Observations of Cathode Spot Movement in AC-GTA Welding of Aluminum Alloy†

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Abstract

Effects of alloying elements and welding current on "cleaning action of Al arc welding" and the phenomenological behavior of cathode spots have been investigated for many kind of commercial aluminum alloys by using an inverter type AC-TIG welder. Cathode spot movements were observed by high-speed cinecamera and also evaporation of some alloying elements from the spots were studied by an emission spectroscopic method. Differences in cleaning action among alloy types are discussed.

KEY WORDS: (Cathode Spot) (Cleaning Action) (Aluminum Alloy) (AC) (GTA Welding)

1. Introduction

In the GTA welding of aluminum alloys, the electrode-positive polarity is usually applied in expectation of cleaning action exerted by the arc itself on the base metal. High-speed films of the arc indicate the widely spread and extremely rapid motion of many cathode spots, which have feature to wander from an oxide particle or impurities to another one. The movements of many spots result in the cleaning up of Al-oxide from the arc area, which might be the cause of weld defect because of exceedingly high melting point compared with that of base metal. However, the characteristics of cathode spots behavior are not understood clearly.

In this study, we observed the cathode spot movements during welding by the use of the high-speed cinecamera. Furthermore, we detected the metal vapor in the boundary layer between arc and metal surface during welding by spectroscopy, and investigated the mechanism of cleaning action on the aluminum alloys.

2. Experimental Procedure

The experimental setup used in this study is shown schematically in **Fig.1**. Power was supplied by an AC-TIG welder with inverter control. All measurements were made at 57% of EN-ratio (Electrode Negative Ratio) during AC welding as shown in **Fig.2**. The electrodes were tungsten rods contained La_2O_3 and their diameters were 3.2 and 6.4mm. The shielding gas was pure Ar, and the base metals with dimension of 150×100×10mm were pure aluminum (A1050) and aluminum alloys (A2017, A5052, A5083 and A6061). The chemical compositions of these metals are tabulated in **Table 1**. The base metals were fixed on the water cooled copper plate and welding speed was set at 100mm/min. In order to observe the cathode spot movement, we used a high-speed cinecamera (8000 frame/sec). The observation of metal vapor in the boundary layer between arc and metal surface was carried out by the emission spectroscopic method. Arc light was led to a monochromater through an optical system.

3. Experimental Results and Discussion

3.1 Observation of cleaning region

Various aluminum alloys (A1050, A2017, A5052, A5083 and A6061) were welded under the conditions of arc current 300A and arc length 2mm, and the appearances of all beads were observed. The cleaning region located at the end of the bead had the structure schematically illustrated in **Fig.3**. For example, the appearances of this region in the case of A1050 and A5083 are shown in **Fig.4**. The cleaning region consists of two zones as

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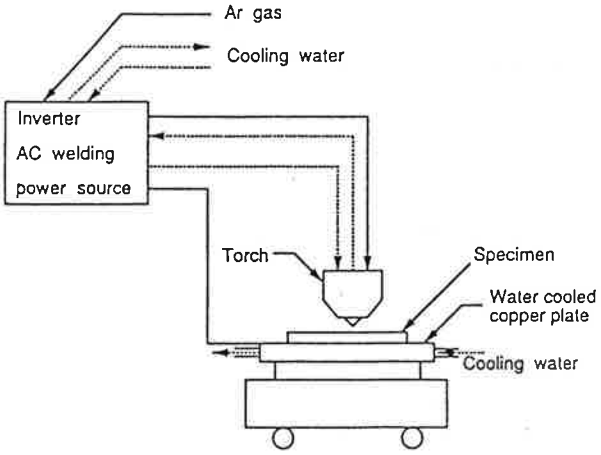


Fig.1 Schematic diagram of TIG welding apparatus.

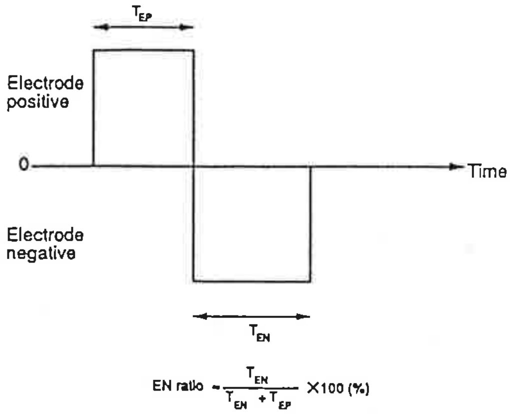


Fig.2 Schematic diagram showing the EN ratio.

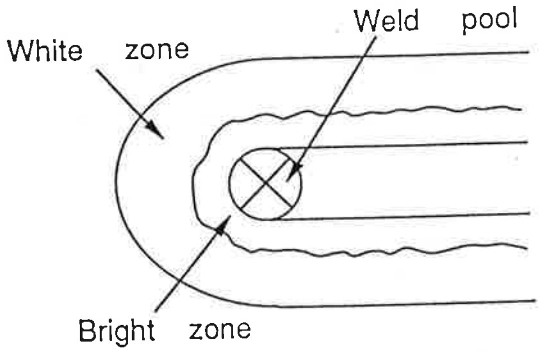


Fig.3 Schematic diagram of the structure of cleaning region.

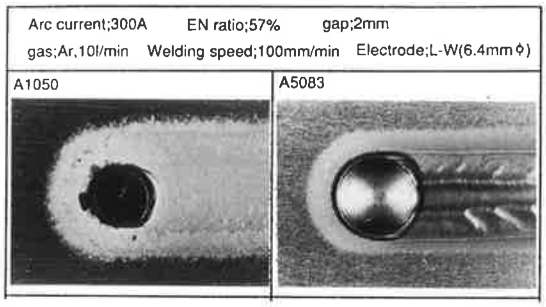


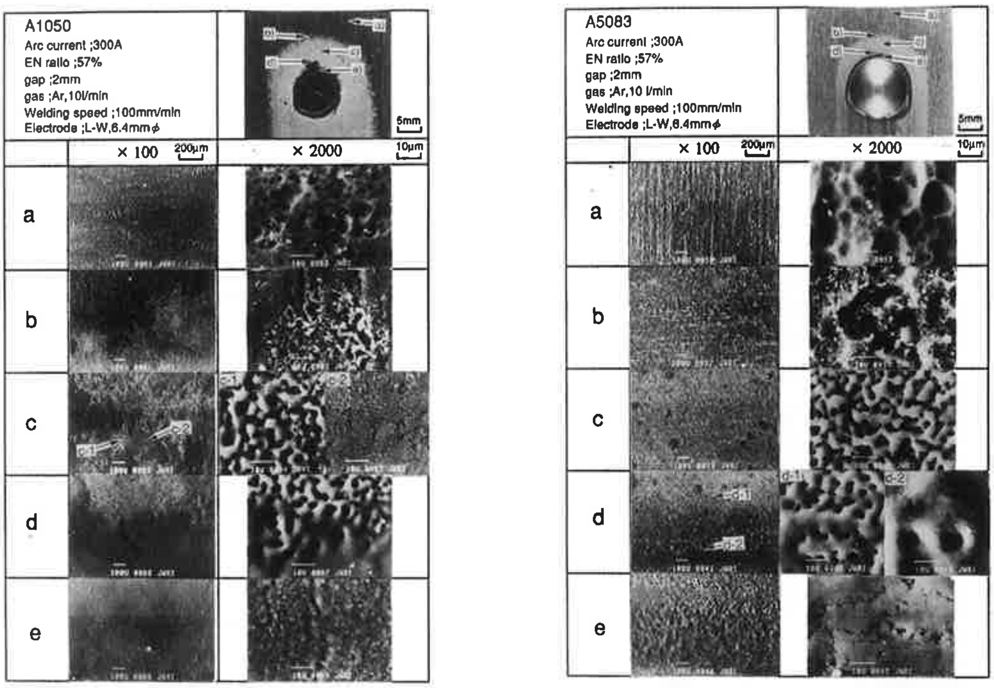
Fig.4 Bead appearance of various Al alloys after welding.

shown in Fig.3: a bright zone and a white zone. The bright zone, which is in the neighborhood of weld pool, presents a metallic gloss, and the white zone, which surrounds the bright zone, has a surface condition like white frosted glass. (The bright zone appears black in the photographs in Fig.4.) When the white zone is carefully observed, it may be noticed that small black islands exist on the zone in the case of A1050, but not in the case of A5083. These small islands had a metallic gloss and were observed in the case of A1050, A2017 and A6061 which contained the much magnesium (Mg).

In order to investigate the micro-structure of both zones, we examined surface conditions of the cleaning region by using the SEM. The typical micrographs in the cases of A1050 and A5083 are shown in **Fig.5**. Points labeled from a to e indicate several observation points in cleaning region, that is to say, a point on the base metal surface not affected by the arc, a point between base metal and white zone, the center of the white zone, the boundary between white zone and bright zone, and the center of bright zone, respectively. In the surface of white zone, there were many craters like a well of a few microns in diameter. On the other hand, in the surface of

Table 1 Composition of the various alloys.

Alloys \ Composition (%)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
A1050	0.09	0.35	0.04	0.03	0.02	<0.01	<0.01	0.01	Bal
A2017	0.49	0.29	3.85	0.67	0.55	0.04	0.16	0.02	Bal
A5052	0.07	0.25	0.02	0.01	2.03	0.19	<0.01	0.01	Bal
A5083	0.13	0.20	0.02	0.60	4.16	0.11	0.02	0.02	Bal
A6061	0.60	0.25	0.23	0.11	1.00	0.18	0.02	0.02	Bal



(a) A1050 (b) A5083

Fig.5 SEM observation of cleaning region.

the bright zone, there were not such craters. When comparing the photographs of the point c (×100) with that of the point e (×100), rolled tracks were found in the white zone, but not in the bright zone. From these observations, it is safe to consider that the bright zone is the melted area of the surface. In the case of A1050, small islands were found in white zone. The c-1 and c-2 are the observation points in the white frosted area and in the small islands, respectively. In c-2 (×2000), there were not rolled tracks but smooth surface. This suggests that small islands in the white zone result from surface melting.

All observations for other kinds of aluminum alloys provided similar results.

3.2 Cathode spot movements and their governing factors

3.2.1 Observations of cathode spot movement

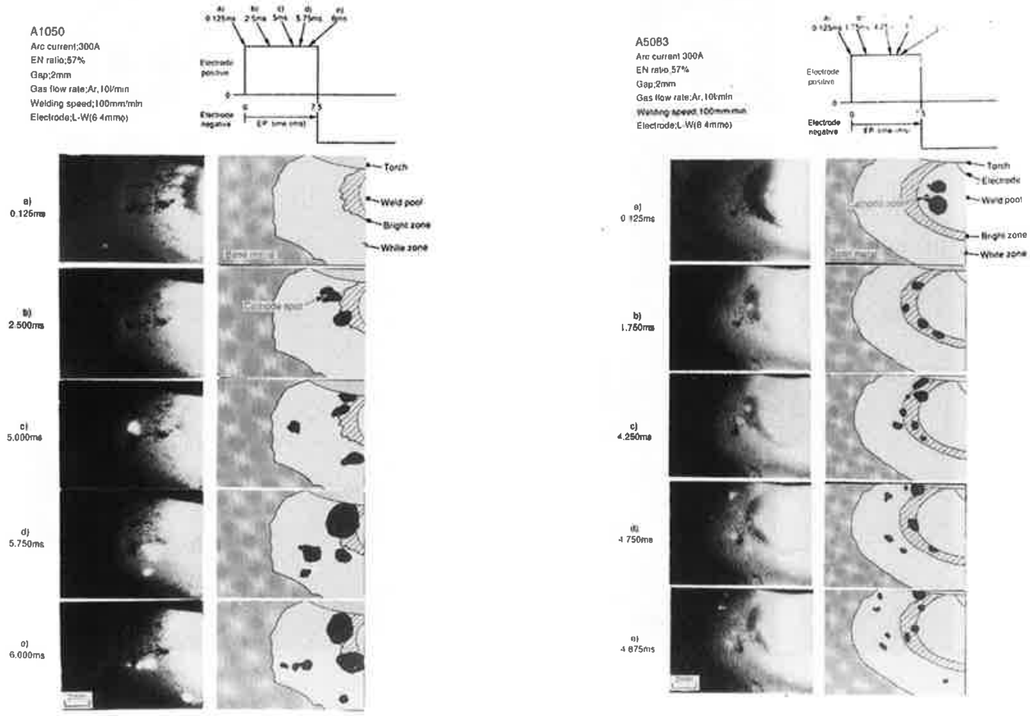
In order to understand the formation mechanisms of white zones and bright zones in the cleaning region and the factors causing the small islands in the white zone, cathode spot movement was observed with a high-speed cinecamera (8000 frames/sec). We filmed from the direction vertical to the welding line. During electrode positive phase, cathode spots were generated at first in the weld pool, and then extended radially to the cleaning region with the passage of time, independent of the kinds of aluminum alloys or the welding current.

The photographs from these films and the schematic illustrations are shown in **Fig.6**. It can be seen that cathode spots are generated at first in the weld pool and then extend to the cleaning region.

In the case of A1050, cathode spots usually stayed at one place for a long time, and then small islands were generated at that place. On the other hand, in the case of A5083, cathode spots always moved without staying at one place. Movement speeds of the cathode spots in A5083 were fast compared with A1050. In the case of A5083, there are a larger number of cathode spots and the diameters of cathode spots are smaller than with A1050.

The differences of the cathode spot behavior among different aluminum alloys can be expressed more quantitatively. **Figure 7** shows the relation between the content of magnesium and the number of cathode spots generated. The number of cathode spots generated was counted on the films of high-speed cinecamera for interval of 2.5ms, from the point of the time which passes 5ms after changing into electrode positive phase until changing into electrode negative one. The condition was fixed at 150A and 300A in the welding current, and the arc length 2mm. The higher the magnesium content in the alloy, the more cathode spots are generated. Under the conditions of welding current 300A, about 4.5 times more spots are generated in A5083 compared with A1050.

Figure 8 shows the relation between the amount of magnesium included in the aluminum alloy and the diameter of cathode spots. The diameter of a cathode spot



(a) A1050 (b) A5083

Fig.6 Dispersion of cathode spots from weld pool to cleaning region.

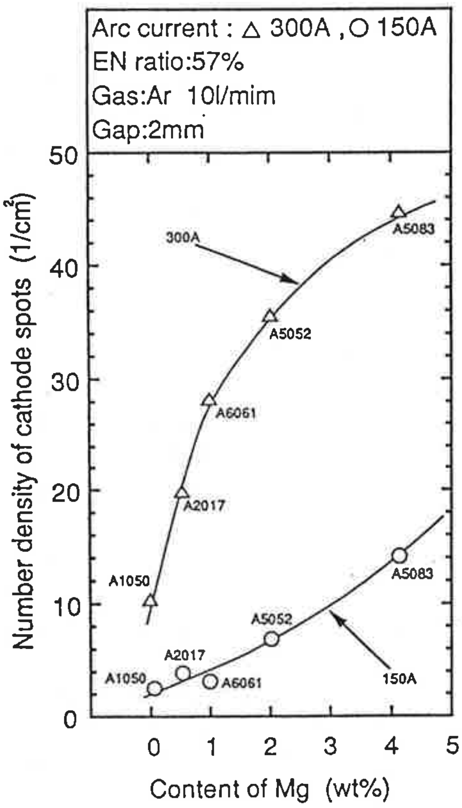


Fig.7 Number density of cathode spots for various Al alloys.

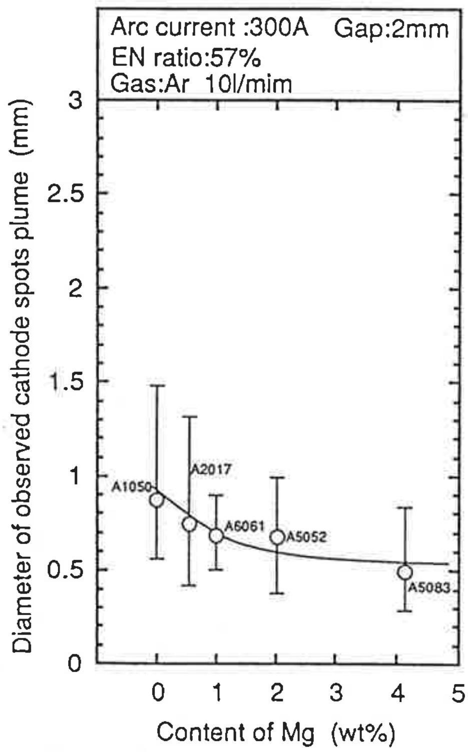


Fig.8 Diameter of cathode spots for various Al alloys.

was assumed to be of the luminescent part in photographs. It is found that the diameter of the cathode spot becomes smaller when the magnesium content of the alloy increases.

3.2.2 Investigation concerning the dominant cause of cathode spot movement

It is generally agreed that for aluminum alloys cathode spots are generated on the oxide films where the work function is low[1]. It follows that the reason for the different number, diameter and speed of cathode spots depending on different kinds of aluminum alloy is the different work functions which caused by different oxide film structures. Oxide film structures of pure aluminum and Al-Mg alloys are described in the literature[2]. The oxide film of pure aluminum is composed of amorphous Al_2O_3, and that of Al-Mg alloys of amorphous Al_2O_3 and amorphous MgO.

The work functions of Al, Mg, MgO and Al_2O_3 are tabulated in **Table 2**[3]. The work function of MgO is smaller than that of Al_2O_3 and may explains why more cathode spots were generated in the aluminum alloys containing magnesium.

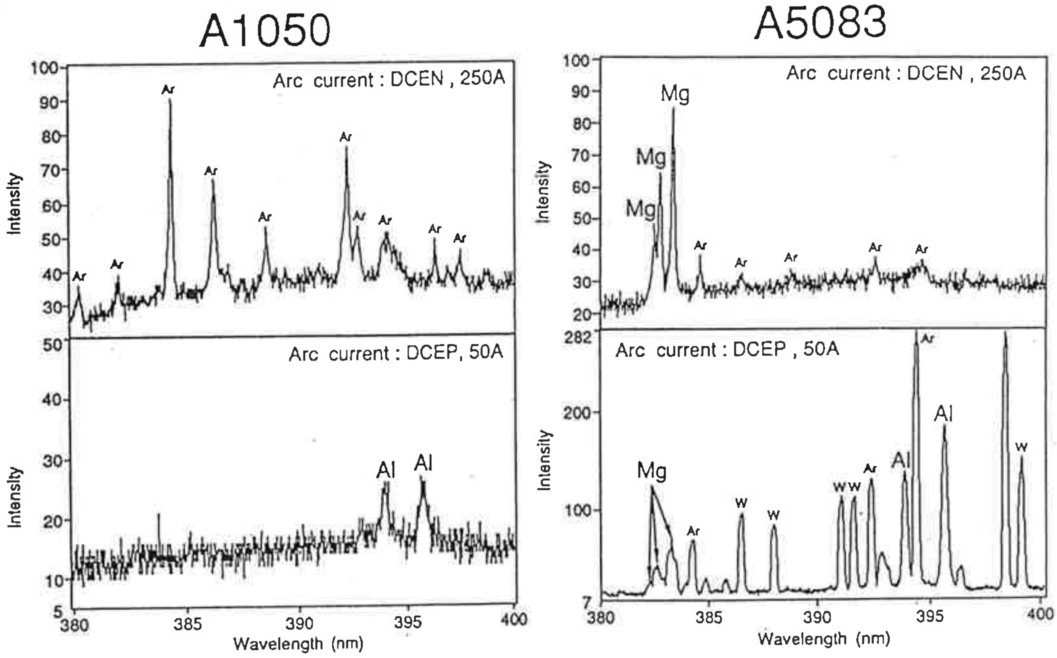
In recent researches concerning the cleaning action, it is held that the oxide film is removed by momentary melting and evaporating of the metal surface. Therefore, the vapor pressure of the alloying element like a magnesium is considered as another reason why the cathode spot movement differ among various kinds of alloys. The boiling-points of aluminum and magnesium are tabulated in **Table 3**. It shows that magnesium evaporates more easily than aluminum. The vapor from the cleaning region was measured by a spectroscopic method. This measurement was made with a stationary arc in a chamber filled with argon gas at 1atm. The measurement point was located at 1mm distant from the base metal, and on the center axis of the arc. The results are shown in **Fig.9**. The vapor was observed under the two conditions: DC-electrode negative 250A and DC-electrode positive 50A. In the case of DC-electrode positive, the current value was suppressed so that the

Table 2 Work function of various elements and their oxides.

Material	Work function (eV)
Al	4.28
Mg	3.66
MgO	3.1
Al_2O_3	3.9

Table 3 Temperature of 1atm vapor pressure for various metals.

Material	Temperature(Vapor pressure : 1atm)
Al	2793 (K)
Mg	1363 (K)



(a) A1050 (b) A5083

Fig.9 Results of spectroscopic analysis.

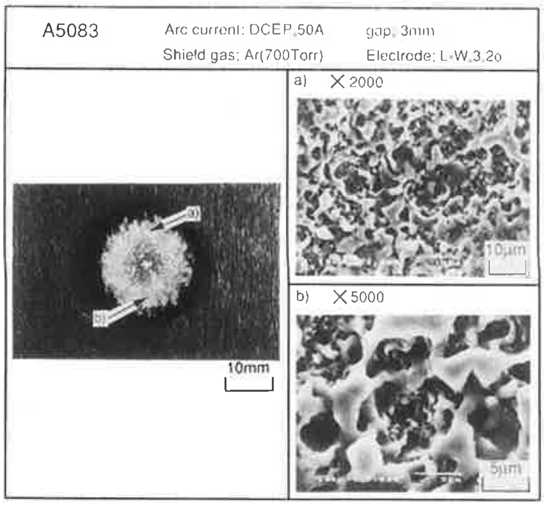


Fig.10 Surface appearance of A5083 after spectroscopic analysis.

cleaning region was only formed on the metal surface and a weld pool was not formed. On the other hand, in the case of DC-electrode negative, the weld pool was formed and then we measured the vapor from weld pool. The Al spectrum can be seen in the DC-electrode positive, but not in the DC-electrode negative in the case of A1050. In the case of A5083, both Mg and Al spectra can be seen in DC-electrode positive, though only the Mg spectrum can be seen in DC-electrode negative. The Mg spectrum is observed independent of the electric polarity. Therefore, it can be said that magnesium evaporates easily compared with aluminum.

In addition, we observed the surface of the arc attachment zone, which was obtained under the same conditions as with the spectroscopic measurement. The result for A5083 is shown in **Fig.10**. There are many crater like wells on the surface and this surface morphology is the same as the white zone mentioned above. The observation in the case of A1050 is similar. Therefore, it is suggested that the crater is evidence that the oxide film have been removed by the passing of cathode spots.

When magnesium is added into the alloys, the oxide film begins to evaporate easily and then the time required for removing oxide film shortens. In addition, the cathode spot is moved easily, because the work function of the oxide film is low. Conversely, when the magnesium content is low, oxide films do not evaporate easily and then the dwell time of cathode spots becomes longer. In this situation, the heat input sometimes becomes excessive and the metal surface is melted. This produces a small island in white zone. Moreover, in the neighborhood of the weld pool, the rate of heat input is large and the heat transfer from the weld pool is also large, because cathode spots extend radially from the weld pool. This condition creates the bright zone where the metal surface is melted.

The structure of the oxide film changes by adding the alloying element into aluminum, and consequently both the work function and evaporation pressure also change. It is supposed that this change influences the cathode spot phenomena (the number, diameter and speed of cathode spot) and the differences between the cleaning region in different kinds of aluminum alloys.

4. Conclusion

The results obtained from this study are brought together as follows.

(1) The surface conditions of the cleaning region in the AC-TIG welding of aluminum alloys were observed. The cleaning region consisted of two zones, namely, a bright zone and a white zone, independent of kinds of aluminum alloys.

(2) The cathode spots were generated at first in the weld pool, and then extended radially to the cleaning region with the passage of time. The several kinds of aluminum alloys showed different numbers, diameters and speeds of cathode spots, and were affected by the kinds of alloying element. The number, diameter and speed of cathode spots became many, small and high, respectively, when the amount of magnesium increased.

(3) The vapor from the cleaning region was measured by a spectroscopic method. This measurement indicated that magnesium evaporates easily compared with aluminum. Moreover, it also indicated that the crater was an evidence that the oxide film had been removed by the passage of cathode spots.

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