New Sintered Electrode of Ir-Y_2O_3 System for Air-Plasma Cutting†

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Abstract

This paper describes on the new developed Ir-Y_2O_3 electrode for plasma cutting torch using air and oxygen in a operating gas.

From the two type consumption tests, the continuous operation and the periodic operation at 25A in air, Ir including 15wt%Y_2O_3 electrode showed a good durability rather than Hf electrode. And Ir-Y_2O_3 system showed the same erosion characteristic of dependency on Y_2O_3 content in metal as Ru-Y_2O_3 system.

Especially, Ir-Y_2O_3 electrode showed a good erosion resistance compared with Hf one until the large arc current (200A) in oxygen operating gas.

KEY WORDS : (Air Plasma Cutting) (Iridium) (Yttrium-Oxide) (Ruthenium) (Hafnium) (Cathode Material) (Erosion)

1. Introduction

We have developed a durable cathode material for plasma cutting using oxidizing gas and investigated a consumption mechanism of its electrode. From the previous study, the new developed electrode which the sintered Ru-Y_2O_3 tip was inserted in a copper sheath showed a good durability from the consumption test under 25A in a arc current using an compressed air, compared with Hf electrode which was widely used in several iudustries[1]. This durability of the sintered 80Ru-20Y_2O_3 electrode was considered due to having the high thermal and electric conductivity of the sintered bulk rather than those of Hf[2], and to different the cathode surface state during arc discharge dependency on the electrode consumption. In case of 80Ru-20Y_2O_3 electrode, the cathode surface was covered with the thick layer Y_2O_3 with a low work function on the cathode surface[3].

This study showed the consumption characteristics of the newly developed Ir-Y_2O_3 electrode which was made by the sintering method same as Ru-Y_2O_3 electrode. The durability of Ir-Y_2O_3 was comparatively investigated from two type consumption tests at 25A in a arc current; the continuous operation and the periodic operation. And also was attempted to apply its electrode to operating at a large arc current (until 250A)[4].

2. Experimental Procedures

2.1 Preparation of Sintered Electrode

The Ir-Y_2O_3 system electrode was made by the following procedure shown in **Fig.1**. The powdered Iridium (Ir) and Yttrium oxide (Y_2O_3) were weighed, mixed and pressed under 0.588MPa in a graphite die. After that, the pellets were sintered in a hydrogen atmosphere in 1.8ks at 2273K. The sintered tip of Ir-Y_2O_3 system were densified above 90% in a average density ratio, especially 85Ir-15Y_2O_3 was reached at 94%.

Figure 2 shows the electrode shapes which were used to the small arc current (a) and the large current (b).

2.2 Electrode Consumption Measurement

Figure 3 shows a schematic diagram of the experimental alignment which was used to evaluate the electrode consumption. This test was carried out by generating a continuous and a periodic arc discharge between the electrode tip and the water cooled copper anode for various periods at 25A using air. In case of a periodic operation, the current pules widths were 10,60 and 300s and the duty factor was 0.5.

And to be compared at the large arc current for oxidizing plasma cutting, the other consumption test was carried out by generating a continuous are discharge with maintaining 6mm in the extension between the cathode nozzle and the anode at various arc currents from 100 to 250A.

The consumption for the small type electrode was estimated by measuring the electrode weight loss using

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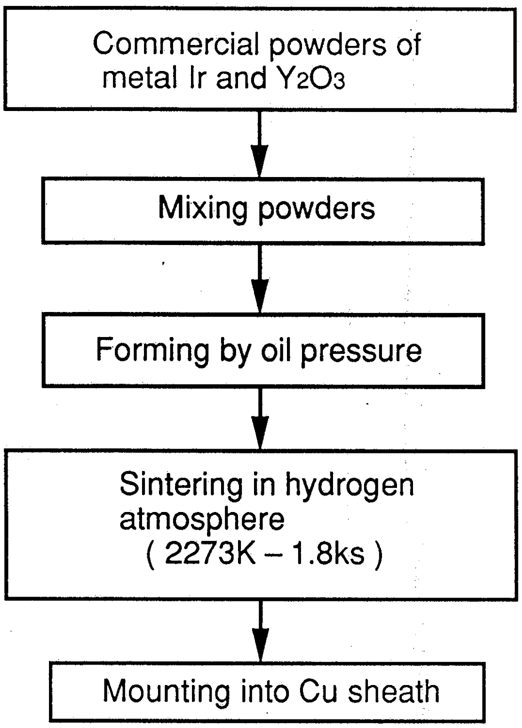

Fig. 1 Production process of Iridium-Yttrium oxide electrode.

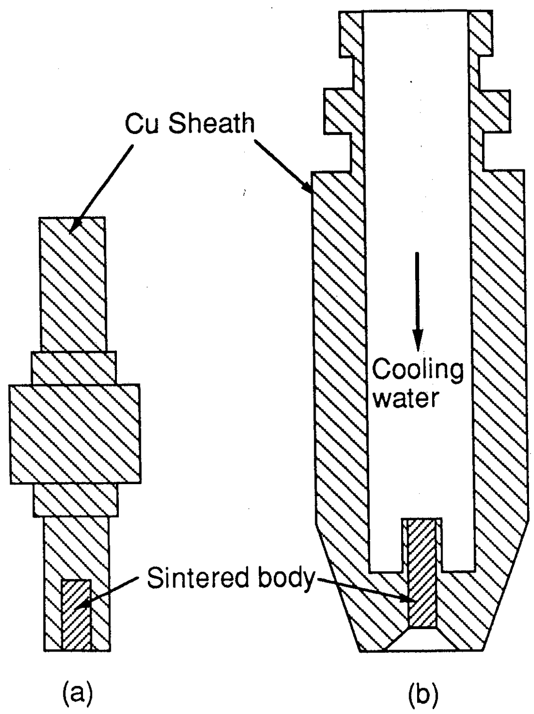

Fig. 2 Shapes of produced electrode.
(a): small current type.
(b): large current type.

the electric balance with sensitivity of 10^{-5}g after each test. On the other hand, the erosion durability for the large type electrode was estimated by measuring the erosion depth of the inserted tip in the copper sheath.

3. Experimental Results and Discussions

3.1 Consumption Characteristic Dependency on Y_2O_3 Content

Figure 4 shows the electrode consumption depending on Y_2O_3 content in Ir metal under the various operating times at 25A in air. From this results, the followings are obvious:

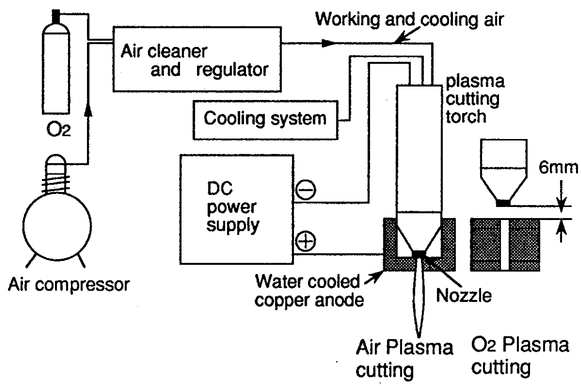

Fig. 3 Schematic diagram of electrode consumption test.

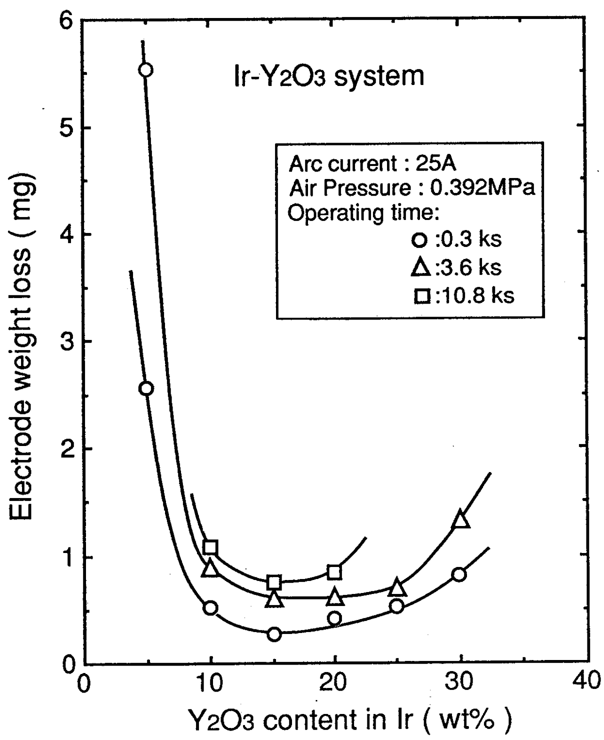

Fig. 4 Relationship between Y_2O_3 content and electrode weight loss of Ir-Y_2O_3 system.

(1) Ir-Y_2O_3 system had an extremely low consumption in the range from 10 to 25wt% in Y_2O_3 content for 3.6ks in a operating time. Above this range, the electrode weight loss increased with increasing the Y_2O_3 content. **(2)** this minimum loss range became narrow and slightly shifted towards the pure metal side. **(3)** Ir including round 15wt%Y_2O_3 showed a good erosion resistance in this system.

Figure 5 shows the appearance of the eroded surface for the typical Ir-Y_2O_3 electrodes with various Y_2O_3 content after discharge for 3.6ks at 25A in air. From the macrographic investigation, it is clearly observed that the eroded area of 85Ir-15Y_2O_3 electrode was very small compared with other component electrodes. And also this consumption characteristic of Ir-Y_2O_3 system showed the same as one of Ru-Y_2O_3 system. This is considered that Ir metal have a similar physical-chemical properties of Ru metal, for instance, melting point and boling point, thermal and electric conductivity, and heat of vaporization as shown in **Table 1**[5]. In particular, standard oxide formation free energy at the operating temperature strongly influences on the arc stability and the durability for Ir-Y_2O_3 and Ru-Y_2O_3 electrodes, because the oxidation-reduction on the cathode surface was ever generated during discharge. Therefore the durability of Ir-Y_2O_3 (or Ru-Y_2O_3) electrode might be depended on the coverage state of the molten Y_2O_3 layer on the cathode matrix according to Y_2O_3 content in metal.

3.2 Electrode Durability at Low Current

To estimate the electrode durability at the low current used, the two type consumption tests were carried out; the continuous and the periodic operations.

3.2.1 Continuous Operation

Here was compared the electrode durability as the volume loss of the inserted electrode material in the copper sheath for the tentavive 85Ir-15Y_2O_3, 85Ru-15Y_2O_3 and the conventional Hf electrodes dependency on the continuous operating time at 25A in air as shown in **Fig. 6.**

In comparing each electrodes, it is obvious that the 85Ir-15Y_2O_3 electrode shows a good durability rather than Hf. This good erosion resistance would be considered to the reduction of heat damage on the electrode, because Ir metal has high thermal and electric conductivity rather than refractory metals and Y_2O_3 acts as a good electron emitter such as the relative low work function material.

Figure 7 shows the macrographs of various electrodes after the consumption test. In case of Hf electrode, the erosion part was extended widely over the copper sheath until 14.4ks (4hrs) only, and was formed the HfO_2 on the cathode surface. On the contrary, the erosion progression of the both 85Ir-15Y_2O_3 and 85Ru-15Y_2O_3 electrodes was

Table 1 Fundamental physical chemical properties of Ru and Ir.

	Ru	Ir
Density (g/cm^3)	12.4	22.4
Melting point (K)	2583	2683
Boiling point (K)	4173	4403
Thermal conductivity (W/mK)	117	147
Electrical resistivity ($\mu\Omega$cm)	7.6	5.3
Heat of vaporization (kJ/mol)	567	612

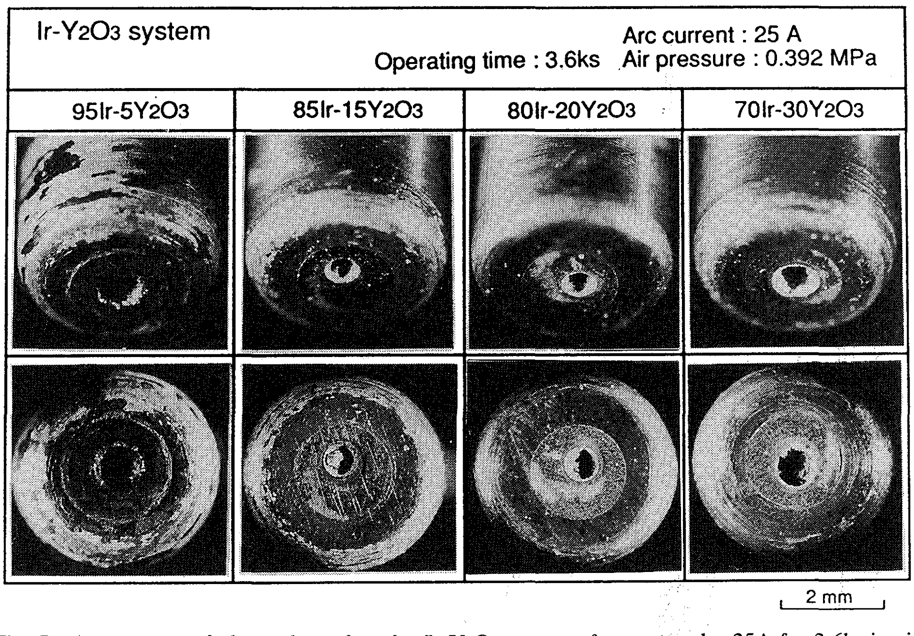

Fig. 5 Appearance of electrode surface for Ir-Y_2O_3 system after test under 25A for 3.6ks in air.

only limited in the sintered tip and showed a clean surface until 21.6ks (6hrs).

3.2.2 Periodic Operation

In the practical conditions, a periodic operation is almost adopted. Thus, the periodic operating test was applied to estimate the electrode consumption. The used conditions of the pulse widths are 10,60 and 300s, and 0.5 in duty factor.

Figure 8 (a), (b) shows the relationship between the cumulative operating time (total amount of ON-time) and the electrode weight loss for the tentative electrodes of the commercial Hf (a) and the tentative 85Ir-15Y_2O_3 (b) until 1.8ks at 25A. The weight loss of Hf electrode was increased with increasing the cumulative operating time and had a tendency to increase with the short periodic pulse. However, the consumption of 85Ir-15Y_2O_3 electrode showed a fractional dependence in the weight loss upon increasing the operating time and was not affected remarkably by the operating in the discharge condition such as 80Ru-20Y_2O_3 electrode. Therefore, the 85Ir-15Y_2O_3 electrode has a good resistance in cases of the erosion during arc and the striking arc.

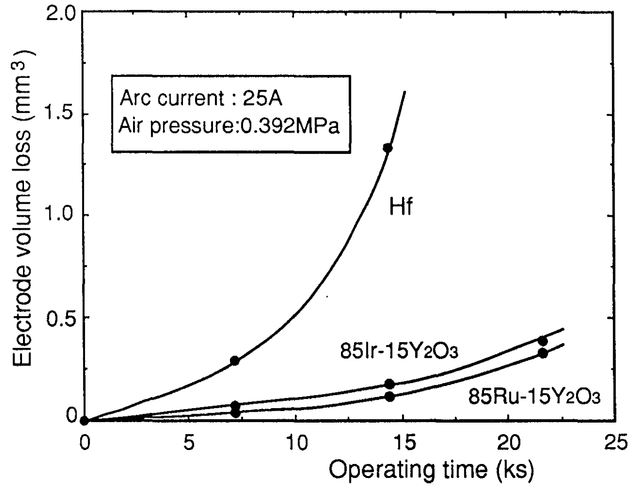

Fig. 6 Estimation of life time for various electrodes, tentative 85Ir-15Y_2O_3, 85Ru-15Y_2O_3 and conventional Hf at 25A in air.

There are considered that this good resistance due to constantly coverage the molten Y_2O_3 layer with a low work function on the cathode matrix.

3.3 Electrode Durability at Large Current

Here was continued investigating the applicability of the Ir-Y_2O_3 electrode on the usage at various arc currents in the range from 100 to 250A.

Figure 9 shows the relationship between the arc current and the electrode erosion depth. The electrode durability was estimated by measuring the eroded depth in the inserted cathode material in the copper sheath after the discharge, because it was impossibility for the large size electrode to measuring the electrode weight loss. The tentative 85Ir-15Y_2O_3 electrode shows a good durability compared with Hf until 200A. However, above 200A in arc current the erosion of 85Ir-15Y_2O_3 was severely

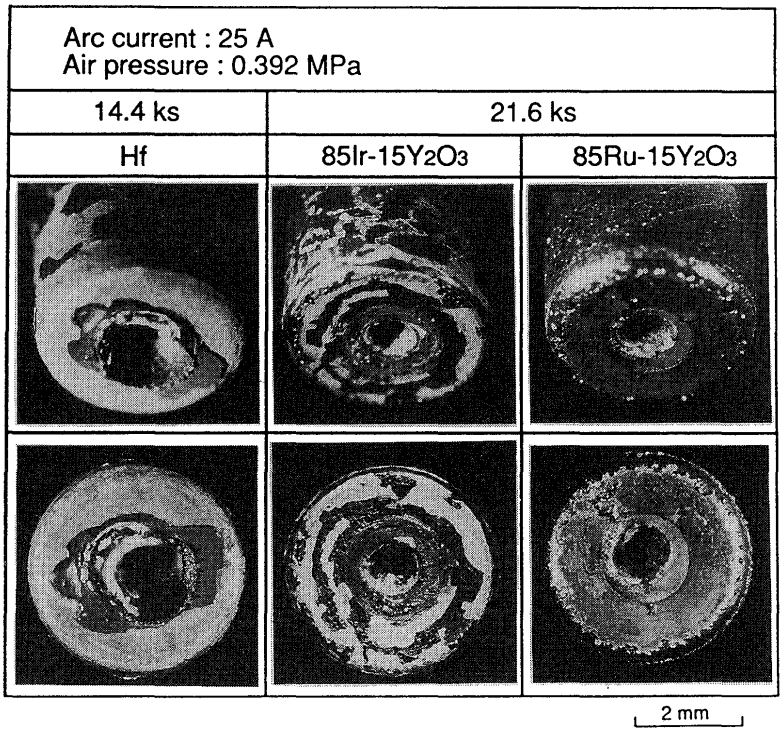

Fig. 7 Appearance of electrode surface for various electrodes after consumption test at 25A in air.

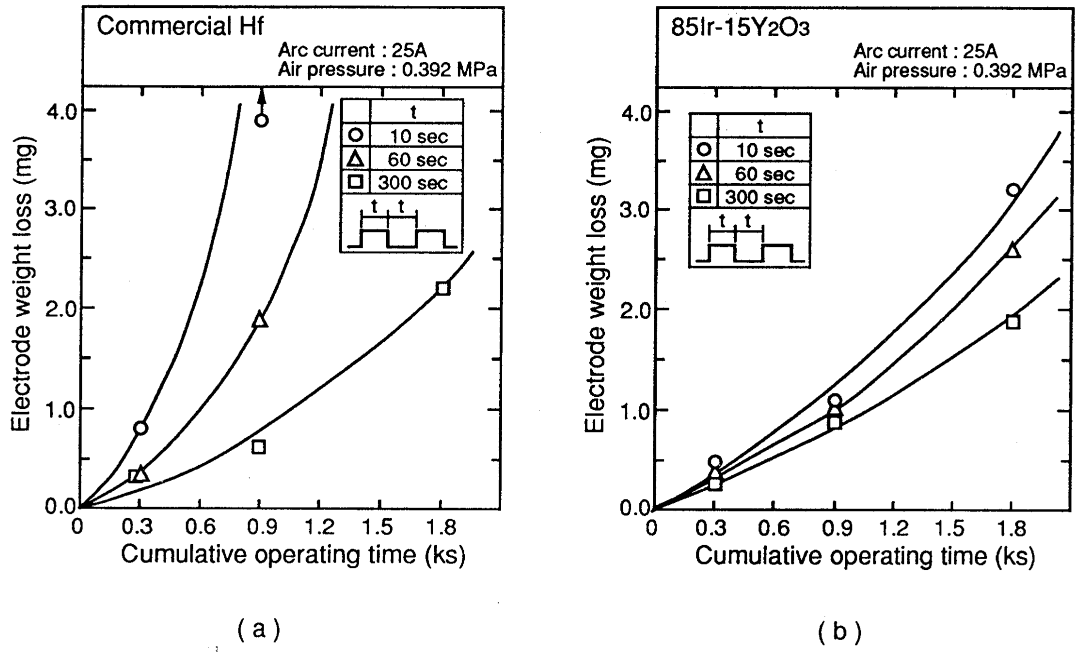

Fig. 8 Relationship between cumulative operating time and electrode weight loss until 1.8ks at 25A. (a): commercial Hf, (b): 85Ir-15Y_2O_3.

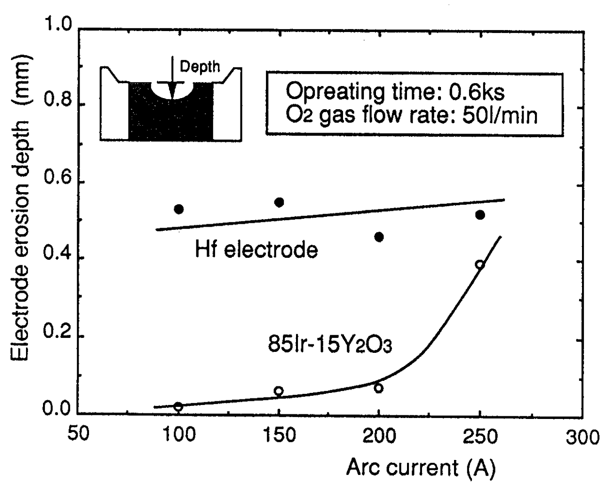

Fig. 9 Estimation of life time of 85Ir-15Y_2O_3 and Hf electrodes at large current until 250A in O_2 operating gas.

increased with increasing arc current.

Figure 10 shows the macrographs of cathode surface after the consumption test, the commercial Hf electrode (a) and the tentative 85Ir-15Y_2O_3 electrode (b). In case of Hf electrode, the unmelted zone in the cathode material was slightly remained in the interface part to the copper sheath at the low eurrent (100A). And with increasing the arc current, the eroded zone was extended until the edge of the copper sheath, and HfO_2 was formed on the sheath surface around the inserted tip.

On the other hand, the erosion of 85Ir-15Y_2O_3 electrode was progressed inner the inserted sintering tip until 200A and the erosion zone was slightly increased with increasing the arc current. The erosion at 250A was severed and expanded at the copper sheath.

This is considered that the consumption mechanism of Ir-Y_2O_3 system electrode different from the Hf. From the previous study for the consumption process, it may be thought that the erosion rate of Ir-Y_2O_3 electrode is strongly depended on the formation of the Y_2O_3 layer during discharge. Therefore, to gain a high performance, is necessary moderate oxygen content on the cathode surface to maintain the stable Y_2O_3 layer with low work function. When the erosion is deeply progressed in the axis direction of electrode, the oxygen partial pressure on the cathode surface where is emitting a thermionic electron is reduced, and would be dissociated the Y_2O_3 layer to Y and YO. On the contrary, the consumption process of Hf electrode can be related to the formation of HfO_2 with high melting point around the cathode spot during discharge.

4. Conclusions

This study has investigated to the consumption characteristic of Ir-Y_2O_3 electrode developed for oxidizing plasma cutting torch.

The main conclusions drawn from this study are as follows:

(1) The tentative Ir-Y_2O_3 electrode which was made by sintering method showed a minmium consumption in the range of 10~25wt%Y_2O_3 content in Ir, and Ir including

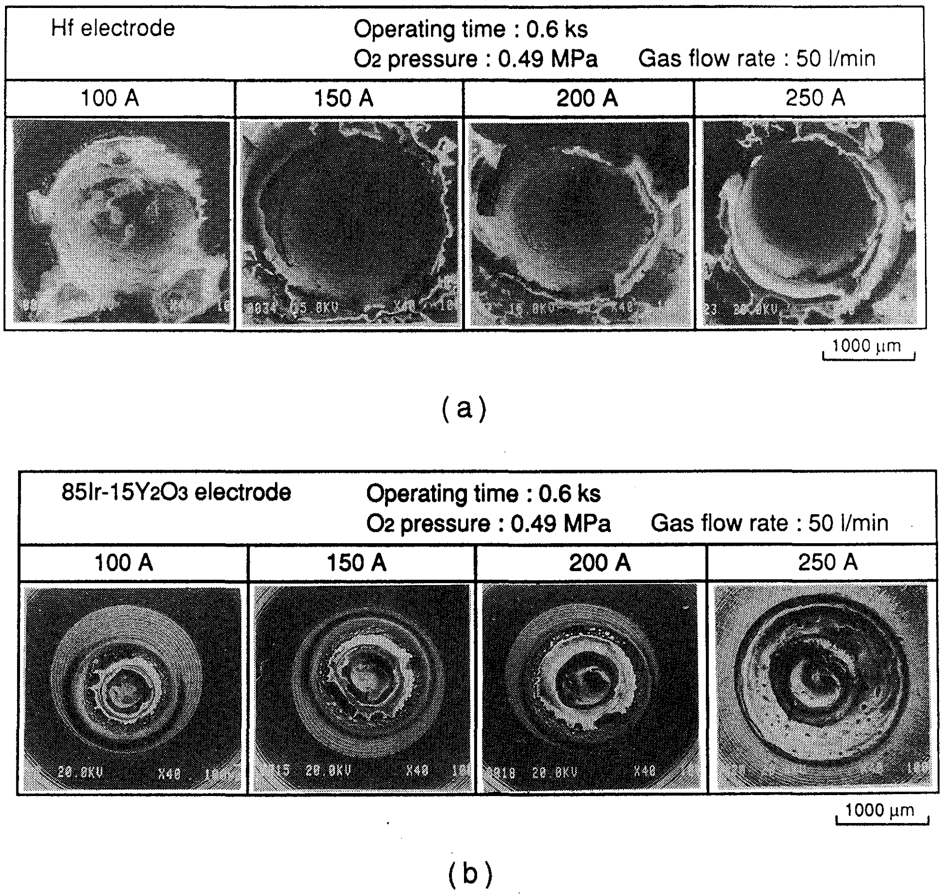

Fig.10 Appearance of electrode surface after test under arc current range from 100 to 250A in O_2.
(a): Hf electrode.
(b): $85Ir\text{-}15Y_2O_3$ electrode.

15wt%Y_2O_3 electrode is the best useful in the Ir-Y_2O_3 system.

(2) In the continuous and periodic operation, $85Ir\text{-}15Y_2O_3$ electrode showed a same durability as $85Ru\text{-}15Y_2O_3$ (or $80Ru\text{-}20Y_2O_3$) which has a good erosion resistance rather than Hf.

(3) From the investigation at various large currents from 100 to 250A in oxygen gas, $85Ir\text{-}15Y_2O_3$ electrode will be expected to the application to 200A in arc current at now stage.

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