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Effects of Anode Heat Transfer on Weld Penetration in Gas Tungsten Arc Welding †

TERASAKI Hidenori*, TANAKA Manabu** and USHIO Masao***

Abstract

n order to clarify the melting phenomena in Gas Tungsten Arc (GTA), the relation between heat transfer mechanism and melting phenomena in the anode is investigated. We also investigate the dependence of melting on the conical angle of cathode and shielding gas. These results show that the physical quantity which dominates the melting behavior is not the total heat input, but the heat input density, controlled by the current density.

1. Introduction

There is disagreement as to the relation between anode heating and anode melting in the GTA welding process. It is important to know the relation for the development of control process, for example in automatic GTA welding

There have been many previous investigations of heat transfer to the anode. Nestor[1] measured heat input and current density in a free-burning arc as a function of pressure, cathode shapes, arc lengths, arc currents and gas composition. Schoeck[2] also investigated the anode heat transfer phenomena as a function of arc current and arc length for argon arcs. Sanders and Pfender[3] measured the electron temperature and plasma space potential using a Langmiur probe. They concluded that the anode fall was negative for the two modes of free-burning arc operation, namely the mode dominated by the anode jet (AJD) and the mode dominated by the cathode jet (CJD). In addition they derived the relationship between the energy transfer rate by (a) electrons, (b) convection and (c) conduction, to the total heat input. As a result, it was shown that energy transfer by electrons was major part of the total heat input. The energy transfer rate by conduction was increased in CJD mode compared with that in AJD mode. However these works do not relate anode heat transfer to anode melting. Thus, the relation between anode heating and melting is not clear.

In the present paper, we measure current and heat input density as a function of radius at the anode, using a segmented anode for 50 amp and 150 amp, and also as a function of arc length. We also measure current density as a function of angle of the conical cathode and shielding gas. We also obtain estimates of the electron temperature of the arc column from laser scattering measurement as a function of radius, arc length, angles of the conical cathode and shielding gas. Deductions are also made of anode heating process from measurements of the amount of electrode melting, which give an indication of electrode temperature.

We conclude from our measurements that the heat input density controlled by the current density dominates the melting behavior.

2. Experimental Procedures

In the present work, the method of Nestor was applied for current and heat input density measurements. A divided anode was used with water-cooled anodes and separated by 0.1 mm to shield the current and heat transfer. An ammeter connected to an anode was used to measure currents. For heat input measurements, fluid temperature was measured by thermocouples set in the water entrance and exit of an anode. Using these temperatures, heat input was estimated by
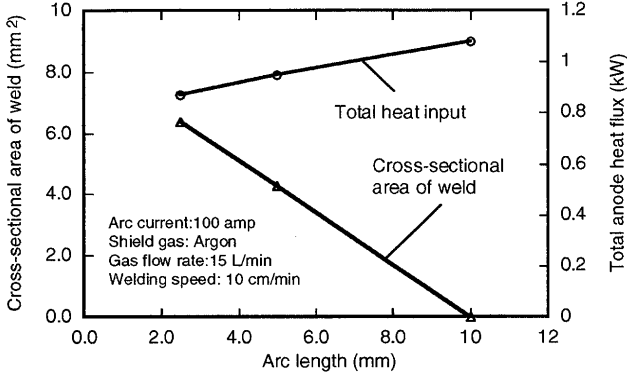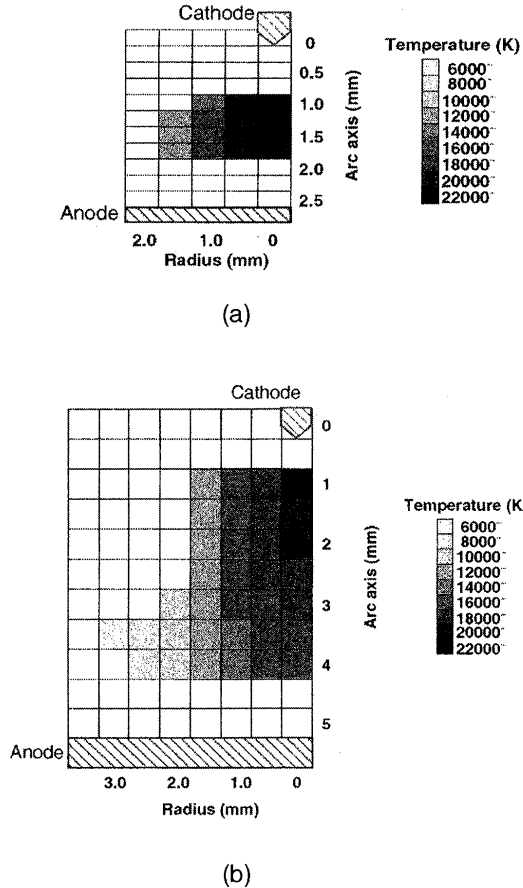

Fig. 1 Melting area and total heat input for 100 amp argon free-burning arc in arc lengths of 2.5 mm, 5 mm and 10 mm.

$$Q_{anode} = c_{water} \cdot (T_{out} - T_{in}) \cdot V_{water} \qquad (1)$$

where Q_{anode} (W) is measured heat input, c_{water} (J/gK) is specific heat of water, T_{in} (K), T_{out} (K) are fluid temperatures in entrance and exit of an anode and V_{water} (g/s) is water flow rate. In order to convert the measured current and the heat input data to radial current and heat input density data, the Abel inversion method was used[4].

The electron temperature of GTA plasma is measured by laser scattering[5-7] in the present work.

(a)

(b)

3. Results and Discussions

Measured melting area formed by bead-on-plate welding and total anode heat input for the 100 amp argon GTA in the arc lengths of 2.5 mm, 5 mm and 10 mm are shown in **Fig. 1**. As arc length increased, the total heat input also increased from 0.87 kW to 1.08 kW. On the other hand, the melting area sharply decreased from 6.39 mm^2 to zero. These results showed that total heat input was not the important physical quantity in considering melting area. In order to observe the thermodynamic state for the 100 amp argon GTA with the arc lengths of 2.5 mm, 5 mm and 10 mm, electron temperatures were measured by the Thomson scattering method. The measured results are shown in **Fig. 2**. The electron temperatures at 1mm below the cathode tip were 22000 K at all arc lengths. On the other hand, electron temperatures at 1 mm above the anode were 21000 K, 16000 K and 10000 K for the arc lengths of 2.5 mm, 5 mm and 10 mm, respectively. Since the arc current was 100 amp, electron temperature distributions have the same tendency as that in negative anode fall[8]. Therefore, electron temperatures at 1 mm above the anode in Fig. 2 can be used to estimate the electron temperatures on the anode. From the results shown in Fig. 2, current density distributions in GTA can be also estimated, because of Joule heating as a function of current density. From the estimation of current density, it can be considered that argon GTA has a shape of self-stabilized arc[9] at all arc lengths. The current density distributions in all arc lengths were measured. The results are shown in **Fig. 3**. As arc length increased, the current density decreased as expected. Measured heat input density is shown in **Fig. 4** in the all arc lengths. It was obviously shown that heat input density had the same tendency as the current

(c)
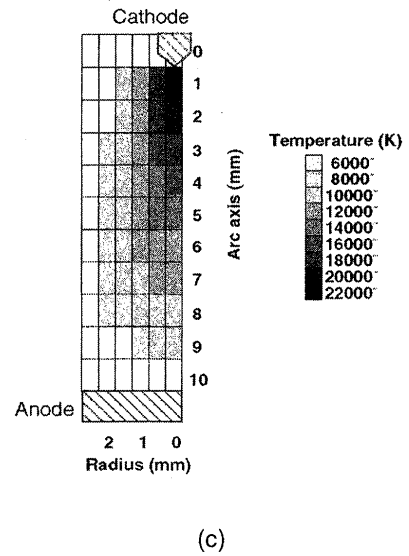
Fig. 2 Electron temperature distributions of argon TIG arc for the arc length of (a) 2.5 mm, (b) 5 mm and (c) 10 mm measured by the Thomson scattering.
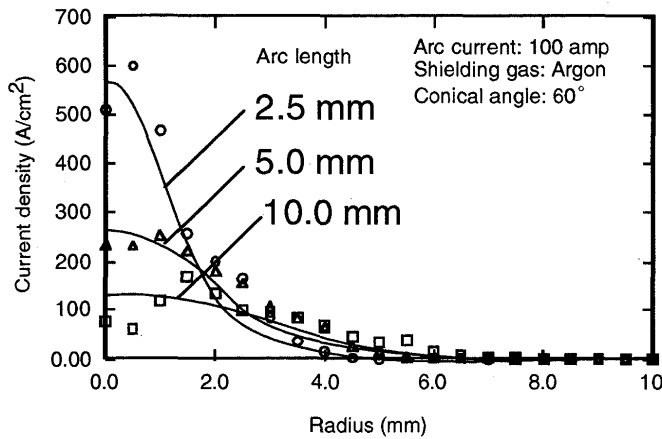
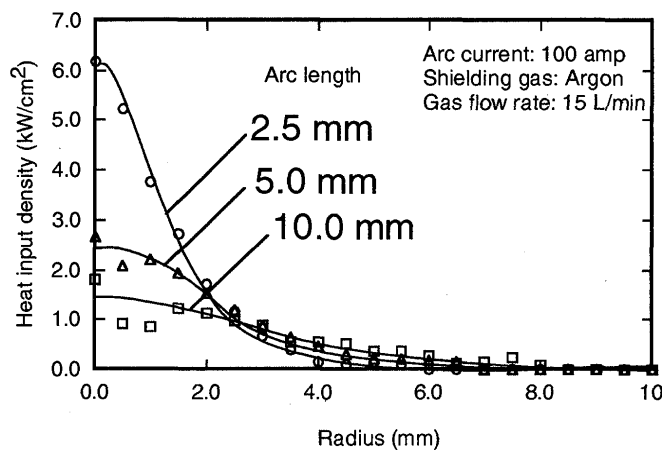**Fig. 3** Current density for the argon TIG as a function of arc length.

Fig. 5 Current density distributions for 100 and 150 amp helium free-burning arc at arc lengths of 5 mm.

Fig. 4 Heat input density distributions for 100 amp argon free-burning arc at arc lengths of 2.5 mm, 5 mm and 10 mm.
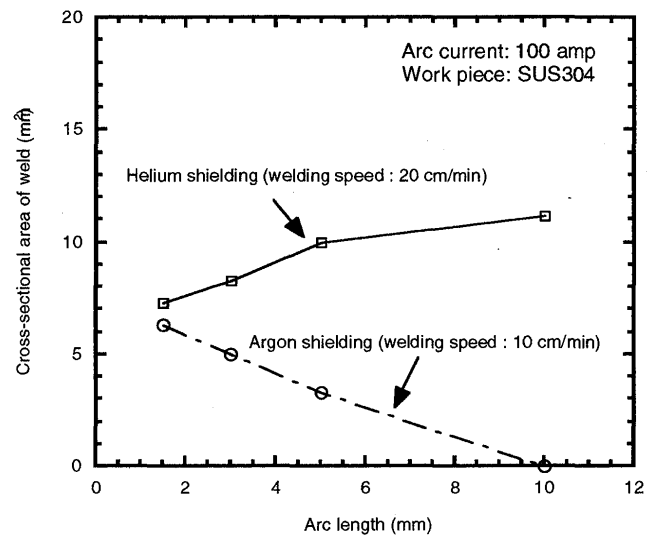
Fig. 6 Cross-sectional area of weld in argon and helium GTA as a function of arc length.

density in Fig. 3. From the above, the decreasing of electron temperature on the anode and current density at the anode were shown as arc length increased. From the relation between these decreases and melting area in Fig. 1, it can be concluded that the physical quantity which dominated melting phenomena was not total heat input, but heat input density at the anode, controlled by the electron temperature and current density on the anode. The relation is valid for the other arc conditions of arc length and shielding gas. The results of current density distribution on the anode and melting area in the helium GTA process, are shown in **Fig. 5** and **Fig. 6**, respectively.

4. Conclusions

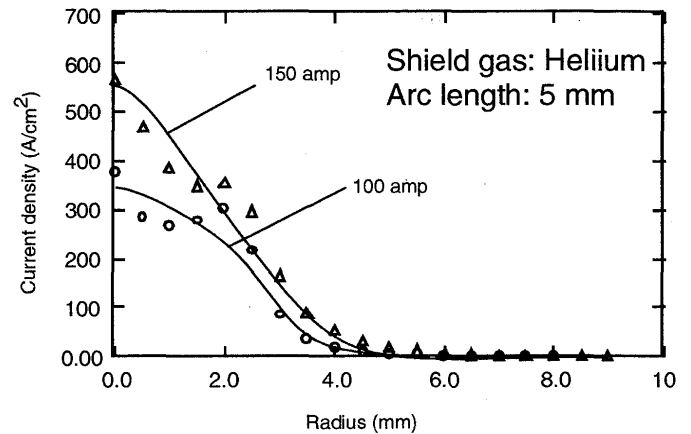From the relation among the heat input density at the anode, electron temperature at the anode and melting

area, it was shown that the physical quantity which dominates melting phenomena is not total heat input , but heat input density, controlled by current density.

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