ANODE HEATING AND MELTING IN THE ARGON GTA

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ABSTRACT

In order to make clear the physical relation among the arc plasma, the anode heat transfer and the weld penetration, the results of experimental measurements of temperatures of arc plasma, the distributions of heat input and current on the anode and the weld penetration were presented. The experimental results showed that the electron temperature above the anode and current and heat input density on the anode was dominated by the position of the cathode. Furthermore, it was showed that electron temperature of arc plasma was dominated by the cathode shape. These results were related with the results of the welded penetration measurements. As a result, it was showed that the electron temperature above the anode and current density distribution on the anode decided the heat input density distribution on the anode and that the heat input density on the anode remarkably dominated the size of the weld penetration in argon GTA welding process. Furthermore, it was suggested that the cathode played the important role in the determination of the weld penetration in argon GTA welding process.

KEYWORDS

GTA, anode heating, anode melting, cathode shape, electron temperature

1. Introduction

In the materials processing by thermal plasmas, it is important to take into consideration not only heat conduction mechanism in the materials but also heat transfer mechanism from the thermal plasma to the materials, because temperature of the plasma would strongly affect the heat input into the materials and then it would decide the results through the heat conduction in the materials. Furthermore, in the materials processing by the Gas Tungsten Arc (GTA), the materials generally become an anode electrode opposite a tungsten cathode electrode. The mechanism of the anode heat transfer is more difficult to understand in comparison with simple heat transfer between thermal plasma and materials, because an electric current, namely, arc current exists in the anode. There are the anode fall heating, the electron enthalpy entering the anode and the electrical potential energy of work function of the anode material other than the conduction and the radiation in the anode heat transfer from the arc plasma. [1-2]

Thus, understanding the relation among the temperatures of the arc plasma, the distributions of current and heat input on the anode, and weld penetration is quite important for the materials processing by the GTA. However, experimental and theoretical investigations of the temperature of arc plasma [2-8], the distributions of current and heat input [9-10], and weld penetration [11-15] were separately conducted and the relation among them has not been made clear. For example, Nestor [9] measured the distributions of current and heat input on the anode of GTA by using the water-cooled copper anode which consists of two separate blocks. He assessed the effects of the process parameters such as arc current, arc length, atmospheric pressure, atmospheric gas and gas flow rate on the current and heat input distributions in GTA. However, no relation between thermodynamic state of the arc plasma and the distributions of current and heat input on the anode was shown in the assessment for the effect of changing the various process parameters. Furthermore, he did not take into consideration weld penetrations.

On the other hand, Haidar and Farmer [16] owed that the temperature of arc plasma depended on the conical angle of the tungsten cathode. This result suggests that cathode conical angle also affect the heat transfer phenomena from the arc plasma to the anode.

In the present work, the temperatures of arc plasma, the distributions of heat input and current on the anode, and the weld penetration were measured as a function of arc length in the GTA at the atmospheric pressure. Furthermore, the temperatures of arc plasma and the weld penetration were also measured as a function of cathode conical angle. Then, the physical relation among the arc plasma, the anode heat transfer and the weld penetration was discussed.

2. Experimental method

2.1 Electron temperature measurements of arc column

The electron temperatures of the arc column were measured as a function of arc length and cathode conical angle by using Thomson scattering method. The theory and the procedures of Thomson scattering method were explicated in our previous papers. [2-8] The measurements were conducted for the argon GTA at atmospheric pressure under the conditions in the arc current of 100 amp.

2.2 Heat and current density measurements

Current and heat input density is measured using a divided anode as shown in Fig. 1. Current is measured by an ammeter connected to an anode and heat is estimated from temperature of water outlet and inlet. The arc is established between cathode and a divided anode. Moving the cathode in the interval of 0.5 mm, Surface probe data of current and heat are acquired. Using Abel inversion method, the surface data is inverted in point function data. [19]

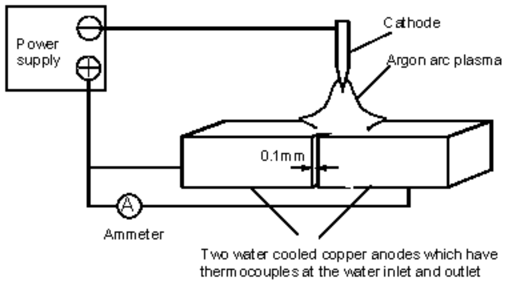

Fig. 1 Experimental apparatus for heat and current density

2.3 Penetration measurements

The bead-on-plate welding was conducted with SUS304 plate by argon GTA under the same condition in Thomson scattering measurements. The penetration was acquired as a function of arc length and the cathode conical angle, and then cress-sectional area of the weld penetration was evaluated in this paper. The welding travel speed was set 10 cm/min.

3. Results

Figure 2 shows the electron temperature in the argon GTA of 100 A for the arc length of 2.5 mm, 5 mm and 10 mm. It is derived by Thomson scattering measurements. The electron temperatures near the cathode are 22000 K thorough the all arc lengths. However, the electron temperatures at 1 mm above the anode are 22000 K for the arc length of 2.5 mm, 16000 K for that of 5.0 mm and 10000 K for that of 10 mm, and then decrease sharply as the arc length increases.

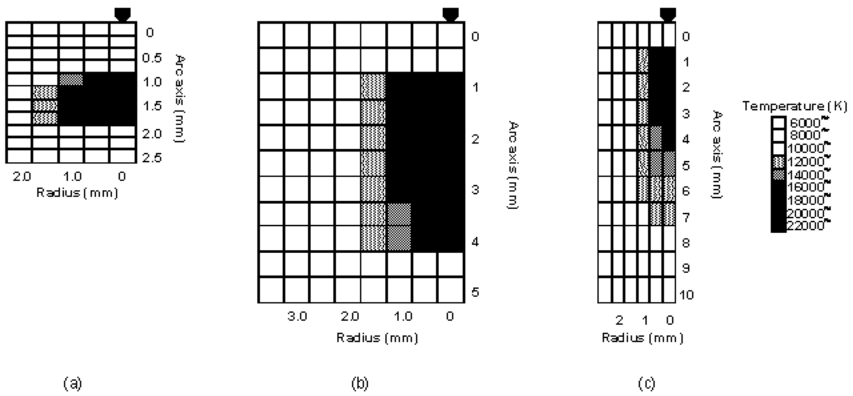

Fig. 2 Electron temperature as a function of arc length.

Figure 3 shows the distributions of current density and heat input density in the same cases in Fig. 2. Both the distributions show the same tendencies. The maximum densities of current and heat input are appeared for the arc length of 2.5 mm. The values are 500 A/cm^2 and 6.2 kW/cm^2 in the arc axis, respectively. These densities decrease to 95 A/cm^2 and 1.75 kW/cm^2 at the arc length of 10 mm.

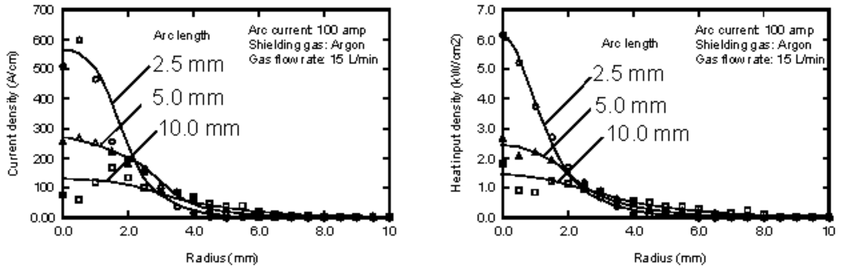

Fig. 3 Current and heat density as a function of arc length.

On the other hand, each anode root size concerned with both fluxes of current and heat at the anode surface is assessed with the full width at half maximum (FWHM) of each distribution. The anode root size is suitable for an effective anode diameter of the arc. The FWHM of current density distributions are 2.8 mm, 5.6 mm and 7.0mm for the arc length of 2.5 mm, 5.0 mm and 10.0 mm, respectively. The FWHM of heat input density distributions are 2.8 mm, 4.6 mm and 6.0 mm for each arc length. These results suggest that the anode root size of each flux should increase with the arc length.

Figure 4 shows the cross-sectional areas of the weld penetration of SUS304 as a function of arc length. Figure 4 also includes the values of heat input density at the center of the anode in Fig. 3. The penetration decreases as the arc length increases. The values are 6.39 mm^2 and 4.26 mm^2 for the arc length of 2.5 mm and 5 mm, respectively. In the case of arc length of 10 mm, no penetration is observed. This tendency is consistent with that of the heat input density

We measured the arc voltage in each arc length. The values are 9.8 V, 11.7 V and 14.4 V for the arc length of 2.5 mm, 5 mm and 10 mm, respectively. This means that input power of the arc increases with the arc length due to constant arc current. Practically, the radial integration value of each distribution of heat input density in Fig. 3 is 0.88 kW, 0.93 kW and 1.00 kW for the arc length of 2.5 mm, 5.0 mm and 10.0 mm, respectively. It is considered that the heat input density is more important than the input power of the arc for the weld penetration.

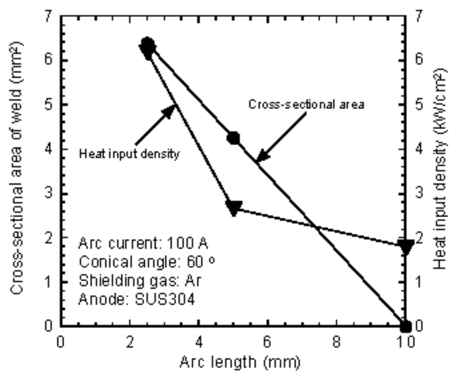

Fig. 4 Cross-sectional area of weld and heat input density at the anode as a function of arc length

4. Discussion

The results in Fig. 2 showed that the maximum electron temperature near the cathode was constant even if the arc length changed under the condition of constant arc current in argon GTA. Oppositely, Fig. 2 showed that the electron temperature near the anode decreased as the arc length increased. Thus, it can be safely concluded that the thermodynamic state of the arc plasma would be mainly dominated by the cathode phenomena. The cathode phenomena are characterized by strong mass flow induced by the arc current with its own magnetic field. This induced mass flow is generally called the cathode jet. [1] The cathode jet gives rise to stiff plasma frame with a visually well-known bell shape or a conical shape. [1] This stiff shape of the arc plasma leads to change of the anode root area of the arc if the arc length changes. If anode root area becomes large with increase of the arc length, it should lead to decrease of the arc current density at the anode surface as shown in Fig. 3. It means that temperature near the anode decrease owing to lower ohmic heating because of lower arc current density. Therefore, the electron temperature distributions above the anode would be strongly affected by the position of the cathode relative to the anode surface. The results in Figs. 2 and 3 are clearly related with the results of the weld penetration in Fig. 4. The relation is that electron temperature above the anode and current density distribution on the anode should decide the heat input density distribution on the anode. The electron temperature above the anode is suitable for the heat transfer by conduction from the arc plasma to the anode, and the current density on the anode is suitable for the heat transfer by electron such as enthalpy of electron entering the anode and the energy of the anode work function. [2, 18] The heat input density on the anode remarkably dominates the size of the weld penetration in the welding process by the free-burning argon arc. It suggests that the heat input density is quite important rather than the input power of the arc for the weld penetration.

From the influence of the cathode position to the relation, it can be suggested that cathode conical angle also affect the penetration phenomena in the welding process. Haidar and Farmer [16] showed that the temperature of arc plasma depended on the cathode conical angle with spectroscopic analysis. Changing a cathode conical angle resulted in changes in the surface temperature of cathode which changed the root size of the arc-cathode attachment region. [16] As a result, in the plasma surrounding the cathode, it was seemed that there was a change in the current density and the plasma temperature. [16] Thus, we measured the electron temperatures of free-burning argon arc of 100 A as a function of cathode conical angle with the Thomson scattering method. The arc length was set 5 mm. Figure 6 shows the electron temperature distributions in the arc axis for different cathode conical angles. As a cathode conical angle increases from 30 to 45 deg. , the electron temperature at 1mm from the cathode tip increases from 23000 to 25000 K, while it decreases to 22000 K for a cathode conical angle of 60 degrees. The maximum electron temperature is found for a cathode conical angle of 45 degrees. A difference of electron temperature between a cathode conical angle of 45 and 60 deg. is about 3000 K. This tendency agrees with the result of arc pressure. [19] Haidar and Farmer [16] showed that temperatures were found to be maximum for a cathode conical angle of 60 degrees. It is because the temperature for a cathode conical angle of 45 deg. was not measured in their experiments. It is presumed that the weld penetration would be maximum at cathode conical angle of 45 deg. , because it was deduced as before that electron temperature above the anode and current density on the anode decided the size of weld penetration in free-burning argon arc.

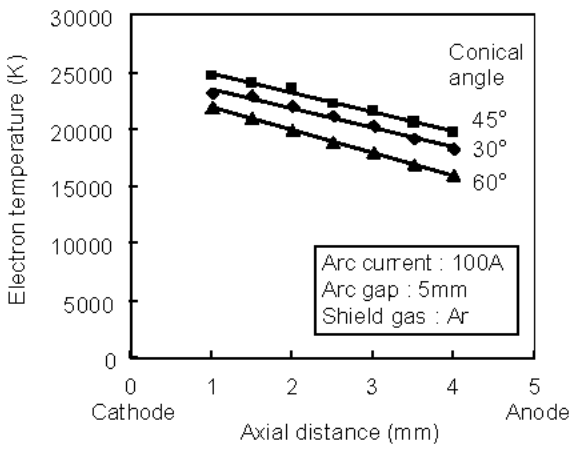

Fig. 6 Electron temperature of argon GTA plasma as a function of angles of conical cathode.

Figure 7 shows the results of the cross-sectional area of the weld penetration as a function of cathode conical angle under the same condition with Fig. 6 except the anode. Figure 7 also includes the results in Figure 6. The weld penetration are 4.5 mm^2, 4.6 mm^2 and 4.26 mm^2 for the cathode conical angles of 30, 45, 60 deg. , respectively. This tendency is consistent with that of the electron temperature of arc plasma as expected.

The above experimental results show the relation among the thermodynamic state of arc plasma, the current and heat distributions on the anode, and the weld penetration in the welding by argon GTA. The relation means that the position and shape of cathode have large effect on temperature of arc plasma and current density on the anode. The temperature of arc plasma and current density on the anode remarkably dominate the heat input density on the anode. It can be concluded that the heat input density is very important for the weld penetration in the welding process by the argon GTA, and it can be, therefore, concluded that the cathode plays the important role in the determination of the weld penetration.

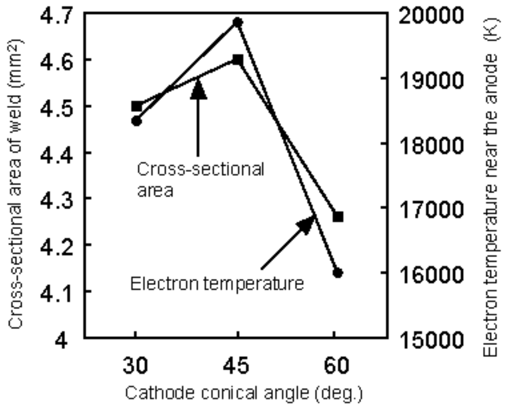

Fig. 7 Cross-sectional area and electron temperature as a function of cathode conical angel.

5. Conclusion

The physical relation among the arc plasma, the anode heat transfer and the weld penetration was shown. It was concluded that the electron temperature above the anode and current density distribution on the anode decided the heat input density distribution on the anode and then the heat input density on the anode rather than input power of the arc remarkably dominated the size of the weld penetration in the welding process by the argon GTA. Furthermore, it was suggested that the cathode played the important role in the determination of the weld penetration in the welding process.

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