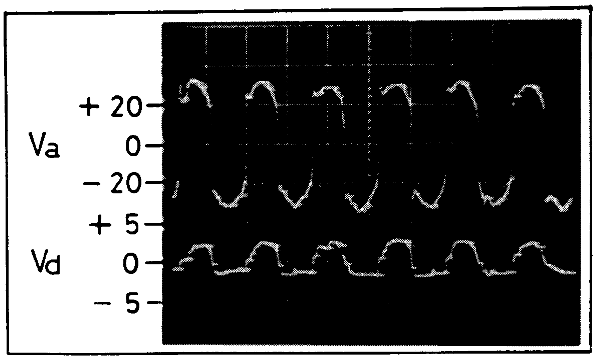

Fig. 2 Typical waveforms of Vd and Va.

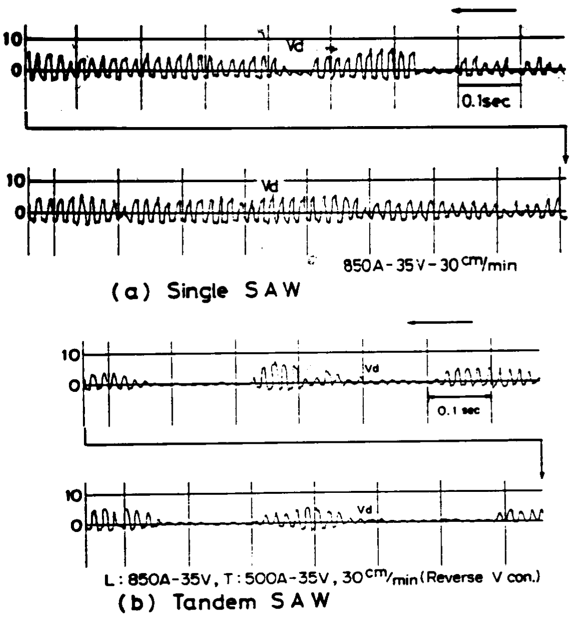

Fig. 3 Examples of the waveform of Vd.

side is lower than that on plus side and the waveform is almost rectangular. Thus the waveform of Vd is unsymmetric with respect to the base line.

It is assummed that the unsymmetric waveform is caused by the effect of electrode polarity because the force of plasma flow and voltage drop in electrode (anode drop & cathode drop) depend on the polarity of electrode.

Fig. 3a shows a typical waveform of Vd in single electrode welding of 850A. Fig. 3b shows a typical waveform of Vd in tandem electrode welding (leading 850A, trailing 500A).

Both figures show that the amplitude of Vd is not always constant but is variable over a few Hz frequency.

In the previous report by the authors, it was recognized that arc light intensity was also variable over a few Hz frequency in a feedback control detecting the arc light intensity.[2-5)]

Moreover, it was confirmed that the size of key-hole varied with a frequency of 2～3 Hz in one side SAW in the case of the observation of weld pool phenomena using X ray fluoroscopy.[7)]

From these facts, it is assumed that Vd has a close correlation with key-hole phenomena in one side welding.

The amplitude of Vd in tadem SAW is lower than that in single SAW comparing Fig. 3a and Fig. 3b. The reason is assumed that the drilling force to form a key-hole of a leading electrode is reduced by the inclination of the leading arc ahead because of a phase difference of 120° with resverse V connection.

According to the experimental result (here figures are not shown), Vd does not appear just after welding start but appears approximately 4 sec after. From the observation using X ray fluoroscopy, it is recognized that it takes about 4 sec from arc starts till a key-hole forms.[7)]

The behaviour of Vd was examined in the case that copper plates were separated and insulated as shown in Fig. 4.

Fig. 5 shows the result in DC SAW (electrode positive). In Fig. 5, when welding is conducted on the copper plate-1, only Vd_1 is recorded and Vd_2 does not appear. When the arc reaches the edge of the copper plate-2 indicated as B in Fig. 4, Vd_2 is first recorded from B point in Fig. 5. When the arc advances to C point in Fig. 4, Vd_1 disappears as shown in Fig. 5. Both Vd_1 and Vd_2 are recorded between B point and C point. The value of Vd_2 is larger than that of Vd_1. The reason is discussed in the next section. From the above mentioned results, an apparent diameter (Da) of the arc column in contact with the copper plate can

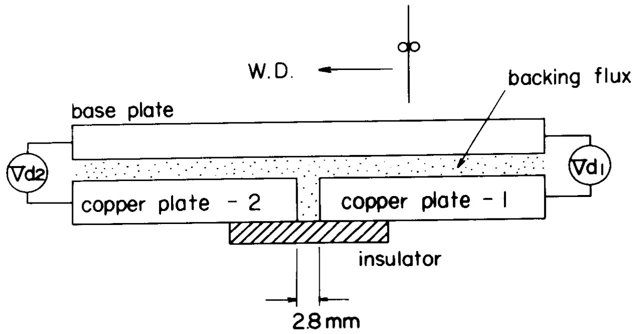

Fig. 4 Experimental procedure with insulated backing.

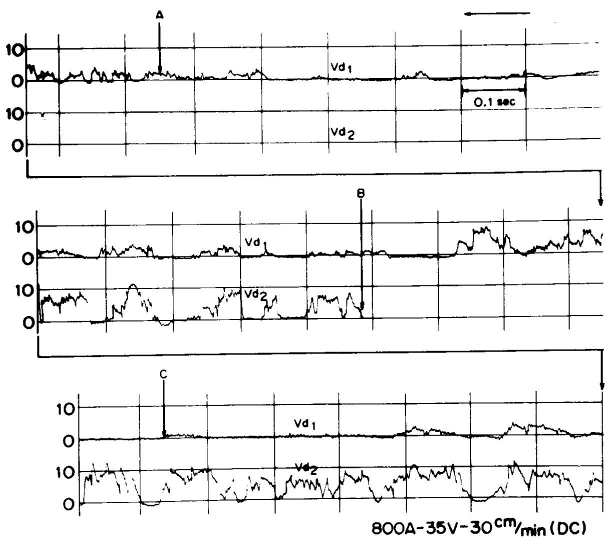

Fig. 5 Change of Vd1 and Vd2 with insulated backing.

be estimated.

As the arc time between B point and C point (t) is 1.14 sec, the welding speed (v) is 5 mm/sec and the clearance of both copper plates (G) is 2.8 mm, the diameter (Da) is calculated as follows:

$$Da = v \cdot t + G$$

where Da : apparent diameter of arc column (mm)
v : welding speed (mm/sec)
t : arc time between B and C (sec)
G : clearance between copper plates (mm)

$$Da = 5 \times 1.14 + 2.8 = 8.5 \text{ mm}$$

The diameter of a key-hole has a close correlation with Da.

The behaviour of Vd is examined in case that the electric circuit between an electrode and a base plate is shorted and then opened using a magnetic switch during welding as shown in Fig. 6.

Fig. 7 shows the result. In Fig. 7, at the moment that the switch is closed, Vd and the arc voltage (Va) disappear at once. (in this case, Va indicates the voltage drop of the electric circuit impedance). Then, when the switch is opened, no load voltage is recorded as Va and a welding current (Iw) are still zero. The arc is re-striken 0.06 sec there after.

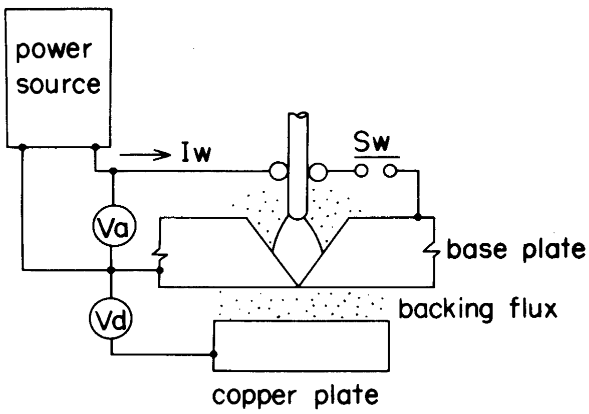

Fig. 6 Experimental procedure with intentional short circuiting.

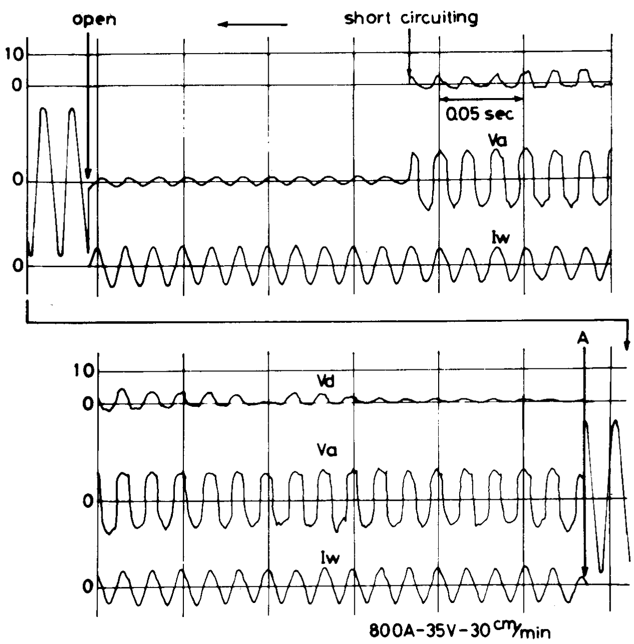

Fig. 7 Change of Vd with intentional short circuiting.

Although Vd appears when the arc is re-striken, the amplitude is very small and it increases as the welding proceeds (about 0.12 sec after re-striken).

3.2 *Cause for Vd*

The reason why Vd occurs is assumed as follows:

When stable one side welding is conducted, a key-hole is formed and the arc plasma reaches the copper backing plate through the key-hole. As a result, Vd occurs.

In order to verify the above estimation experimentally by a different welding method, a transfer type plasma arc welding is conducted to measure Vd.

In Fig. 1 (b), the copper plate is positioned 5 mm below the back of the base plate and isolated, then Vd is recorded by the same procedure as used in SAW.

Fig. 8 shows an example of the results of plasma arc welding. In this case, Vd is detected at a level of –2 volts and a plasma jet which passes through the key-hole reaches at right angles to the copper plate.

According to another experiment in which the clearance between the copper plate and the base plate is continuously varied 6∼13 mm and the welding parameters are the same as those in Fig. 8 (arc voltage is maintained at 29 volts constant by AVC), no particular change is recognized in Vd. Feasibility of welding control using Vd in plasma arc welding was already confirmed more than ten years ago[8-10].

Considering the above results and discussion, Fig. 9 is illustrated to explain why Vd occurs. In Fig. 9, the most part of the arc plasma directly (or indirectly through the molten slag) comes in contact with the copper plate in SAW as in plasma arc welding. Therefore the current path "c∼d" indicated in Fig. 9 exists. Of course, a current path "a" shown in Fig. 9 also exists.

It is well known as an inserting probe method to measure the potential distribution in the plasma column

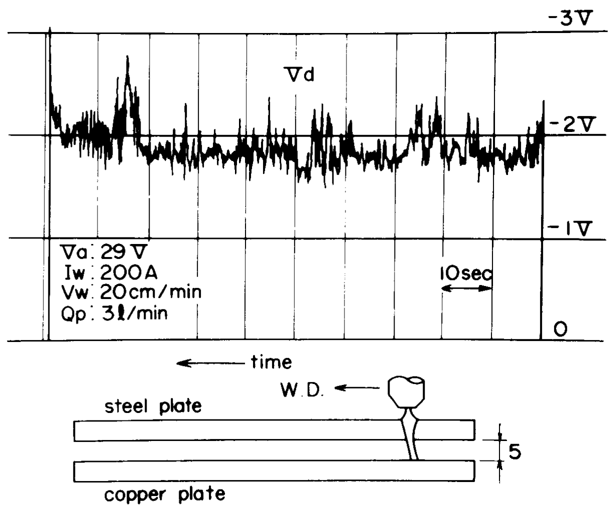

Fig. 8 Vd in plasma arc welding.

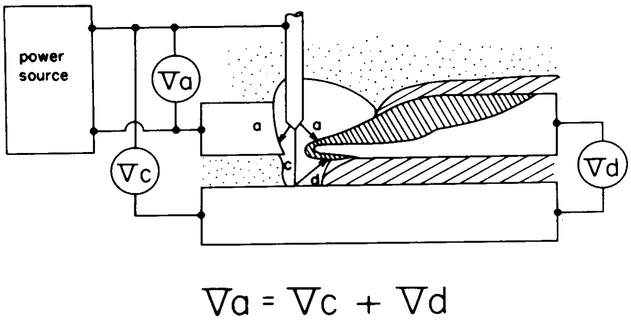

Fig. 9 Arc voltage distribution in SAW.

between electrodes.[11]

Recently, a paper which deals with the inserting probe method for the application of a contactless seam tracking is reported.[12]

This paper points out that if the plasma atmosphere is considered a power source, the current-voltage characteristics between the inserted probe and an electrode corresponds to that of the power source having a high impedance and it is a drooping one. Therefore, in the case of measuring Vd, the measuring apparatus must have a high input impedance.

In the inserting probe method, a needle is used as the probe and the potential difference is measured against the arc column. On the contrary, in this study a plain copper plate corresponds to the probe, and Vd is measured against the most part of the arc atmosphere including the arc column and the welding current is 2 or 3 times higher. Although the procedure of measuring Vd in this study is different from the inserting probe method, it is considered that there is no particular difference in substance.

The problems concerning the impendance such as an influence of the input impedance of a measuring apparatus, an influence of the impedance between the base plate and the copper plate including the slag and an influence of the welding length will be discussed in the next report.

The reason for $Vd_2 > Vd_1$ between B and C in Fig. 5 is assumed that the impedance of Vd_1 side is lowered by the existence of a molten slag.

3.3 *Correlation among Vd, back bead width and major welding parameters*

Fig. 10 shows a correlation between the back bead width and Vd. In the region "a" where the back bead width is more than 12 mm, a good correlation exists between the back bead width and Vd. But in the region "b" where the back bead width is less than 11 mm, Vd is not detected. In this case, it is estimated that the back bead is formed by heat convection of weld pool considering the macrosection and the shape of the back bead.

In the case that an extremely high welding current is applied, the back bead becomes wide and Vd disappears. The reason is that the back bead burns the surface of the copper plate and comes into close contact and, as the result, the impedance between the base plate and the copper plate becomes almost zero.

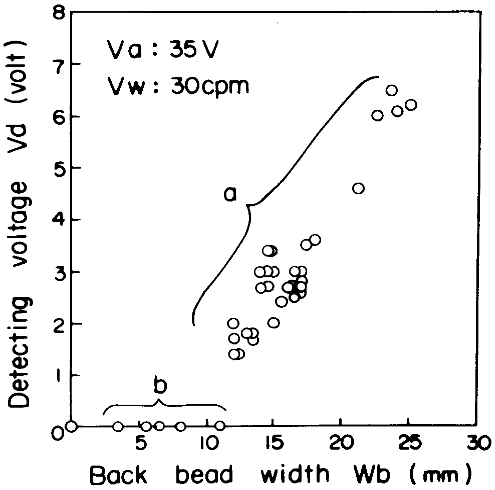

Fig. 10 Correlation between back bead width and Vd.

However, in an abnormal state, Vd indicates a high level (7～8 volts). It is expected that if the welding current is feedback-controlled by detected Vd, an excessive current and the burning of copper plate will be prevented.

Influence of major wleding parameters is summarized in Fig. 11.

In Fig. 11 (a), Vd is detected in the region with a welding current over 700A. But when the welding current is 700A, Vd is zero and a narrow back bead is obtained. As the macrosection of 700 A shown in Fig. 12(a) shows that the back bead does not spread to the end, it is suspected that the back bead is formed by heat convection in this case.

Fig. 11 (b) shows influence of arc voltage. In Fig. 11 (b), both the maximum back bead width and the maximum Vd are obtained when the arc voltage is approximately 25 volts.

The reason why Vd is reduced as the arc voltage becomes high is that the root of the arc goes up to the surface of the base plate.

The reason why Vd is extremely reduced when the arc voltage is lowered to 20 volts is assumed that an arc flame cannot reach the copper plate because the arc modeis changed to a buried arc in which arcking occurs between the side wall of the wire and the base plate.

The fact that the maximum back bead width is obtained at an arc voltage was also recognized in the previous paper.[2]

Fig. 12 (b) shows macrosections in case of changing the arc voltage.

Fig. 11 (c) shows influence of welding speed. In Fig. 11 (c), in the region of more than 30 cm/min., Vd is detected, but at 20 cm/min, Vd is not detected. Fig. 12 (c) shows macrosections in case of changing the welding speed. The reason why Vd is not detected in the case of 20 cm/min. is assumed that the quantity of molten metal is increased when reducing the welding speed and the height of the gravity head of molten metal is increased, then the arc force cannot overcome the gravity head and as the result, a key-hole cannot be

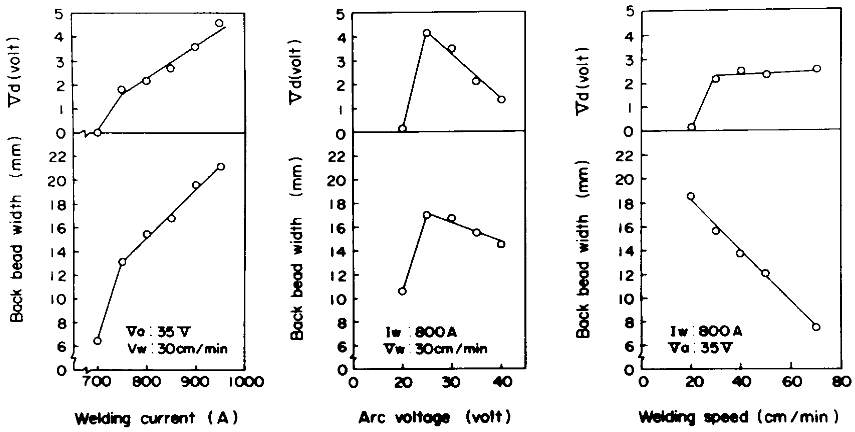

Fig. 11 Influence of major welding parameters on back bead width and Vd.

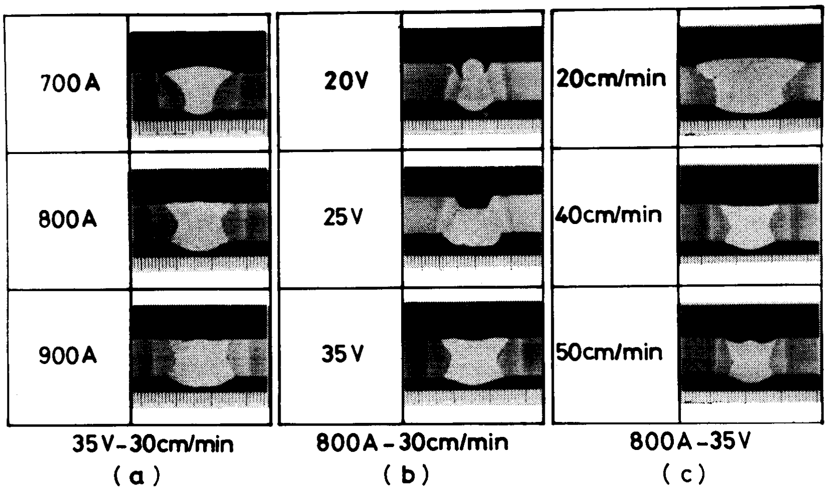

Fig. 12 Typical macro sections in case of changing major welding parameters.

formed.

In this case the back side bead is a convection formation type, not a key hole formation type.

In the region of more than 30 cm/min., the back bead width is decreased as the welding speed increases but no particular change is recognized in Vd. As the welding speed is increased, the deposited metal as well as the heat input is decreased and then the gravity head of a molten metal is reduced. Therefore the diameter of the key-hole is reduced. An apparent diameter of the arc column (Da) under the condition of 800 A, 35 V, 30 cm/min, is about 8.5 mm as described in section 3.1 and corresponds to half the back bead width of about 16 mm. Although a correlation between the real diameter of the key-hole (Dk) and the apparent diameter of the arc column estimated by a potential distribution (Da) is not clear yet, Dk is larger than Da in the region of slow welding speed. In the region of high speed in which Dk is nearly equal to Da, no particular change is recognized in Vd.

Thus, as the correlation of Vd and the back bead width is changed in the case of changing the welding speed, it is necessary to consider such facts when applying an automated control. The correlation above mentioned was also recognized in a feedback control using the arc light intensity[2].

3.4 *Influence of layer thickness and kind of backing flux*

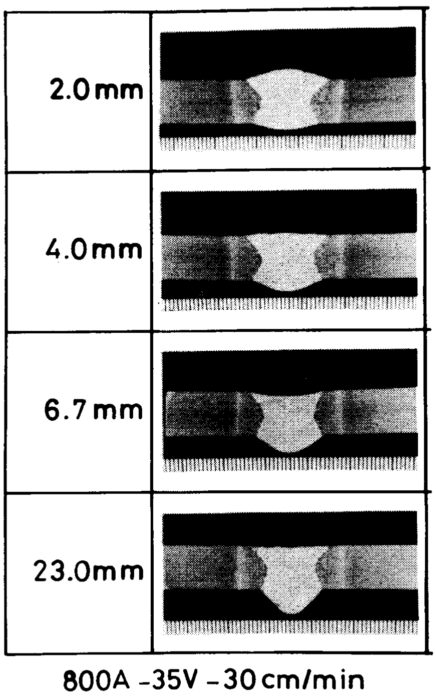

Fig. 13 Influence of backing flux layer thickness.

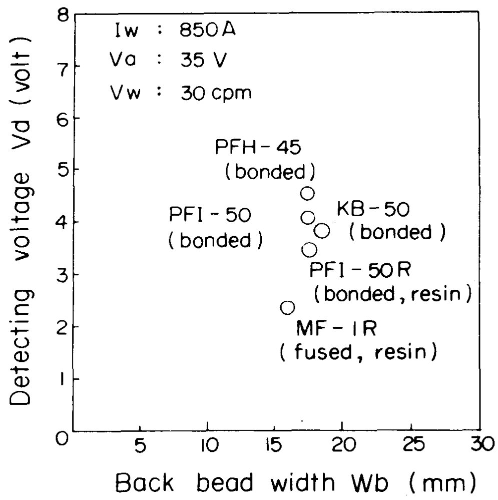

Fig. 14 Influence of fluxes.

The thickness of the backing flux layer is an important factor which should be carefully controlled in one side FCB SAW.

The influence of the flux layer thickness on Vd and the bead shape is examined. Fig. 13 shows an example of the test results showing macrosections.

In Fig. 13, the thickness of the flux layer indicates a clearance between the base plate and the copper plate after pressed by air hose. In the case that the flux layer thickness is in the range of 2.0∼6.7 mm, Vd measured is almost the same level (2∼3 volts.) but the height of the back bead is increased as the flux layer thickness is increased.

In the case of the flux layer thickness of 23 mm, the flux is not melted all over the thickness and Vd does not appear.

Fig. 14 shows the influence of backing flux types as shown in Table 1. Fig. 14 and Table 1 show a tendency that Vd is decreased as the bulk density of flux is increased.

3.5 *Development of a back bead width control*

On the basis of the good correlation between Vd and the back bead width as shown in Fig. 10, a feedback welding current control in which the welding current is controlled such that Vd is kept at a constant level has been developed.

Fig. 15 shows a block diagram of the control circuit.

An example of the effect of the feedback welding current control is summarized in Fig. 16.

Welding tests were carried out on a plate having 3 different groove conditions in a weld line such as V groove with zero gap, V groove with 3 mm wide gap and V groove with heavy sealing bead.

When applying the feedback welding current control, the required back bead width is obtained in both grooves having zero gap and heavy sealing bead. But in the case of a groove having 3 mm wide gap, the welding current is over-controlled and the resulting back bead width is reduced. The reason is explained as follows:

When the groove has a gap, an arc flame easily passes through the key-hole and the welding current is reduced by the feedback control. As a result, with the height of gravity head decreased, the arc whose force is weaker can pass through the key-hole.

However, it is expected that this drawback will be

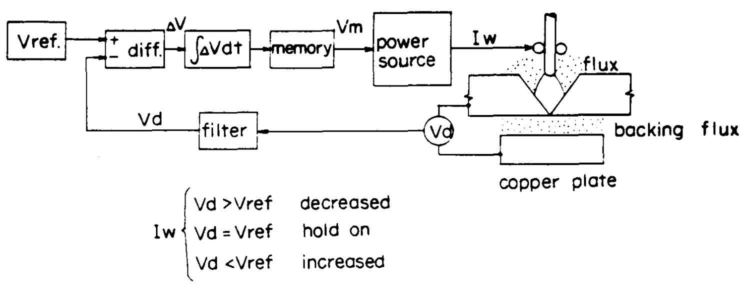

Fig. 15 Block diagram of welding current control with Vd.

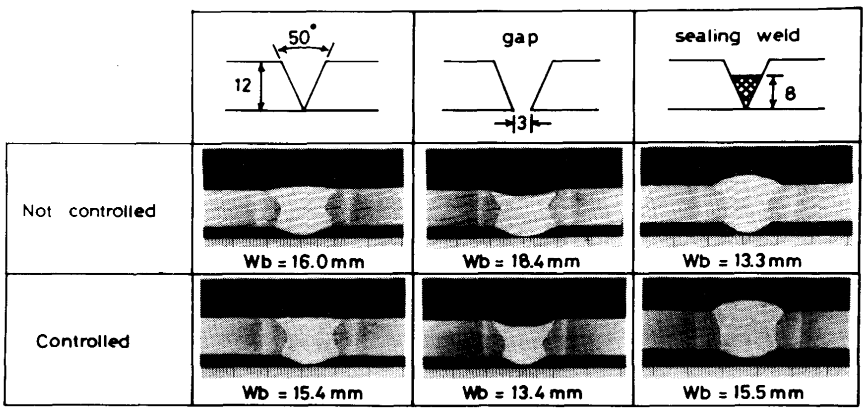

Fig. 16. Effect of welding current control.

overcome by applying the nugget height control system previously developed by the authors in which a filler wire is added so that the controlled welding current reaches a preset level which is determined by a plate thickness equivalent to the nugget height or the height of gravity head.[4,5)]

4. Conclusions

(1) In one side SAW using the flux and copper backing method, when the base plate and the copper backing plate are electrically insulated before welding and a stable back bead is being formed, it is confirmed that a signal voltage having a few volts level is detected between the base plate and the copper backing plate during welding, and the polarity and the phase of the signal voltage agree with those of arc voltage.
(2) The reason why the voltage occurs is assumed as follows:

The arc plasma passes through the key-hole of weld pool by key-hole action of the arc and comes into contact with the copper backing plate electrically and then is reflected to the base plate.

The detected voltage is caused by the reflection of arc plasma and it is a part of the arc voltage.
(3) As far as the back bead is formed by a key-hole action of the arc, a good correlation holds between Vd and the back bead width.
(4) A back bead width control in which the welding current is controlled such that Vd is maintained at a constant level has been developed. It has been confirmed that the back bead width control using Vd is applicable to a one side FCB-SAW.

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