

# EFFECTS OF ELECTRODE SIZE ON ELECTRODE EROSION IN AC PLASMA TORCHES

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## ABSTRACT

The effects of electrode size on the electrode erosion in case of AC argon plasma were clarified at a low current of 200A. A good correlation was obtained quantitatively between the calculated temperature of the electrode tip and the measured electrode erosion. The optimal temperature of the electrode tip for reducing the electrode erosion to the commercial level was discussed.

## 1. INTRODUCTION

Recently, AC arc plasma heating techniques have been used for melting flyash [1] and for keeping molten steel at high temperature in a tundish of continuous casting process [2]. However, in using AC arc plasma heating, there are some problems that the electrode erosion in plasma torch is severe and that arc plasma is apt to be unstable at current zero [3].

In this paper, in order to examine and reduce the electrode erosion, we present experimental results concerning the effects of electrode stem size (diameter and length) and tip shape on the electrode erosion in case of argon plasma at a low current of 200 A, together with calculative results concerning the heat balance in the electrode and the electrode tip temperature.

## 2. EXPERIMENTAL SETUP AND CONDITIONS

The experimental setup is shown in Fig. 1. The AC argon plasma of 200A was generated between the copper nozzle and the tungsten electrode for 1-2 hours. The resistance thermometer sensors (Pt100) were set at the electrode coolant inlet and outlet. The electrode coolant loss was obtained from the coolant temperature increase and flow rate. The electrodes used were solid type and the material was tungsten containing 2 wt% of lanthanum oxide.

## 3. EXPERIMENTAL RESULTS

### 3.1 Influence of Electrode Stem Size on Electrode Erosion

Fig. 2 shows the electrode erosion rates  $E_R$  (●) and the electrode coolant losses  $Q_{water}$  (○) obtained by using electrodes of 5mm<sup>2</sup> in tip area  $S_t$ , 11,16 and 31mm in length  $l$ , and 6,8 and

10mm in diameter  $d$  ( $28,50$  and  $80\text{mm}^2$  in cross section  $S_c$ ). X-axis " $l/S_c$ " can be considered as the electrode thermal resistance. As the electrode diameter increased or the electrode length decreased, that is, the electrode thermal resistance decreased, the electrode coolant loss increased and the electrode erosion rate decreased, where  $l\text{ng}/C$  is the commercial level.

### 3.2 Influence of Electrode Tip Area on Electrode Erosion

Fig. 3 shows the electrode erosion rates  $E_R$  (●) and the electrode coolant losses  $Q_{\text{water}}$  (○) obtained by using electrodes of  $l=26\text{mm}$ ,  $d=6\text{mm}$  ( $S_c=28\text{mm}^2$ ),  $S_t=7,14$  and  $28\text{mm}^2$ . As the electrode tip area increased, the electrode coolant loss remained constant and the electrode erosion rate decreased.

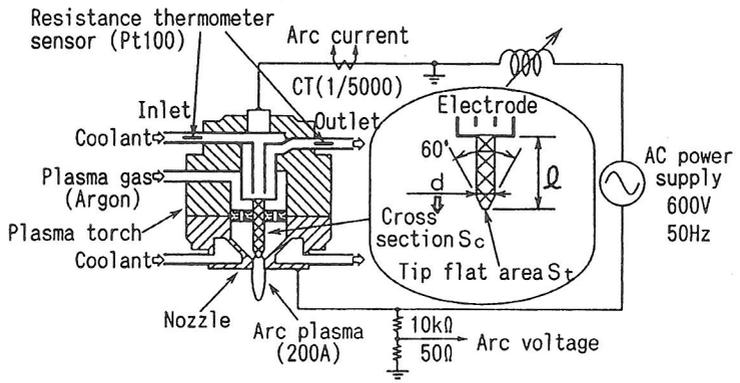


Fig.1 Experimental setup

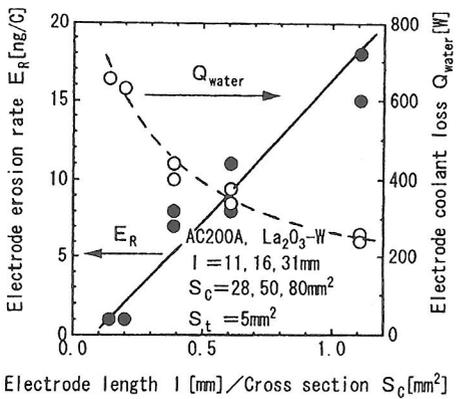


Fig.2 Dependence of electrode erosion rate and electrode coolant loss on electrode size (length and thickness)

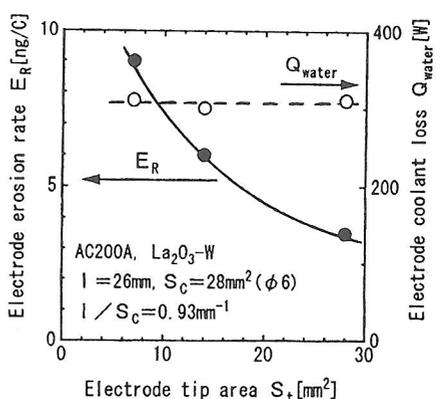
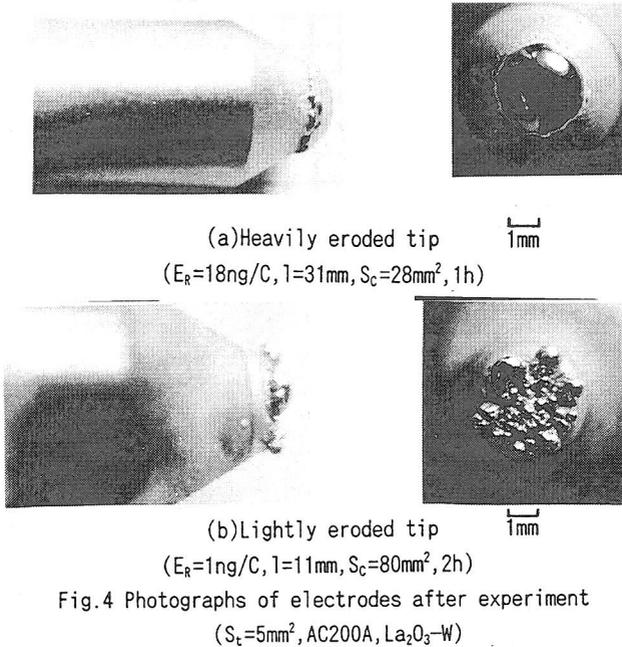


Fig.3 Dependence of electrode erosion rate and electrode coolant loss on electrode tip area

### 3.3 Electrode Tip After Operation

Fig. 4 shows photographs of electrode tips after operation. Fig. 4(a) shows a heavily eroded electrode. The electrode tip was molten uniformly. The electrode tip condition suggests that the average temperature of the electrode tip reached the melting point(3,660K). On the other hand, Fig. 4(b) shows a lightly eroded electrode. The electrode tip was molten partially. This electrode tip condition suggests that the average temperature of the electrode tip was somewhat lower than the melting point.



## 4. DISCUSSION

In this chapter, we pay attention to the electrode tip temperature that would influence the electrode erosion and discuss the relation between the electrode tip temperature and the electrode erosion. First, in order to calculate the heat that passes through the electrode, the heat balance in the electrode was calculated. Second, in order to calculate the electrode tip temperature, the temperature distribution along the electrode axis from electrode root to tip was calculated.

### 4.1 Calculation of Heat Balance in the Electrode

Typical heat quantities put into and extracted from the electrode were as follows:

[ I ] Heat put into the electrode ( $Q_{in}$ )

- ① Heat due to electrode drop voltage ( $Q_{drop}$ )
- ② Heat due to radiation from arc plasma ( $Q_{radA}$ )
- ③ Heat due to Joule effect in the electrode ( $Q_{RI}^2$ )

[ II ] Heat put into the electrode used as an anode and  
 extracted from the electrode used as a cathode

④ Heat due to electron energy ( $Q_{ele}$ )

[ III ] Heat extracted from the electrode ( $Q_{out}$ )

⑤ Heat due to cooling water ( $Q_{water}$ )

⑥ Heat due to flowing plasma gas ( $Q_{gas}$ )

⑦ Heat due to radiation from the electrode tip surface ( $Q_{radE}$ )

⑧ Melting heat of electrode tip ( $Q_{melt}$ )

⑨ Evaporation heat of electrode tip ( $Q_{vapor}$ )

Fig. 5 shows each heat calculated under experimental conditions.  $Q_{ele}$ (④) was zero because of AC.  $Q_{drop}$ (①) was calculated supposing that  $Q_{in}$  was equal to  $Q_{out}$  after calculation of other heats(②~⑨). Main results are as follows:

- (1) Most (70~80%) of  $Q_{in}$  was  $Q_{drop}$ .
- (2) As the electrode diameter increased or the electrode length decreased,  $Q_{in}$  increased due to  $Q_{drop}$  increase. The cause of  $Q_{drop}$  increase was not obvious, and there is a report [4] that the electrode drop voltage increased as the electrode diameter increased.
- (3) Most (80~90%) of  $Q_{out}$  was  $Q_{water}$ .

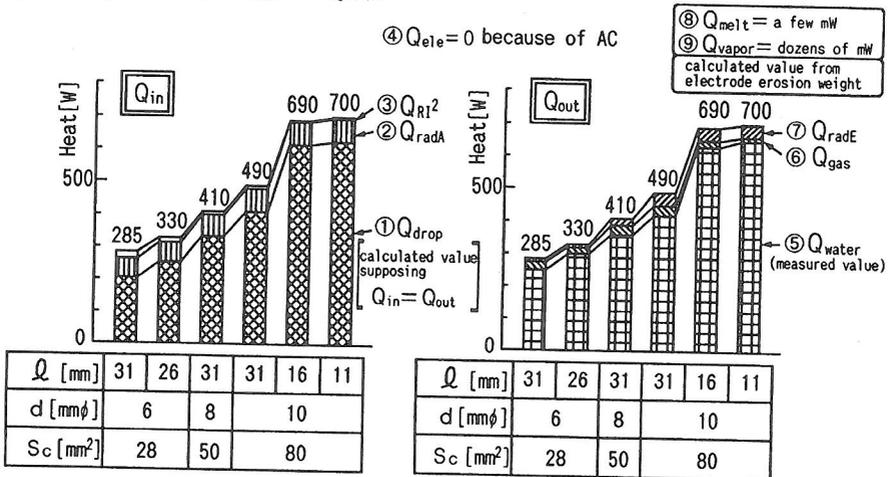


Fig.5 Calculation results of heat balance in the electrode(AC200A, La<sub>2</sub>O<sub>3</sub>-W)

## 4.2 Calculation of Electrode Tip Temperature

The calculation steps were as follows:

- (1) temperature of coolant → (2) temperature of the electrode root in touch with coolant → (3) temperature of the electrode from the root to the tip.

The details are explained below.

- (1) The temperature of coolant was 5°C(278K) as experimentally set.
- (2) The calculation of temperature of the electrode root in touch with coolant was carried out,

using calculated heat transfer coefficient, calculated heat transfer area and measured  $Q_{\text{water}}$ . As a result, the heat transfer with boiling was supposed to occur at the electrode root in touch with coolant. Therefore, the temperature of the electrode root in touch with coolant was supposed 100°C (373K) corresponding to the water boiling point.

- (3) The analysis of steady-state heat conduction along the electrode axis was carried out, considering the dependence of thermal conductivity on temperature [5]. The heat that passed through the electrode from the tip to the root was  $(Q_{\text{in}} - Q_{\text{radE}})$  calculated in the paragraph <4.1>.

Fig. 6 shows the dependence of calculated temperature of the electrode tip  $T_t$  on electrode length  $l$  and electrode cross section  $S_c$ . X-axis is the same as Fig. 2. As the electrode size ratio of  $l/S_c$  decreased, the temperature  $T_t$  decreased. We consider that the decrease of  $l/S_c$  caused the decrease of the electrode thermal resistance and the decrease of the electrode tip temperature.

On the other hand, the dependence of calculated temperature  $T_t$  on the electrode tip area  $S_t$  was discussed. As the area  $S_t$  increased, the temperature  $T_t$  decreased. We consider that the increase of  $S_t$  caused the decrease of the heat density from arc plasma to the electrode and the decrease of the electrode tip temperature.

### 4.3 Relation between Electrode Erosion and Electrode Tip Temperature

Fig. 7 shows the relation between the measured electrode erosion rate and the calculated temperature of electrode tip. As the electrode tip temperature decreased, the electrode erosion rate decreased. That is, as the tip temperature decreased to 2,700K (c.f. tungsten melting point: 3,660K), the electrode erosion rate decreased to 1ng/C.

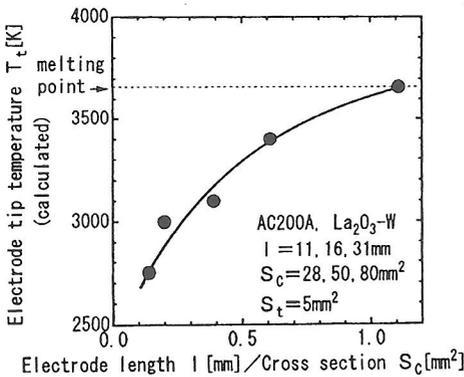


Fig. 6 Relation between electrode size ratio of length/cross-section and calculated temperature of electrode tip

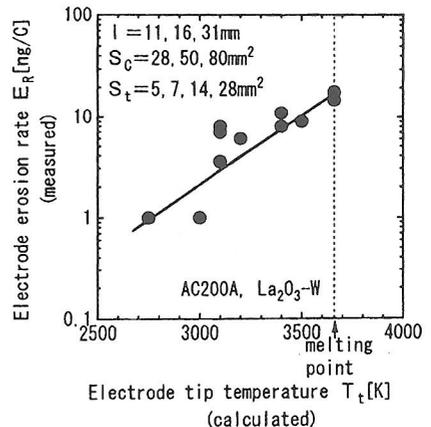


Fig. 7 Relation between measured electrode erosion rate and calculated temperature of electrode tip

## 5. CONCLUSION

The effects of electrode stem size (diameter and length) and tip shape on the electrode erosion in case of argon plasma were clarified at a low current of 200A. The electrodes used were solid type and the material was tungsten containing 2 wt% lanthanum oxide. Main results are as follows:

1. As the electrode diameter increased or the electrode length decreased or the flat area of electrode tip increased, the electrode erosion rate decreased.
2. A good correlation was obtained between the calculated temperature of the electrode tip and the measured electrode erosion rate. That is, as the tip temperature decreased to 2,700K, the electrode erosion rate decreased to 1ng/C (commercial level).

## ACKNOWLEDGMENT

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