New Cathode Materials for Air—Plasma Cutting†

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Abstract

This study has been carried out to develop new cathode materials for air plasma cutting. The consumption of Rhenium-Yttria and Ruthenium-Yttria electrodes was compared with that of Hafnium and Zirconium electrodes, which have been widely used. Rhenium including 15~40%Yttria and Ruthenium including 10~35%Yttria showed lower consumption rates rather than Hafnium electrode and Zirconium in case of continuous life time test. Furthermore, the Ruthenium including 15%Yttria showed a superior erosion resistance in case of periodic operating test at 25A, compared with other electrodes.

KEY WORDS: (Air-plasma Cutting) (Oxide Cathode) (Rhenium) (Yttrium-Oxide) (Ruthenium)

1. Introduction

Recently, the use of compressed air as a cutting gas has extended the capability of the plasma arc cutting process. However the advantages of air plasma cutting can be supplied only with an electrode material with an adequate life in air. Hafnium and Zirconium insert electrodes have been selected to be a barely satisfiable cathode materials[1]. From this point of view, the development of more durable cathode material has been required urgently.

As mentioned above, only Hafnium and Zirconium have been regarded to be usable materials in the air plasma cutting cathode. And some works have been made to study the reason for the durability of these electrodes[2,3]. From these works it could be considered that the key requirement for cathode material to decrease the erosion rate are relatively low operation temperature, high thermal and electrical conduction, high melting point and formation of stable oxide at the surface and so on.

The aim of this work is to show the possibility to develop the more durable cathode material for air plasma cutting by oxide-doped metal. Some electrode were produced by sintering of high thermal conductivity metals and low work function material. Rhenium and Ruthenium were applied as matrix metals.

2. Experimental Procedures

2.1 Preparation of specimens

The tentative electrodes were made by following procedure shown in **Fig. 1**. Powdered Rhenium and Yttrium oxide (Yttria) were used as starting materials. These powders were weighed, mixed and pressed under 0.588MPa in a graphite die. After that, the pellets were made by sintering in hydrogen atmosphere in 60 min at 2473K. Ruthenium-Yttria system electrodes were prepared by using the same method, but sintering in 30 min at 2373 K.

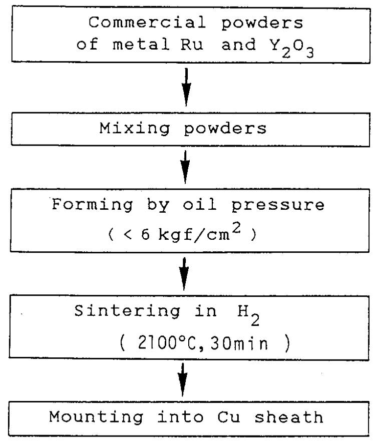

Fig. 1 Flow chart about production process of Ruthenium-Yttria system electrode.

2.2 Electrode consumption measurement

Figure 2 shows a schematic diagram of the experi-

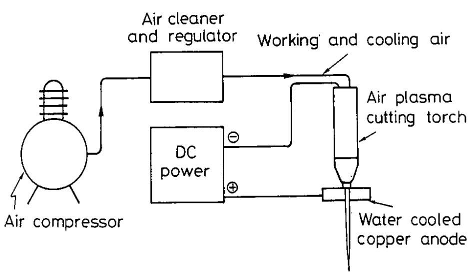

Fig. 2 Schematic diagram of experimental alignment.

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mental alignment which used to electrode consumption measurement. This test was carried out by generating an arc discharge between tentative electrode tips and cooling anode at a stated period. The electrode consumption was measured by the weight loss using electric balance with sensitivity of 10^{-5} g after each test.

3. Experimental Results

3.1 Rhenium-Yttrium oxide electrode

The relationship between electrode consumption and Yttria content of the tentative Rhenium-Yttria system is shown in **Fig. 3**. From this figure the followings are obvious: **(1)** There is a suitable content of oxide, showing the minimum consumption at a fixed current and arcing time. The consumption is minimum in the range from 15% to 40% in Y_2O_3 content at 25 A, 0.3 ks. Above this range, the electrode weight loss increases with increasing the Yttria ratio. **(2)** At 18A, the minimum loss range became narrow with increasing the operating time from 3.6 ks to 10.0 ks. **(3)** The new electrodes showed a good erosion resistance comparing with the widely used Hafnium and Zirconium electrodes. The weight loss of Zirconium and Hafnium electrodes was about 0.8 and 0.5 mg respectively, while in case of Rhenium with 35~40%Yttria the weight loss is about 0.2~0.3 mg under the same conditions.

Figure 4 shows the appearance of Rhenium-Yttria electrodes surface with different mixing ratio, after operating in air at 25 A for 5 min. It may be pointed out as follows: **(1)** in case of pure Rhenium, the tip was

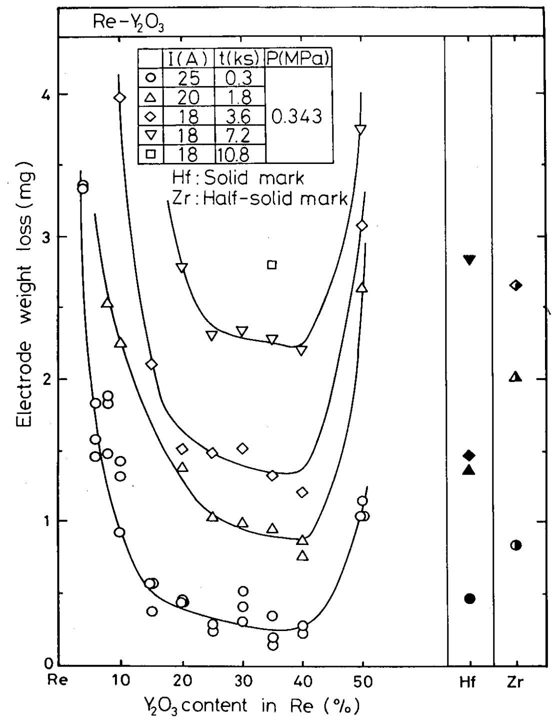


Fig. 3 Relationship between Yttria content and electrode weight loss for Rhenium-Yttria system.

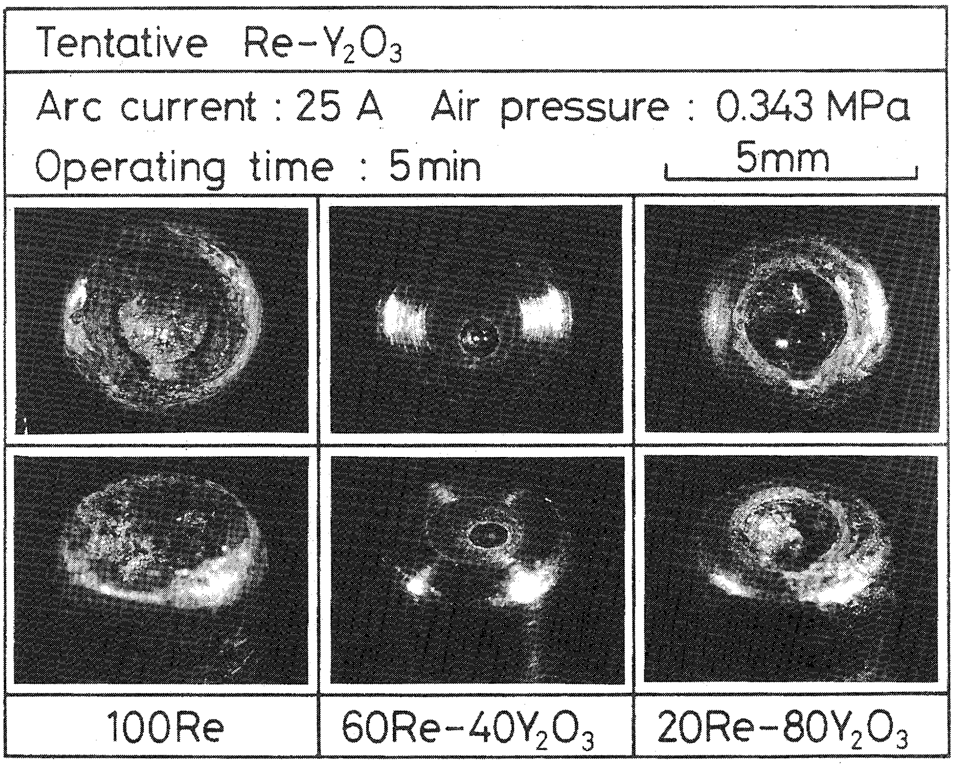


Fig. 4 Appearance of Rhenium-Yttria electrodes with different mixing ratio.

completely damaged and the erosion extended to copper sheath. (2) On the other hand, Rhenium including about 40%Yttria showed acceptably a good appearance compared with the other electrodes, the arc rooting was settled on the center of tip and the eroded area was spherical. (3) In case of Rhenium including 80%Yttria, the consumption is very severe similarly as 100%Rhenium electrode.

3.2 Ruthenium-Yttrium oxide electrode

The consumption on Ruthenium-Yttria system, is shown in **Fig. 5**, under the various conditions of operating time (3.6, 7.2, 10.8 and 14.4ks), with fixed arc current (18 A) and air pressure (0.343MPa). From this figure, it can be seen that the electrode consumption decreases with increasing Yttria ratio, until a minimum consumption ranging from about 10% to 35% in Yttria contents. Above this range, the weight loss increases with increasing Yttria ratio.

This minimum range of electrode consumption was being narrow and shifted towards the pure metal side as the operating time increases from 3.6ks to 14.4ks at 18 A. The weight loss of Ruthenium including 15%Yttria electrode was 0.17mg, which is lower than that of Hafnium electrode (1.46mg) for operating time 3.6ks. Consequently, Ruthenium-Yttria electrode have a good erosion resistance rather than other electrodes.

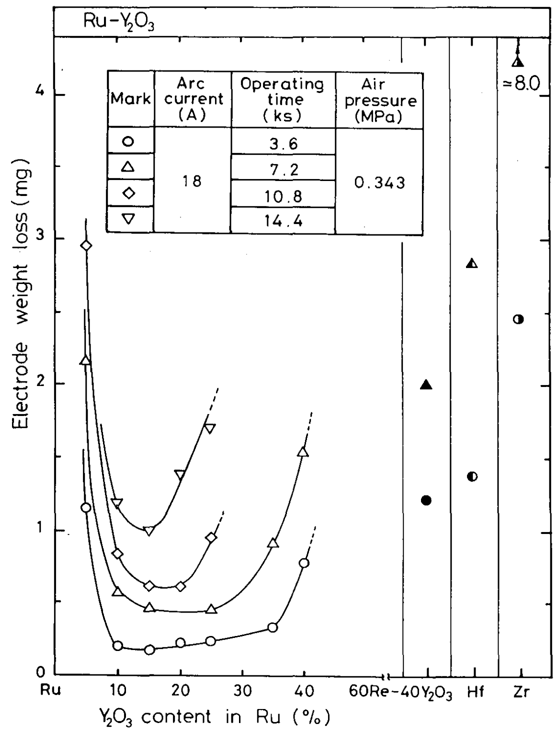


Fig. 5 Relationship between Yttria content and electrode weight loss for Ruthenium-Yttria system electrode.

3.3 Effect of arcing conditions

3.3.1 Arc current

Figure 6 shows the relationship between the arc current and the consumption of Hafnium electrode. It is obvious that the electrode weight loss increases with increasing the arc current for same operating time (0.3 ks).

Figure 7 shows the relationship between the arc current and the consumption for two types Ruthenium-Yttria electrode after testing for 0.3ks. The weight losses of both electrodes increased with increasing operating current. And, the Ruthenium including 10%Yttria showed a good erosion resistance rather than Ruthenium including 25%Yttria. However, both electrodes have good erosion resistance rather than Hafnium electrode, as can be seen from *Fig. 6 & Fig. 7.*

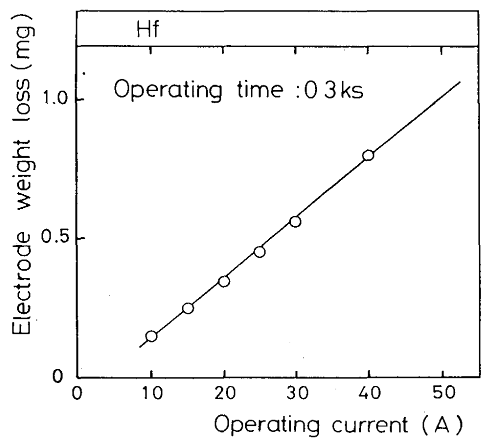


Fig. 6 Electrode weight loss as a function of operating current for Hafnium electrode for operating time 0.3 ks.

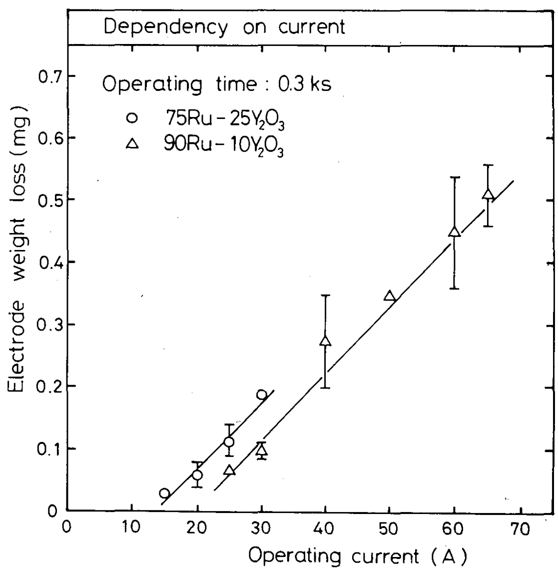


Fig. 7 Electrode weight loss as a function of operating current for tentative two type Ruthenium-Yttria electrode (75%Ru-25%Y_2O_3 and 90%Ru-10%Y_2O_3) for operating time 0.3 ks.

3.3.2 Operating time

Here, was compared electrode life for commercial and tentative electrodes as a function of operating time. The experimental results is shown in **Fig. 8**. In general, the data shows that the electrode life decreases linearly with increasing the operating time. This linear consumption behavior means that the electrode erosion can be continuous and its rate is stationary with increasing the operating time. However, from these results it can be said that the time need for consuming same volume from Ruthenium including 15%Yttria electrode is about six times longer than that in case of Hafnium electrode. In other words the life of Ruthenium including 15%Yttria electrode is about six times of Hafnium electrode one.

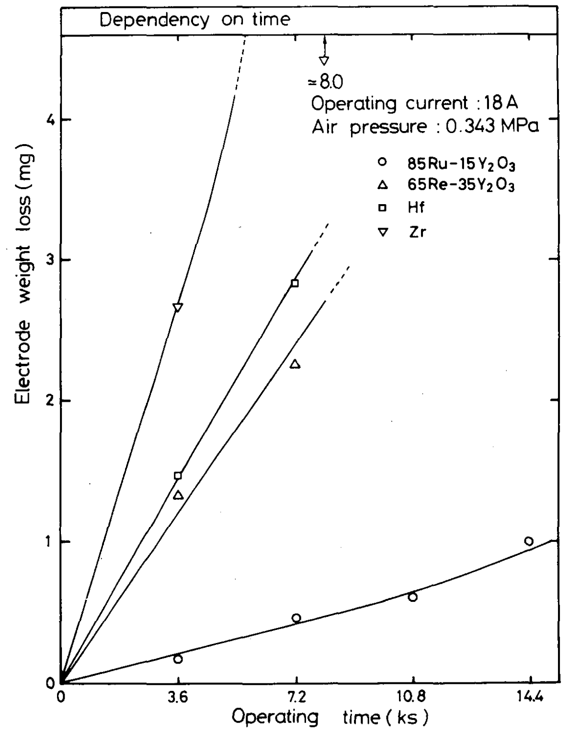


Fig. 8 Electrode weight loss as a function of operating time for various electrodes.

Figure 9 shows the macrographs of several electrodes after operating for 3.6ks at 18 A in arc current. It may be noted that the eroded volume of these investigated electrodes is in the following order.

$$85Ru\text{-}15Y_2O_3 < 65Re\text{-}35Y_2O_3 < Hf < Zr.$$

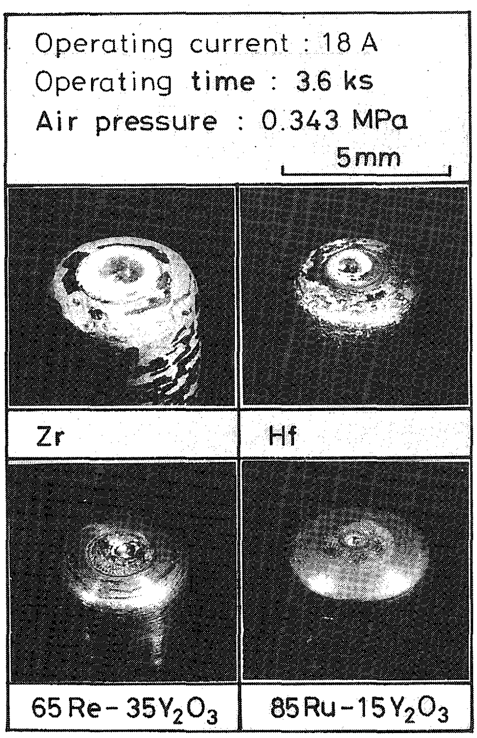


Fig. 9 Macrographs of various electrodes after operating for 3.6 ks.

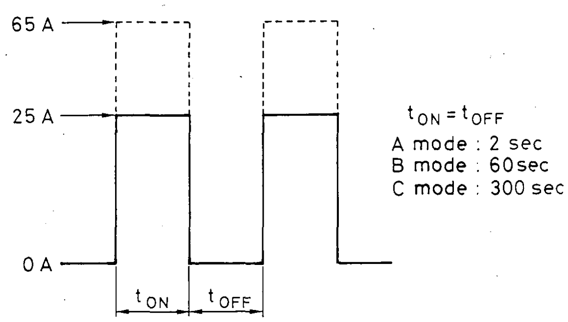


Fig. 10 Pulse mode conditions used for the periodic consumption test.

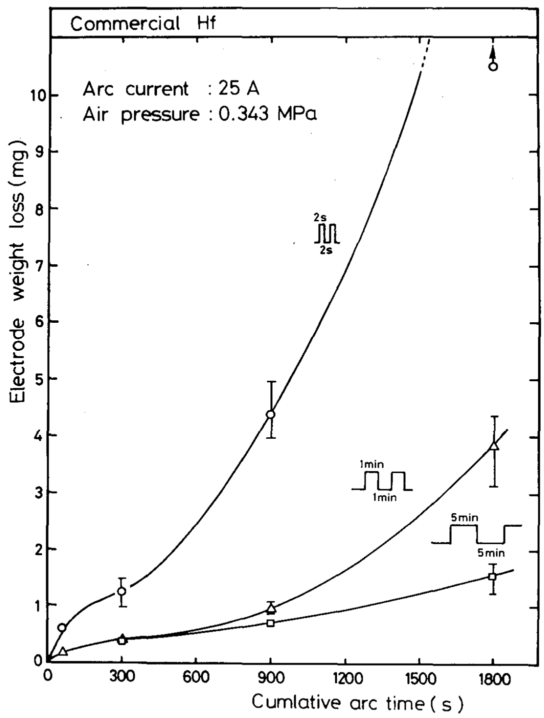
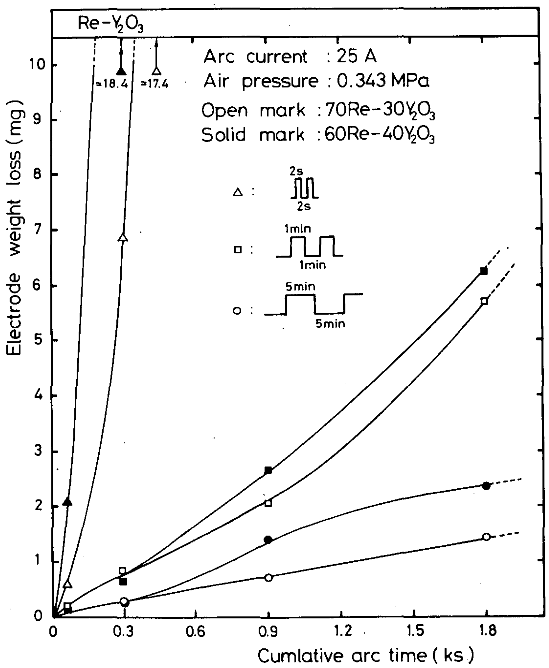


Fig. 11 The consumption characteristics for Hafnium electrode in case of periodic operating at 25 A.



The qualitative evaluation (as shown here) was in a good agreement with the weight loss measurement.

3.3.3 Periodic operation

In the practical working condition, the periodic operation is adopted almost rather than the continuous arcing operation. The consumption test of periodic operation was curried out under the typical three conditions of pulsed current mode, shown in **Fig. 10**. The consumption characteristics for commercial Hafnium is shown in **Fig. 11** which is related with the cumulative arc time for each pules mode at arc current 25 A. The electrode weight loss increased with increasing the cumulative arc time. In this case, the electrode consumption has a tendency to increase with short periodic time. Rhenium-Yttria electrodes were tested under the same condition and the

Fig. 12 The consumption characteristics for Rhenium-Yttria electrode in case of periodic operating at 25 A.

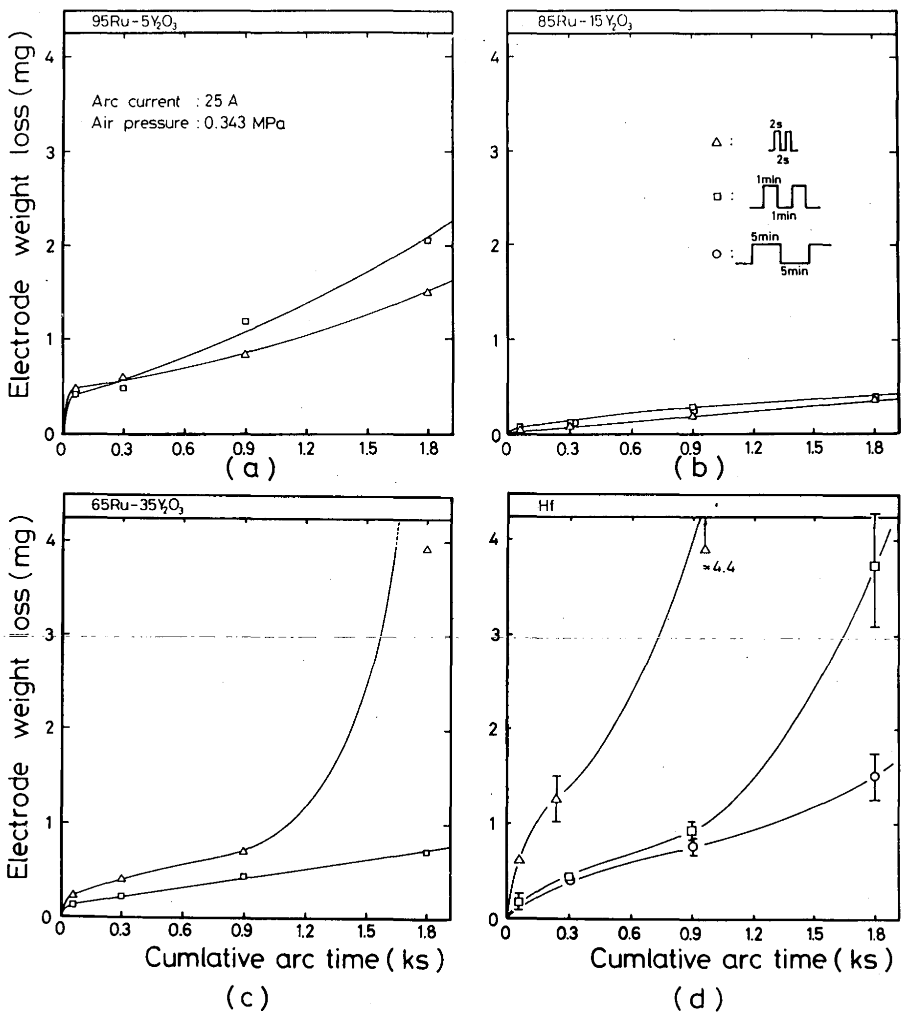


Fig. 13 The consumption characteristics for Ruthenium-Yttria system electrode at arc current 25 A.
(a) 95%Ru-5%Y_2O_3 (b) 85%Ru-15%Y_2O_3
(c) 65%Ru-35%Y_2O_3 (d) Hf

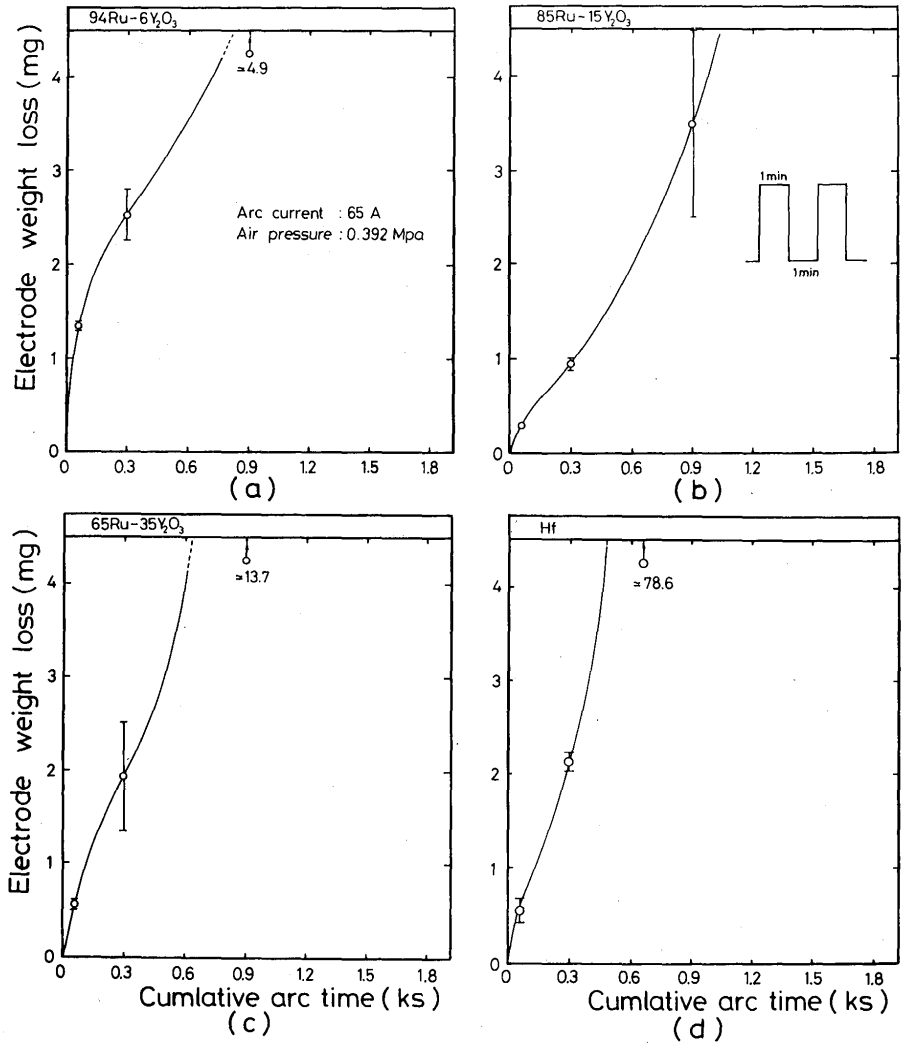


Fig. 14 The consumption characteristics for Ruthenium-Yttria system electrode at arc current 65 A.
(a) 94%Ru-6%Y_2O_3 (b) 85%Ru-15%Y_2O_3
(c) 65%Ru-35%Y_2O_3 (d) Hf

results are shown in **Fig. 12**. The electrode weight loss increases as the cumulative arc time increases, similarly to Hafnium electrode. At the shortest periodic time (2 sec). Rhenium-Yttria electrode was rapidly eroded rather than the Hafnium electrode. That is may be related to the cathode surface conditions under the periodic operation, that is, the formation of oxide film layer during arc off period and its destruction occured by arcing.

For Ruthenium-Yttria electrode showed a superior consumption characteristics in continuous life time test, the similar test was made. **Figure 13** shows the relationship between the cumulative arc time and the weight loss of various combination of Ruthenium-Yttria electrodes. Ruthenium including 15%Yttria, which had a minimum consumption rate in the continuous arcing test, showed a fractional dependence in the weight loss upon increasing in the arcing time and is not affected remarkably by various periodicity in arcing condition. On the other hand, for Ruthenium including 35%Yttria electrode, the weight loss increased rapidly as same as that of Hafnium electrode.

From the results as described above it is considered that Ruthenium including 15%Yttria electrode is the most excellent among those electrodes investigated in this study.

The consumption mode of electrodes can be classified as follows, the erosion during arcing and the erosion at arc striking. It was found that the erosion at arc striking is high rather than that during arcing. Ruthenium including 15%Yttria has little consumption for arc starting and also during arcing though the reason is not clear yet. Next, experiment with Ruthenium-Yttria system at relatively large current, 65 A, was carried out under periodic conditions. **Figure 14** shows that Ruthenium-Yttria electrode including 15~25%Yttria has an about half consumption rate of the Hafnium one as indicated before when tested at arc current 25 A.

4. Conclusion

This study has been carried out to develop new cathode materials for air plasma cutting. The results were compared with that of Zirconium and Hafnium which are widely used nowadays.

The main conclusions drawn from the experimental data are:

(1) Generally, the weight loss of both tentative and commercial electrodes increased linearly with increasing in the arc current and the operating time.

(2) The tentative Rhenium-Yttria electrode showed a minimum consumption in the range of 15~40%Yttria content in case of the continuous life test.

(3) The tentative Ruthenium-Yttria electrode showed a minimum consumption in the range of 10~35%Yttria content in case of the continuous life test.

(4) The life of Ruthenium including 15%Yttria electrode is about six times of Hafnium electrode one under the continuous consumption test.

(5) In the periodic life test, Rhenium-Yttria and Hafnium electrodes showed high consumption rate.

(6) Ruthenium including 15%Yttria showed extremely low erosion in both cases of the continuous arcing test and the periodic arcing one. Therefore it can be said that Ruthenium-Yttria system electrode will be durable cathode material for air plasma cutting at present time.

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