Effect of Gravity on Arc Shape in GTA Welding*

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Abstract

In order to investigate the effect of gravity on the arc shape in gas tungsten arc (GTA) welding, GTA welding was carried out using the drop-shaft type microgravity system at the Japan Microgravity Center (JAMIC). The materials used were an aluminum alloy and pure silver. It has become clear that the effect of gravity on the arc shape is not observed under general welding conditions (over 70 A) regardless of the observed region and the shielding gas flow rate. The displacement of the arc gap during the transition from the terrestrial environment to the microgravity environment can change the arc shape.

Key words: gas tungsten arc welding, microgravity, arc shape, aluminum alloy.

1. Introduction

An arc is the heat source of the arc welding processes, and its condition significantly affects the welding phenomena and the condition of the final product. Accordingly, arc shapes under several conditions have been observed by many researchers¹⁻⁵⁾, and the results have provided valuable information on the plasma phenomena in the arc. For example, Nishiguchi *et al.*¹⁾ observed arc shapes at low pressure argon atmosphere in gas tungsten arc (GTA) welding and clarified the relationship between the cathode plasma zone and the pressure level. Matsunawa *et al.*²⁾ observed arc shapes at high pressure argon atmosphere in GTA welding as well as gas metal arc (GMA) welding and found that the current density at the electrode tip increased in GTA welding and was suppressed in GMA welding. Muller³⁾ and Finkelnburg⁴⁾ pointed out the arc stiffness in GMA welding and in carbon arc welding, respectively. Key⁵⁾ assessed the relationship between the shielding gas composition and the electrode geometry in GTA welding.

The authors have investigated the gravitational effect by observing the arc shapes both in a microgravity environment and in a terrestrial environment⁶⁾. The arc shapes were found to be very similar in both environments. Kaihara *et al.*⁷⁾ and Abe *et al.*⁸⁾ reported that gravity did affect the arc shape in spite of similar current conditions (60-100 A). Accordingly, in this study, in order to investigate the effects of shielding gas

flow rate, arc current, arc gap and the observed region in detail, the arc shapes in a microgravity environment and in a terrestrial environment are compared under various conditions.

2. Experimental

In this study, gas tungsten arc (GTA) welding was performed both in a microgravity environment and in a terrestrial environment, and the arc shapes in both environments were observed and compared. The GTA welding process uses a nonconsumable tungsten electrode and can avoid the fusible electrode transfer in the arc. Accordingly, the welding process has a great advantage in the observation of the arc shape compared with the other arc welding processes. A microgravity condition was obtained using the free fall system at the Japan Microgravity Center. The system can maintain a 10 s microgravity of less than 10^{-5} G. The GTA welding apparatus used in this study consists of a welding chamber, a battery, a welding power source, a shielding gas supply and a welding control system, as shown in Figure 1. The welding chamber is equipped with a specimen and a torch sliding system. In this study, several CCD cameras with different transmissivity filters were used in order to observe both regions of the arc core and the arc flame simultaneously. The battery is an uninterruptible power system (UPS) which supplies 2.4 kW (AC100 V, 3000 VA) to the welding power source.

The material selected was an aluminum alloy A2219 because it is commonly used in the aerospace industry.

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Table 1 Chemical composition of Al-Cu alloy A2219, mass%.

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Pb	V
Bal	0.07	0.16	6.26	0.30	—	—	0.01	0.04	0.18	0.01	0.09

Table 2 Welding conditions.

sample	A2219	Silver
welding current (A)	80	71
welding voltage (V)	12	16
welding speed (m/s)	3.6×10^{-3}	4.0×10^{-3}
shielding gas flow rate (m ³ /s)	8.3×10^{-5}	0
arc length (m)	2.0×10^{-3}	3.0×10^{-3}

Fig. 1 Schematic diagram of GTA welding apparatus.

Table 1 shows the chemical composition of the aluminum alloy. For aluminum alloys, the anode spot often moves discontinuously due to the distribution of the oxide layer on the surface⁹⁾. To avoid the arc movement, pure silver (99.99 mass%) was also used. The size of the samples is 100 mm^l × 50 mm^w × 3 mm^t. Table 2 shows the welding conditions. The welding current was 70–80 A. It was set a small value in the range of general welding operations. The shielding and atmospheric gases were argon (99.9995% in purity). Bead-on-plate welding was performed with the flat welding position. The polarity was direct current electrode negative (DCEN) in order not to consume the electrode. The electrode was made of a 2%-thoriated-tungsten and its diameter was 1.6 mm with a 30 deg tip angle. In this study, careful attention was also paid to the arc gap in

both environments being the same.

3. Results and Discussion

3.1 Observed Region

An arc is generally compressed by the electromagnetic force due to the current flowing in the arc. This phenomenon is called the electric pinch effect^{3,4,10,and11)}. The effect is larger in the arc core region, because the temperature and the current density are higher there. Accordingly, it seems that the arc core region will not easily be affected by gravity. The surroundings of the arc core, that is, the arc flame, on the other hand, may be affected by gravity. Thus, when a different part of the arc is measured, a different result might be obtained. In this study, several optical filters with different transmissivity were used to observe both regions of the arc.

Figure 2 shows the appearance of the high temperature region, that is, the arc core, observed through a welding filter (JIS 11). The transmissivity of the filter is 0.005 in the visible range. Figure 3 shows the surroundings of the arc core, that is, the arc flame, observed through an ND filter. The transmissivity is 0.03. Tanaka *et al.* reported that the electric pinch effect was negligible when the position was 1.5 mm far from the center under conditions of welding current; 50–150 A, arc gap; 5 mm, electrode diameter; 3.2 mm, tip angle; 60 degree¹²⁾. Accordingly, the electric pinch effect should be negligible in the arc frame shown in Fig. 3. As shown in Figs. 2 and 3, the shapes of the arc core and the arc flame in both environments are almost the same. No

Fig. 2 Appearances of high temperature region (arc core) observed through welding filter (JIS 11) in both environments.

Fig. 3 Appearances of low temperature region (arc flame) observed through ND filter in both environments.

Fig. 4 Arc shape images without shielding gas observed through ND filter in both environments.

effect of gravity is observed in both high temperature and low temperature regions.

3.2 Flow rate of shielding gas

The results in section 3.1 were also obtained with argon shielding gas flowing at a rate of $8.3 \times 10^{-5} \text{ m}^3/\text{s}^{(6)}$. In these cases, the arc shapes were very similar in both environments. When the shielding gas flows around the arc, the arc may be stabilized by a stable shielding gas flow around the arc. In this study, in order to investigate the effect of shielding gas on the arc, welding was performed in an argon atmosphere without shielding gas flowing, in both environments. When no shielding gas flows for aluminum alloys, the arc is usually unstable due to the discontinuous movement of the anode spot because the thermal pinch effect decreases. In this study, silver was chosen for the experiments in order to

estimate the effect of gravity precisely. The welding current is also reduced in order not to form a weld pool so that the effect of the pool could be reduced.

Figure 4 shows arc shape images without a shielding gas in both environments. In this case, an ND filter with 0.05 transmissivity was used. The arc shapes were very similar in both environments, though the arc shape in the microgravity environment was less stable. Thus, no effect of gravity on the arc shape was observed regardless of the shielding gas flow rate.

3.3 Arc gap

A possible reason for the change in the arc shape is the displacement of the arc gap during the transition from the terrestrial to the microgravity environment. Figure 5 and 6 show the change in the arc shape and the arc voltage during the transition from under a terrestrial condition to under a microgravity condition, respec-

Fig. 5 Change in arc shape during transition from terrestrial environment to microgravity environment.

Fig. 6 Change in arc voltage during transition from terrestrial environment to microgravity environment.

tively. As shown in Fig. 5, the arc shape in the microgravity environment is larger than that in the terrestrial environment. In the microgravity experiment, the tension of the welding torch is released during the transition from the terrestrial environment to the microgravity environment. For this reason, the arc gap becomes about 0.6 mm (20%) longer. In this case, the arc voltage increases during the transition, as shown in Fig. 6. This result is consistent.

4. Conclusions

The effect of gravity on the arc shape was investigated by performing gas tungsten arc welding both in a terrestrial environment and a microgravity environment. As a result, the following conclusions were

achieved.

(1) In both the high temperature and the low temperature regions, that is, in the arc core region and in the arc flame region, no effect of gravity is observed under general welding conditions (over 70 A) regardless of the shielding gas flow rate.

(2) The displacement of the arc gap during the transition from the terrestrial environment to the microgravity environment can change the arc shape.

Acknowledgments

The authors greatly appreciate the support from the Japan Space Utilization Promotion Center (JSUP), the Japan Microgravity Center (JAMIC) and the Japan Space Forum.

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