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Fundamental Characteristics of the Hollow Cathode Arc as Welding Heat Source†

NISHIKAWA Hiroshi*, OHJI Takayoshi** and TAKEMOTO Tadashi**

Abstract

A feasibility study has been conducted to determine whether the Hollow Cathode Arc (HCA) can be used for a welding heat source in space, that is with high vacuum and microgravity conditions. The HCA is a low pressure arc discharge, which is formed under low pressure conditions by purging a small amount of gas through the center of the hollow cathode. Investigations into the characteristics of HCA have been experimentally performed. In the present paper, fundamental characteristics of the HCA in a vacuum chamber, such as volt-ampere characteristics, melting properties and plasma properties, have been investigated. Results show that, under the condition that the gas flowrate is low, the HCA column is concentrated under the cathode and the HCA is characterized by a high arc voltage and a high electron temperature. Regarding melting properties, penetration profiles for the HCA melting are sensitive to gas flowrate, and deep penetration can be formed if the gas flowrate is low.

KEY WORDS: (Hollow Cathode Arc), (Vacuum), (Heat Source), (Plasma Property), (Melting Property)

1. Introduction

Construction of the International Space Station (ISS) in orbit has been steadily progressing, and ISS is scheduled for completion in the year 2006. In this project, there is no schedule that welding technology will be used for construction in space. However, in the near future, it will be necessary to build various kinds of space structure, such as space stations and lunar bases, and then welding technology will be required to play a role in their assembly, operation and support.

The USSR and the USA recognized the necessity of space welding technologies, and research in this field has been performed since the 1960s[1-3]. Efforts have been made to establish space welding technologies, however several problems, such as safety and reliability of an electron beam process, remain to be solved for space welding technologies. In our researches, a feasibility study has been carried out to determine whether arc welding can be used for welding in space. It is considered that one of the most promising methods of forming an arc discharge in the vacuum of space is the Hollow Cathode Arc (HCA) method[4].

The pioneer work on HCA discharge was published in 1962 by Lidsky et al[5]. A considerable number of studies of HCA discharge as a plasma source were made in 1960s and 1970s[6]. Whereas most of the research on HCA as a heat source for materials processing seems to have been carried out in the USSR[7].

In the present work, the investigations into the fundamental characteristics of HCA, such as volt-ampere characteristics, melting properties and plasma properties, have been conducted under low pressure conditions.

2. Experimental

The HCA method enables an arc discharge to form under low pressure conditions, when it is extremely difficult for the conventional GTA method to form an arc discharge. Details of the welding torches are shown in **Fig.1**. In GTA welding, a solid tungsten electrode is usually used, whereas in HCA welding, a hollow tungsten electrode is used to supply a plasma forming gas from the tip of the electrode to the arc place. Argon was used as the plasma forming gas. **Table1** shows range of experimental conditions in the present work.

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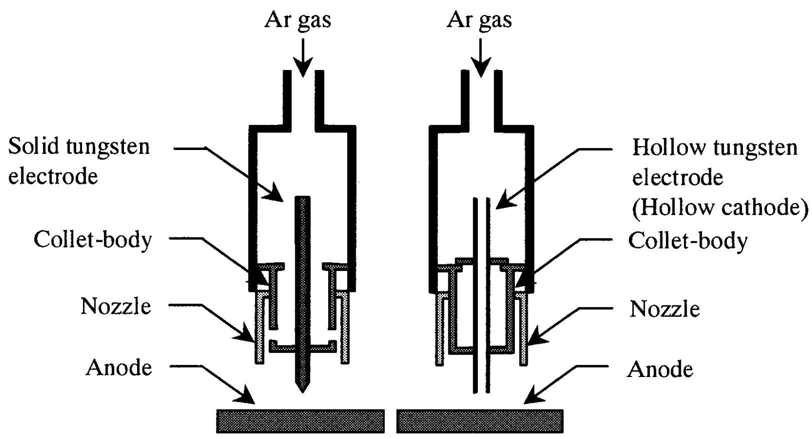
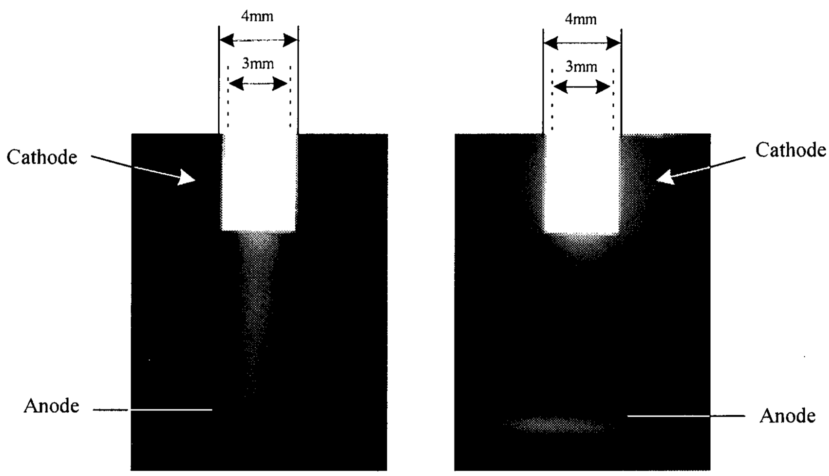


(a) Conventional GTA torch (b) HCA torch

Fig.1 Detail of welding torches

Table 1 Range of experimental conditions

Ambient pressure (Pa)	Electrode	Size of electrode (mm)	Arc current (A)	Arc length (mm)	Gas flowrate (ml/s)
5	Tungsten containing 2% thorium oxide	Outside diameter:4.0 Inside diameter :3.0	10-200	10	0.17, 1.7



(a) 0.17ml/s (b) 1.7ml/s

Fig.2 Effect of gas flowrate on HCA discharge (P =5Pa, I =100A, L=10mm, anode Copper)

3. Result and Discussion

3.1 Arc characteristics

Figure 2 shows HCA discharges in operation on Copper anode for the gas flowrates of 0.17ml/s and 1.7ml/s. The arc discharge under the condition of low gas flowrate (0.17ml/s) differs completely from that under the condition of high gas flowrate (1.7ml/s). In the case of low gas flowrate, a cylindrical discharge was clearly formed from the electrode to the anode.

The effect of the gas flowrate on the volt-ampere characteristics of the HCA is shown in **Fig.3**. The arc voltage of the HCA at low gas flowrate is higher than that at high gas flowrate by more than 10V.

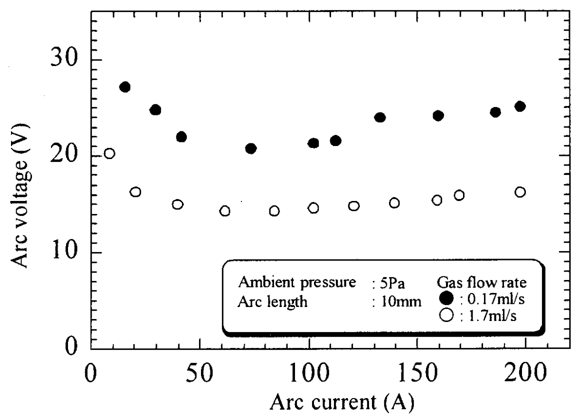
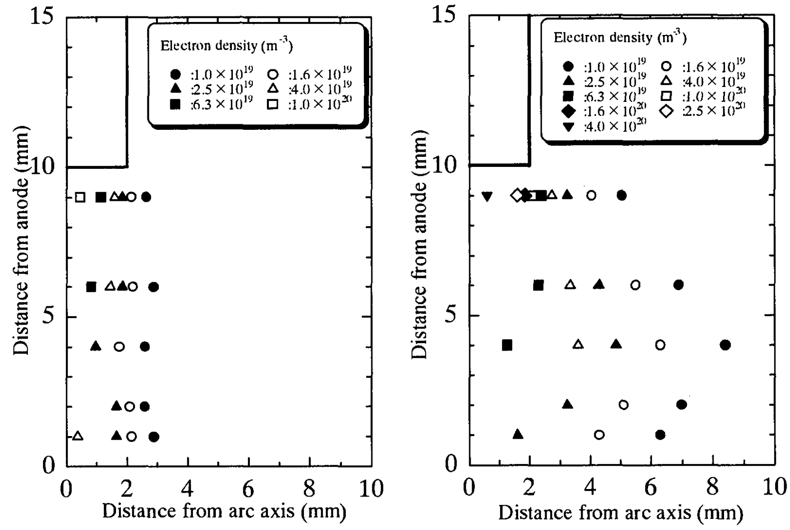
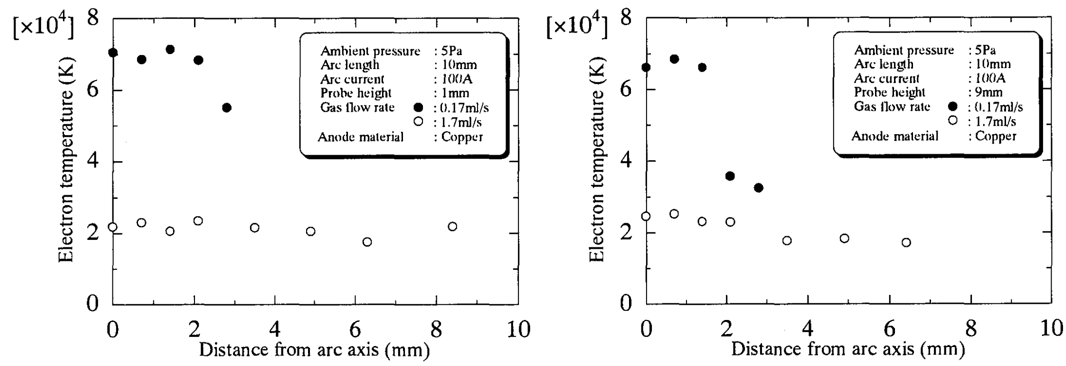


Fig.3 Effect of gas flowrate on volt-ampere characteristics (P=5Pa, L=10mm, anode Copper)



(a) 0.17ml/s (b) 1.7ml/s

Fig.4 Electron density distribution between electrodes
(P =5Pa, I =100A, L =10mm, anode Copper)



(a) 1mm (b) 9mm

Fig.5 Electron temperature distribution between electrodes
(P =5Pa, I =100A, L =10mm, anode Copper)

3.2 Electron temperature and density

The measurement of electron temperature and electron density in the arc space has been performed by using the Langmuir probe method to reveal the plasma property of the HCA.

Figure 4 shows the distribution of electron density in the arc space for the cases of low gas flowrate (0.17ml/s) and high gas flowrate (1.7ml/s). The distribution of electron density at low gas flowrate is concentrated under the electrode and is completely different from that at high gas flowrate. It is certain that a cylindrical discharge is formed between electrodes under the condition of low gas flowrate.

The electron temperature distributions in the HCA column at a height of 1mm and 9mm from the anode are indicated in **Fig.5**. Copper plate is used as the anode to avoid the influence of the metal vapor from the anode. The closed circle (●) shows the case for low gas flowrate and the open circle (○) shows the case for high gas flowrate. In the case of low gas flowrate, the electron temperature of the arc axis is about 65000~70000K and the electron temperature when the gas flowrate is 0.17ml/s is much higher than when the gas flowrate is 1.7ml/s.

As mentioned above, it has been made clear that Hollow Cathode Arc is a high and concentrated energy source in the case of low gas flowrate.

3.3 Melting tests

Melting experiments have been carried out to investigate the properties of the HCA as a welding heat source. The tests were performed on 12mm thick stainless steel (SUS304) and 30mm thick aluminum (A1050). The results are shown in **Fig.6** and **Fig.7**.

As shown in Fig.6, penetration profile is deep at the gas flowrate of 0.17m/s whereas, at 1.7ml/s, the penetration profile is shallow. It was found that the penetration dramatically increases with decreasing the

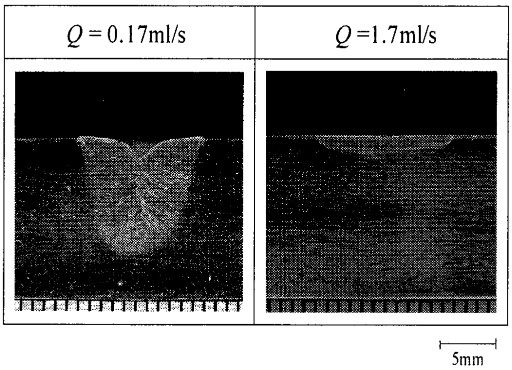


Fig.6 Effect of gas flowrate on penetration in HCA melting (P =5Pa, I =150A, L =10mm, Stainless steel)

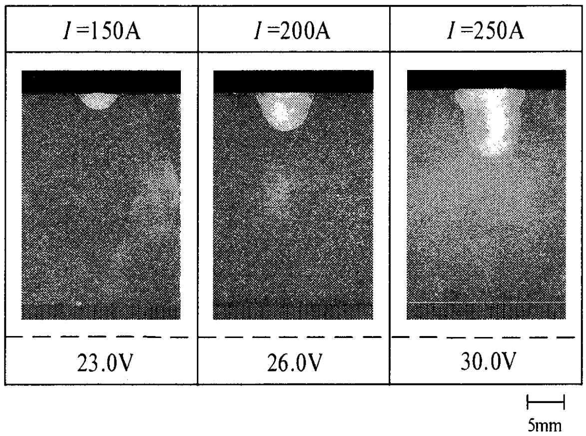


Fig.7 Effect of arc current on penetration in HCA welding (P =5Pa. L=10mm, Q =0.17ml/s v=5mm/s, Aluminum)

gas flowrate when the arc length is 10mm. Fig.7 shows that the penetration increases with increasing arc current and deep penetration is formed by HCA method, even when aluminum is used as a base metal.

4. Conclusion

Investigations into the fundamental characteristics of the Hollow Cathode Arc under low pressure conditions have been experimentally performed:

(1) Arc characteristics, melting properties and plasma properties are sensitive to gas flowrate.
(2) HCA is a high and concentrated energy source in the case of low gas flowrate.
(3) Deep penetration can be achieved under the condition of low gas flowrate, even when aluminum is used as a base metal.

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