Title	New Cathode Material for Air-Plasma Cutting (Report II) : Effect of Sintering Temperature on Electrode Consumption(Physics, Process, Instrument & Measurement)
Author(s)	Matsuda, Fukuhisa; Ushio, Masao; Kusumoto, Kazuomi
Citation	Transactions of JWRI. 1989, 18(2), p. 211-216
Version Type	VoR
URL	https://doi.org/10.18910/3929
rights	
Note	

New Cathode Material for Air-Plasma Cutting (Report II)†

— Effect of Sintering Temperature on Electrode Consumption —

Fukuhisa MATSUDA*, Masao USHIO, and Kazuomi KUSUMOTO*****

Abstract

This study has been carried out to explain the effect of sintering temperature on an electrode consumption of air plasma cutting.

$Zr\text{-}Y_2O_3$, $Hf\text{-}Y_2O_3$ and $Ru\text{-}Y_2O_3$ systems were studied and compared. It was concluded that; in the case of $Zr\text{-}Y_2O_3$ and $Hf\text{-}Y_2O_3$ systems, the sintering temperature was a little effect on the electrode consumption. Also, the erosion resistance during arcing was not improved by adding Y_2O_3.

On the other hand, in $Ru\text{-}Y_2O_3$ system, the erosion resistance during arcing was remarkably improved by adding Y_2O_3. It is related to the high density of the electrode which is sintered at comparatively high temperature, 2373K.

KEY WORDS : (Air-Plasma Cutting) (Cathode) (Consumption) (Zirconium) (Hafnium) (Ruthenium) (Yttrium-Oxide)

1. Introduction

In a previous study, it was shown that Ruthenium including Y_2O_3 in 10 ~ 35 wt% have a superior erosion resistance in case of continuous and periodic arcing tests (max 65A), compared with that of Hafnium which is widely used[1]. It is considered that this good erosion resistance is due to the reduction of heat damage on the electrode that because, Y_2O_3 acts as a good electron emitter and Ruthenium metal has higher thermal and electric conductivity than Hafnium. Generally, the heat conduction is severely influenced by the density ratio of material, which is defined by the ratio between the measured density and theoretical one. Sintered material has a little pores in it and the pore content is affected by the sintering condition, practically, by the sintering temperature and starting powder states.

Since the electrode is produced by the sintering process, the effect of sintering temperature on the erosion resistance is an important factor to develop an endurable cathode for plasma cutting[2].

2. Experimental Procedures

2.1 Preparation of specimens

In order to make a comparative study, various electrodes were fabricated by the following condition shown in **Table 1.** Powder Zirconium (98% including 2%Hf, mean particle diameter 5 μ), Hafnium (99.9% including 2%Zr, mean particle diameter 5 μ), Ruthenium (99.99% pure, mean particle diameter 3 μ) and Yttria (99.9% pure, mean particle diameter 2 μ) were used as starting materials.

These powders were weighed, mixed and pressed under 0.588MPa in a graphite die. After that, the pellets

Table 1 Experimental materials and sintering conditions

Metal	Y_2O_3 content (wt%)	Sintering temperature (K)	Sintering time (ks)	Atmosphere
Zr	0, 5, 10, 20, 30	1373, 1573, 1773	3.6	Vacuum
Hf	0, 5, 10, 20, 30	1573, 1773, 1973	1.8	Vacuum
Ru	0, 5, 10, 20, 30	1573, 1773, 2373	1.8	Hydrogen

† Recieved on November 6, 1989

* Professor
** Associated Professor
*** Graduate Student, Osaka University

Transaction of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka 567, Japan

(Tip) of $Zr-Y_2O_3$ system was made by sintering in vacuum at 1373K, 1573K and 1773K for 3.6ks. $Hf-Y_2O_3$ system was sintered in vacuum at 1573K, 1773K and 1973K for 1.8ks.

$Ru-Y_2O_3$ system was made by sintering in hydrogen atmosphere at 1573K, 1773K and 2373K for 1.8ks. The sintered tips were mounted into copper-sheath as shown in **Fig.1.**

The bulk density of sintered tip was measured from the weight and length of tips using an electric balance and a micro-meter.

2.2 Electrode consumption measurement

The consumption test was carried out by generating an arc discharge between electrode tip and water cooled copper anode for 0.3ks at 25A using compressed air as operating gas.

The electrode consumption was estimated by weighing an electrode before and after the test using an electric balance with sensitivity of 10^{-5}g.

2.3 Observation of appearance and cross section of electrode

The observation of eroded appearance and cross section were carried out by low-powered microscope in order to confirm an eroding process of electrodes with different Y_2O_3-mixing ratio and sintering temperature.

3. Experimental Results

3.1 Density ratio of sintered tip

3.1.1 $Zr-Y_2O_3$ system

The relationship between a sintering temperature (at 1373K, 1573K and 1773k) and density ratio of sintered $Zr-Y_2O_3$ system is shown in **Fig.2.** In case of 100%Zr, the density ratio decreased with increasing a sintering temperature from 1373K to 1773K. On the other hand, density ratio of Zr including Y_2O_3 increased slightly except of $95Zr-5Y_2O_3$.

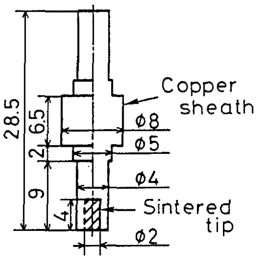

Fig.1 Shape of tentative electrode.

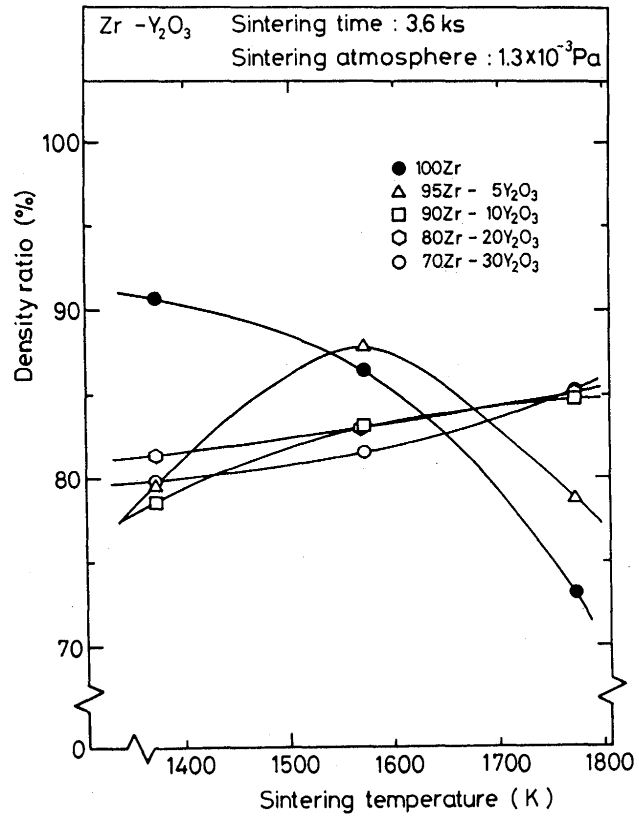

Fig.2 Relationship between sintering temperature and density ratio of $Zr-Y_2O_3$ system.

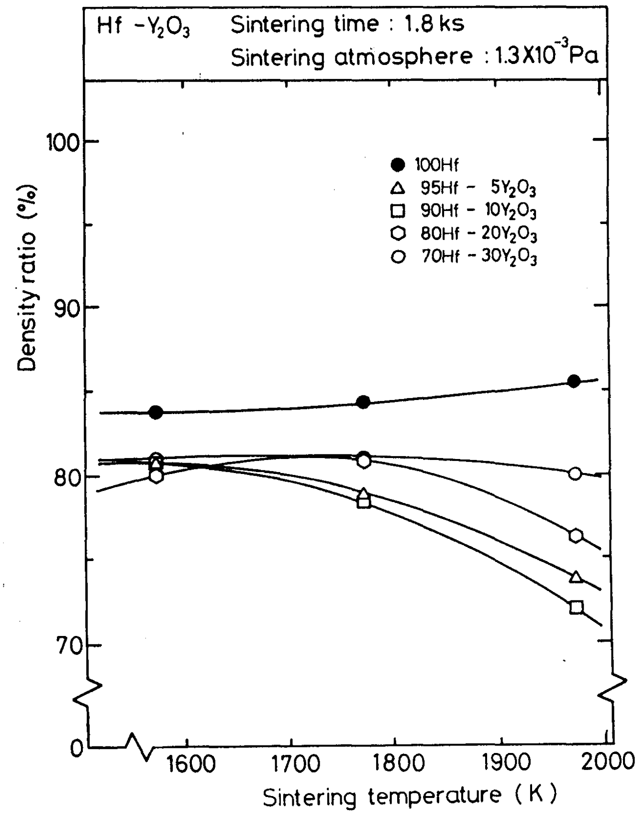

Fig.3 Relationship between sintering temperature density ratio of $Hf-Y_2O_3$ system.

3.1.2 Hf-Y_2O_3 system

The relationship between a sintering temperature (at 1573K, 1773K and 1973K) and density ratio of sintered Hf-Y_2O_3 system is shown in **Fig.3.** In the case of 100%Hf, the density ratio slightly increased with increasing a sintering temperature from 1573K to 1973K and reached about 84% or over in all specimens. On the other hand, in case of Hf-Y_2O_3 system, the density ratio decreased with raising the sintering temperature. Maximum density ratio of 82% was obtained with 70Hf-30Y_2O_3 at 1573K. In this system, the addition of Y_2O_3 has no effect on increasing the density of sintering tip.

3.1.3 Ru-Y_2O_3 system

The relationship between the sintering temperature and the bulk density of sintered Ru-Y_2O_3 system is shown in **Fig.4.** The density ratio of all specimens increased with raising the sintering temperature from 1573k to 2373K. Densification rate ρ (%) is defined as following,

$$\rho(\%) = \frac{(D_{r2} - D_{r1})}{D_c} \times 100$$

where, D_{r2}: Density at 2373K, D_{r1}: Density at 1573K, D_c: Theoretical density.

Densification rate ρ (%) are 6.7% for 100%Ru, 19.4% for 90Ru-10Y_2O_3, and 28.7% for 70Ru-30Y_2O_3. The densification rate increased with Y_2O_3 addition. 70Ru-30Y_2O_3 sintered at 1573K showed the lowest density in this series, and the density ratio increased from 69.4% (at 1573K) to 98.2% (at 2373K) , that was the maximum densification rate of all specimens.

3.2 Characteristics of electrode consumption

3.2.1 Zr-Y_2O_3 electrode

The relationship between an electrode weight loss (consumption) and a sintering temperature of Zr-Y_2O_3 system is shown in **Fig.5.** For both 100%Zr and Zr including Y_2O_3 electrodes, the consumption increased with raising a sintering temperature. In the case of 100%Zr, the weight loss increased rapidly in the range between 1573K and 1773K of sintering temperature. It may be considered that the pore growth might take place because of high sintering temperature shown in Fig.2.

90Zr-10Y_2O_3 sintered at 1373K showed a minimum weight loss of about 0.1mg in this series. The weight loss of 90Zr-10Y_2O_3 was nearly equal to that of 80Ru-20Y_2O_3, which showed a good erosion resistance.

3.2.2 Hf-Y_2O_3 electrode

The relationship between an electrode weight loss and a sintering temperature of Hf-Y_2O_3 system is shown in **Fig.6.** In the case of 100%Hf, the minimum weight loss (0.4mg) was given by the electrode sintered at 1773K.

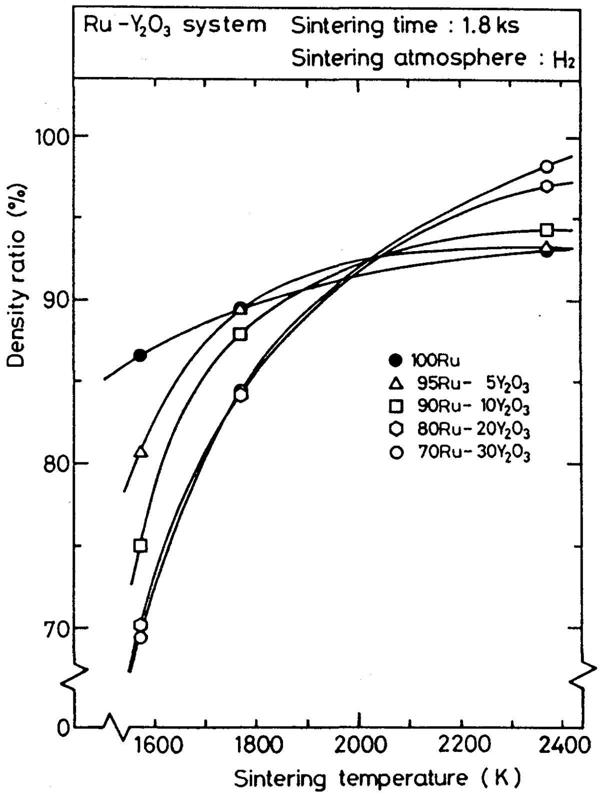

Fig.4 Relationship between sintering temperature and density ratio of Ru-Y_2O_3 system.

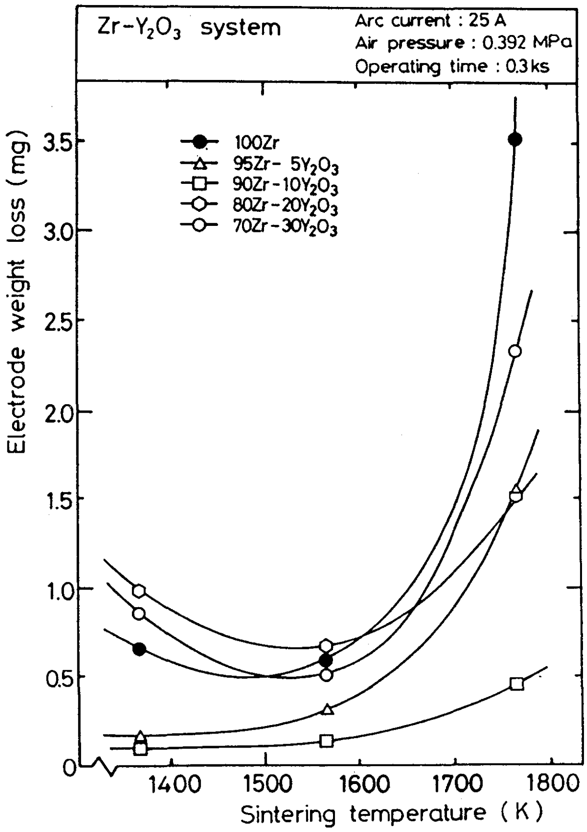

Fig.5 Relationship between sintering temperature and electrode weight loss of Zr-Y_2O_3 system.

And in case of Hf-Y_2O_3 system, the weight loss increased with increasing a sintering temperature except of 90Hf-10Y_2O_3.

The electrode with higher content of Y_2O_3 (20 and 30wt%) showed an extreme consumption in the case of high sintering temperature (1973K). It may be attributed to the decrease of the thermal and electrical conductivity due to the increased volume fraction of Y_2O_3, and having a low conductivity rather than metals.

Hafnium oxide was formed tightly on the electrode surface after test. This formation of oxide has some influence on the measurement of an electrode weight loss. Hf including Y_2O_3 was eroded severely rather than Zr including Y_2O_3.

The addition of Y_2O_3 to Hf has no effect on the improvement of erosion resistance.

3.2.3 Ru-Y_2O_3 electrode

The relationship between electrode weight loss and sintering temperature of Ru-Y_2O_3 electrode is shown in **Fig.7**. In case of Ru including Y_2O_3 electrodes, the weight loss decreased rapidly by the use of higher sintering temperature ranging from 1573K to 2373K. In this study the best fabrication conditions to increase the erosion resistance is to mix about 20wt%Y_2O_3 and sintering at 2373K. This electrode has a dense structure such as density ratio of about 90%. Even in case of low sintering temperature like 1573K, the consumption was lower than some others (100Zr or 100Hf). It may be considered that the combination of Ru and Y_2O_3 is satisfactory for plasma cutting electrode using in air.

3.3 Observation of appearance and cross section of electrodes

3.3.1 Zr-Y_2O_3 electrode

Figure 8 shows the eroded appearance of 100%Zr and Zr-Y_2O_3 electrodes surface at different sintering temperature, after operating in air at 25A for 0.3ks. It is clear that : **(1)** in case of 100%Zr, the eroded area limited in the central parts of the tip. **(2)** It might be due to the high operating temperature by lower heat conduction, which is attributable to generating pores by unsuitable sintering temperature.

3.3.2 Hf-Y_2O_3 electrode

Figure 9 shows the eroded appearances of 100%Hf and Hf-Y_2O_3 electrode surface at different sintering temperature, after operating under same condition as in the case of Zr-Y_2O_3. Appearance of electrode were also very similar to that in case of Zr-Y_2O_3 system. In case of 100%Hf, the erosion limited inside the sintered tip, showed a good erosion resistance rather than the other electrode in this system. In case of Hf including Y_2O_3, the erosion

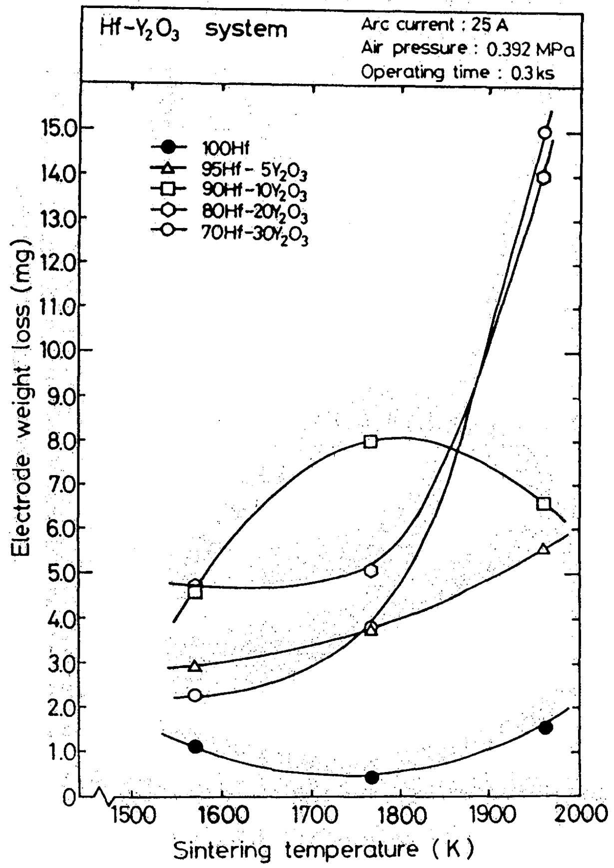

Fig.6 Relationship between sintering temperature and elctrode weight loss of Hf-Y_2O_3 system.

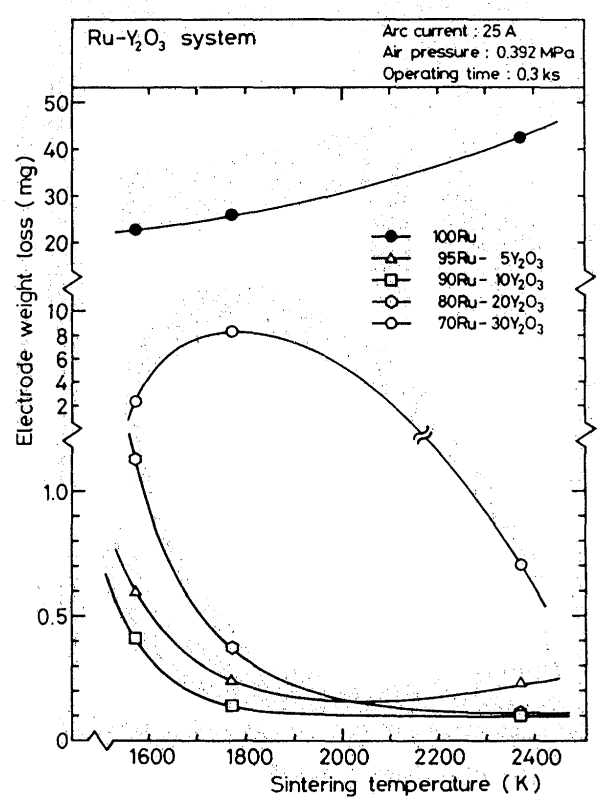

Fig.7 Relationship between sintering temperature and elctrode weight loss of Ru-Y_2O_3 system.

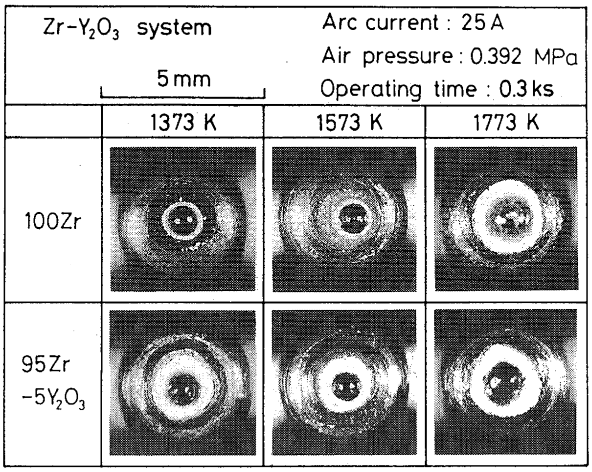

Fig.8 Appearance of Zr-Y_2O_3 system electrodes after test (25A, 0.3ks).

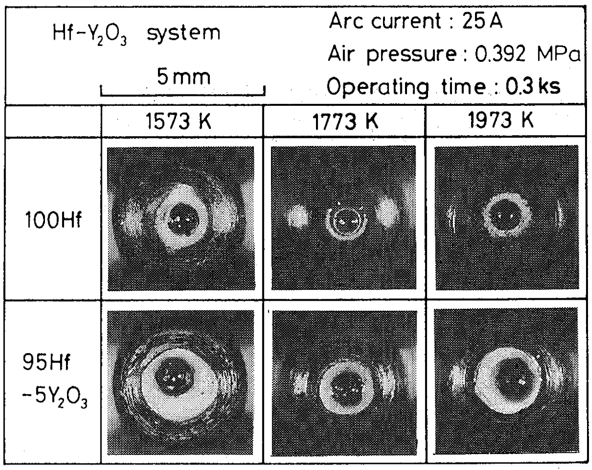

Fig.9 Appearance of Hf-Y_2O_3 system electrodes after test (25A, 0.3ks).

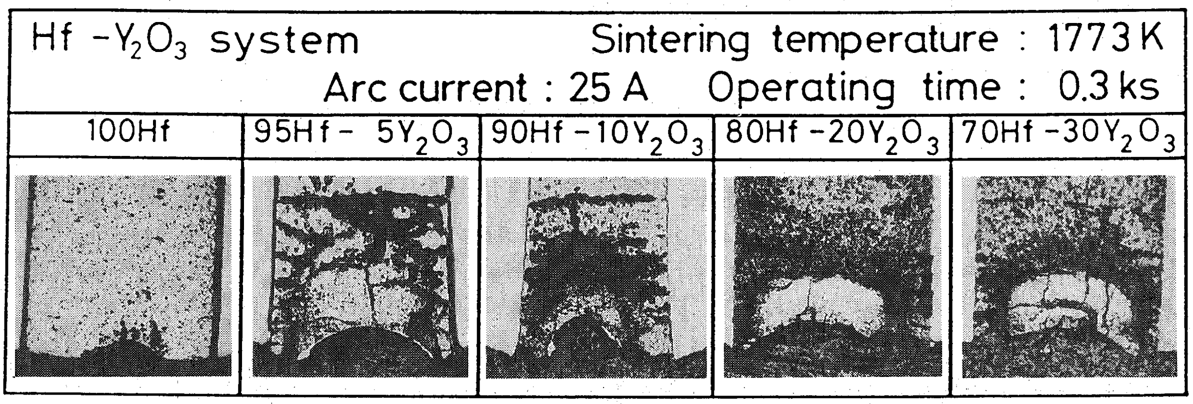

Fig.10 Cross section of Hf-Y_2O_3 system electrodes after test (25A, 0.3ks).

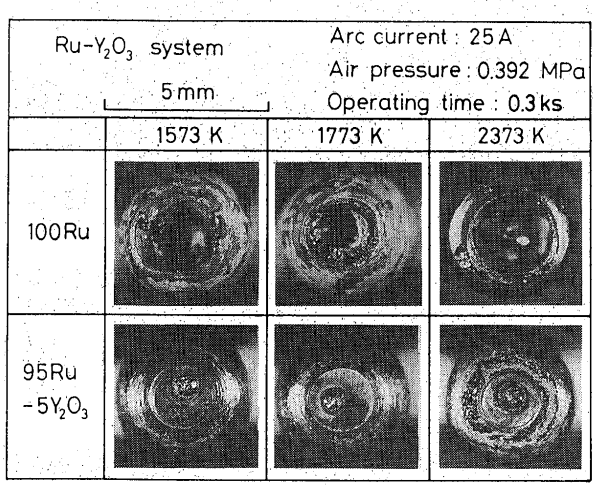

Fig.11 Appearance of Ru-Y_2O_3 system electrodes after test (25A, 0.3ks).

extendend to copper sheath and Hafnium oxide was formed and covered on an eroded surface.

Figure 10 shows the electrode cross section of Hf-Y_2O_3 electrodes sintered at 1773K. It may be said that the erosion or consumption of an electrode was progressed as a semi-spherical wall which was formed at the center of the tip. The size of eroded wall was very small in 100% Hf, but in 95Hf-5Y_2O_3 the size of eroded wall was large and its depth increased with increasing the content of Y_2O_3.

3.3.3 Ru-Y_2O_3 electrode

Figure 11 shows the eroded appearances of eroded surface in Ru-Y_2O_3 electrode at several sintering temperatures. In case of 100%Ru, the electrode tip was completely damage and the erosion area extented to copper sheath. In case of Ru including Y_2O_3, the consumption was very low and the eroded wall was limited in the central parts of electrode tip. From the investigation of the electrode cross section sintered at 2373K, it is clearly observed the remarkable effect of Y_2O_3 addition on decreasing electrode erosion contrary to the case of Hf and its additional effect of Y_2O_3 as shown in **Fig.12.**

4. Conclusions

This study was made to explain the effect of sintering

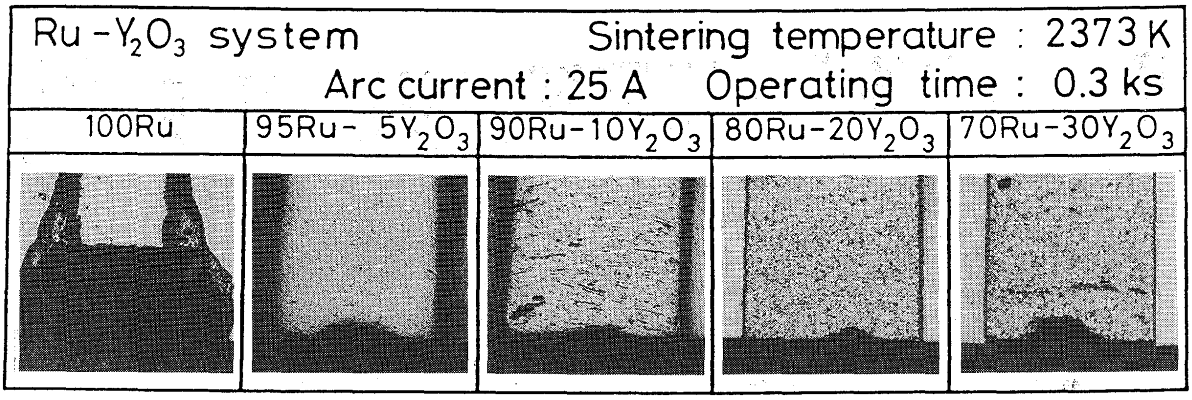

Fig.12 Cross section of Ru-Y_2O_3 system electrodes after test (25A, 0.3ks).

temperatures on the electrode consumption in the case of Zr-Y_2O_3, Hf-Y_2O_3 and Ru-Y_2O_3 systems for air plasma cathode.

The main conclusions drawn from this study are as follwos:

(1) In 100%Zr, the electrode consumption increase with decreaseing a density by higher sintering temperature like at 1773K. In Zr including 5 ~ 30wt%Y_2O_3, the consumption is lower rather than in the case of 100%Zr. But in fact the oxide is formed on the eroded surface which is wide comparing with that of 100%Zr.

(2) In 100%Hf, the electrode consumption is hardly affected by increasing the sintering temperature from 1573K to 1973K. In case of Hf including 5 ~ 30wt%Y_2O_3, the erosion resistance is not improved at any sintering temperatures.

(3) In Ru including 5 ~ 30wt%Y_2O_3, the electrode consumption is extremely reduced comparing with that in the case of 100%Ru under all sintering temperatures. And this effect is hardly affected by increasing the sintering temperature from 1573K to 2373K. Small addition of Y_2O_3 in Ru improve remarkably the erosion resistance, contrary to the case of Y_2O_3 addition to Hf and Zr.

Acknowledgements

The authors would like to express their appreciation to TOHO KINZOKU CO., for the production of many kinds of electrodes.

References

1) F.MATSUDA, M.USHIO and K.KUSUMOTO, Trans.of JWRI, (1989), Vol. 18, No.1, P.127
2) F.MATSUDA, M.USHIO and K.KUSUMOTO, Annals Meeting of Japan Welding Society, Vol.45 (1989), p104