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Characteristics of a CO_2 shielded gas tungsten arc†

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Abstract

In order to develop a novel heat source for materials processing with low costs and high productivity in comparison with the TIG arc, the characteristics of a CO_2 gas shielded plasma arc are studied. A double gas shielded system which consists of CO_2 gas and inert gas is employed for the plasma arc torch, so avoiding the consumption of tungsten electrode, and then achieves equivalent arc stability to a TIG arc for 1800 seconds operation. The arc voltage of the CO_2 gas shielded plasma arc in the conditions of arc current 150 A and arc gap 3 mm is about 19 V, which is much higher than the 12 V of a TIG arc. The CO_2 gas clearly constricts the arc and the maximum heat intensity at the anode surface in the CO_2 gas shielded plasma arc becomes about 10 times larger than that of the TIG arc. The penetration depth of stainless steel melted by the CO_2 gas shielded plasma arc is much larger than that for the argon TIG arc. It is concluded that the greater heating power of the CO_2 gas shielded plasma arc due to the arc constriction remarkably contributes to the high productivity of materials processing.

KEY WORDS: (CO_2 gas), (Thermal plasma), (Arc), (Heat source), (Materials processing), (Low cost), (High productivity)

1. Introduction

The TIG (tungsten inert gas) arc has become indispensable as a tool of materials processing, for example, surface treatment, arc furnace, melting, welding, processing of minerals, etc. for many industries because of the stable heat source and low equipment cost [1]. However, the principal disadvantages of TIG lie in the low productivity due to the diffuse heat source [2]. In order to improve the disadvantages of TIG, helium in the shielding gas has been used. For given values of arc current and arc gap, helium transfers more heat with its higher intensity into the material than argon [3, 4]. The greater heating power of the helium arc can be advantageous for the above materials processing in which the high productivity will be required. However, the cost of helium is higher than that of argon, specially, it is above twice the price in Japan. In the welding process, carbon dioxide (CO_2) or argon-CO_2 mixture has been generally used [5]. The cost of CO_2 is remarkably lower than that of argon, for example, it is below half in Japan. **Figure 1** shows typical physical properties of argon, helium and CO_2 which we calculated under the assumption of local thermodynamic equilibrium (LTE) in the same manner with the literature [6]. The characteristics of CO_2 principally show high specific heat in lower temperature regions, because helium effectively has the same specific heat as argon due to 10 % atomic weight of argon. The characteristics of helium principally show low electrical conductivity due to its higher ionization potential than argon. The low electrical conductivity of shielding gas in the arc leads to an arc constriction, because the arc current can exist only in the high temperature region of the plasma. Therefore, helium contributes toward higher productivity in the materials processes using the TIG arc due to its high heat intensity at the material and high arc voltage [3, 4]. On the other hand, the high specific heat of shielding gas should also lead to arc constriction, because it limits the heat transfer

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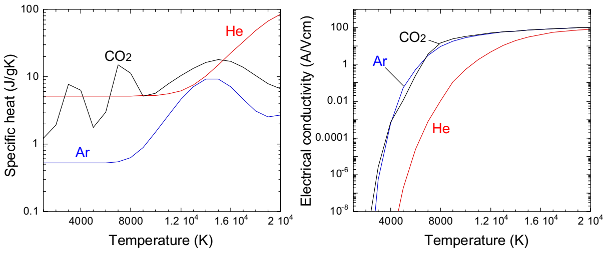

(a) (b)

Fig. 1 Typical physical properties of (a) specific heat and (b) electrical conductivity for argon, helium and CO_2 at atmospheric pressure.

in the arc fringes and then fixes an arc current passage in the arc axis area. The increase of arc current density due to the fixed arc current, specially, close to the cathode region will increase the electromagnetic force and, therefore, the cathode jet for cooling the arc column. The net effect of cooling the arc by the heat convection due to the cathode jet is an increase of its axis temperature because of the arc constriction [7]. It is frequently called 'thermal pinch effect' in Japan [8]. The thermal pinch effect, also, would contribute toward higher productivity in the materials processes using the TIG arc.

This paper presents the characteristics of a CO_2 gas shielded plasma arc in order to develop a novel heat source for materials processing with low costs and high productivity in comparison with the argon TIG arc. A double gas shielded system which consists of CO_2 gas and inert gas is employed for the plasma arc torch so avoiding the consumption of tungsten electrode. We give arc appearances with arc voltages for the same arc current and also heat intensity distributions at the surface of a water cooled copper anode, in comparison with the argon TIG arc. We also assess the performance of the CO_2 gas shielded plasma arc in terms of penetration depth by melting stainless steel.

2. Experimental Procedure

Figure 2 shows the appearance of a torch for the CO_2 gas shielded plasma arc and its schematic illustration. The cathode electrode was of tungsten, with 2% La_2O_3, having a diameter 2.4 mm and a conical tip of angle 45 degrees. A double gas shielded system which consisted of CO_2 gas and inert gas was employed for the torch so avoiding the consumption of tungsten electrode. The small amount of inert gas was supplied to an inner copper nozzle, but the CO_2 gas was supplied to an outer ceramic nozzle. We defined an electrode extension as a distance from the tip of the inner copper nozzle to the tip of the tungsten electrode. The electrode consumption after arc operation on a water cooled copper anode for 1800 seconds was measured in response to given electrode extensions and also gas flow rates of inert gas. We observed arc behavior of the CO_2 gas shielded plasma arc at atmospheric pressure by using a digital camera and measured its arc voltage, in comparison with the conventional TIG arc.

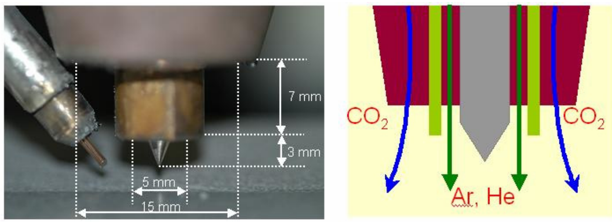

Fig. 2 A torch for the CO_2 gas shielded plasma arc and its schematic illustration.

To measure the heat flux intensity at the anode as a function of radius, we used the configuration of Nestor [9]. For these experiments the anode must be of copper for efficient heat transfer in the measurements of flux intensity. The method consists of splitting a water cooled copper anode and measuring the heat flux to one of the sections as a function of arc position relative to the splitting plane. The heat flux was calculated from measured changes in the temperature of the cooling water to the copper and also measuring the flow velocity of the water. The radial distributions of heat flux intensity as a function of radius at the anode surface could be then derived by the Abel inversion [10] of the heat flux measurements as a function of the displacement of the split anode relative to the center of the arc.

To evaluate a performance of the CO_2 gas shielded plasma arc, melting of stainless steel was carried out. The stainless steel was SUS304 (30 ppm sulfur content) and its plate size was 150 mm in length, 50 mm in width and 10 mm in thickness. The torch travel speed was set 9 cm/min and the arc current was also set 120 A. The cross-sections of the penetration were observed, in comparison with the conventional argon TIG arc.

3. Results and Discussion

Figure 3 shows the electrode consumption after arc operation on a water cooled copper anode for 1800 seconds at 100 A in arc current and 10 L/min in CO_2 gas flow rate, in comparison with the case of argon TIG arc at the same current. The electrode consumption depends on the electrode extension and the gas flow rate of argon from the inner copper nozzle, but it is equivalent to the electrode consumption for argon TIG arc under the conditions, namely, below 3 mm in the electrode extension and also above 5 L/min in argon gas flow rate. The CO_2 gas shielded plasma arc achieves equivalent arc stability to TIG arc under the conditions.

Figure 4 shows the appearances and arc voltages of CO_2 gas shielded plasma arcs using argon and argon-hydrogen mixture as inert gas from the inner copper nozzle at 150 A in arc current and 3 mm in electrode extension. Fig. 4 also shows the appearances and arc voltages of conventional TIG arcs in argon. All arcs were operated on the water cooled copper anode at 3 mm in arc gap. The arc constriction for CO_2 gas shielded plasma arc is clearly observed compared with the conventional TIG arc. The CO_2 gas shielded plasma arc remarkably increases arc voltage and, specially, reaches

18.9 V for argon-hydrogen mixture as the inner nozzle gas. **Figure 5** shows the heat intensity distributions at the anode surface for CO_2 gas shielded plasma arc using argon as the inner nozzle gas and for argon TIG arc at 50 A in arc current and 3 mm in arc gap. The CO_2 gas clearly constricts the arc due to the thermal pinch effect, and the maximum heat intensity for the CO_2 gas shielded plasma arc becomes about 10 times larger than that for argon TIG arc.

The greater heating power of the CO_2 gas shielded plasma arc due to increase of arc voltage and also heat intensity will be advantageous for the materials processing in which the high productivity is required. **Figure 6** shows typical cross-sections of melts for a stainless steel, which were conducted under conditions of 120 A in arc current, 3 mm in arc gap and 9 cm/min in torch travel speed. The penetration depths for CO_2 gas shielded plasma arcs are 4.9 mm for argon and 6.9 mm for argon-hydrogen mixture as the inner nozzle gas, and they are considerably larger than that for argon TIG arc. We think that the arc constriction for the CO_2 gas shielded plasma arc largely contributes to the high productivity of the materials processing.

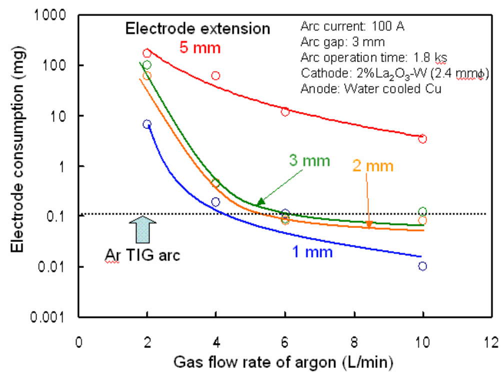

Fig. 3 Electrode consumption after arc operation for 1800 seconds at 100 A in arc current and 10 L/min in CO_2 gas flow rate, in comparison with the case of argon TIG arc.

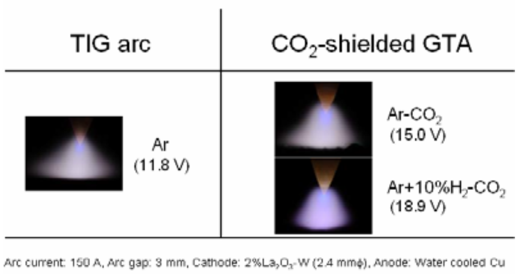

Fig. 4 Appearances and arc voltages of CO_2 gas shielded plasma arcs using argon and argon-hydrogen mixture as inner nozzle gas, in comparison with conventional TIG arcs in argon.

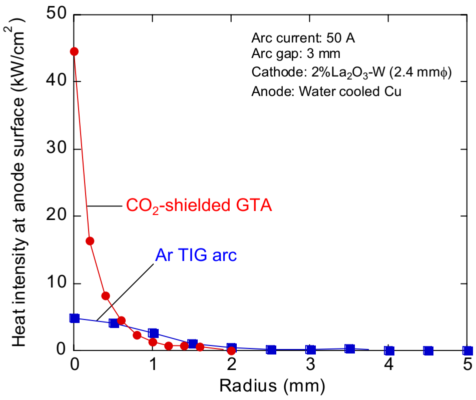

Fig. 5 Heat intensity distributions at anode surface for CO_2 gas shielded plasma arc using argon as inner nozzle gas and for argon TIG arc at 50 A in arc current and 3 mm in arc gap.

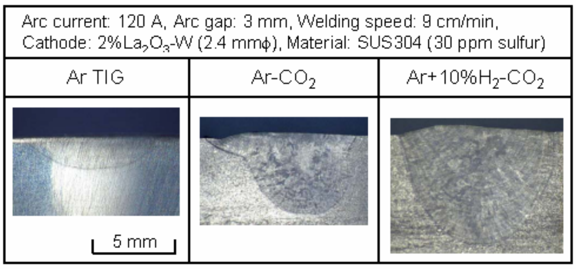

Fig. 6 Typical cross-sections of penetrations for a stainless steel, which were melted by using CO_2 gas shielded plasma arc and argon TIG arc.

4. Conclusions

The conclusions in the present paper are summarized as follows.

(1) A CO_2 gas shielded plasma arc was developed.
(2) A double gas shielded system which consists of CO_2 gas and inert gas was employed for the plasma arc torch so avoiding the consumption of tungsten electrode and then achieved equivalent arc stability to the conventional TIG arc during 1800 seconds operation.
(3) The arc voltage of the CO_2 gas shielded plasma arc at 150 A in arc current and 3 mm in arc gap reached about 19 V which was much higher than 12 V of argon TIG arc in the same conditions.
(4) The CO_2 gas clearly constricted the arc and the maximum heat intensity at the surface for the CO_2 gas shielded plasma arc became about 10 times larger than that for argon TIG arc.
(5) The penetration depth of a stainless steel melted by the CO_2 gas shielded plasma arc was much larger than that for the argon TIG arc. The greater heating power of the CO_2 gas shielded plasma arc due to the arc constriction strongly contributed to the high productivity of the materials processing.

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