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Study of Tungsten Electrode at High Current Operation†

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Abstract

Characteristics of tungsten cathode activated by rare earth metal oxide are described at first, which is widely used as hot cathode material of plasma torch. It is shown that behavior of rare earth metal oxide included in tungsten electrode has decisive effect on the properties, durability and consequently consumption, and is governed by temperature field inside the cathode. And some types of temperature fields with which the rare earth metal oxide could well behave. Essential factors for designing the long life plasma gun are discussed.

KEY WORDS: (GTA Electrode) (Rare Earth Metal Oxide) (Low Lrosion) (Plasma Torch)

1. Introduction

One of the issues to be solved in thermal plasma technology is the serious consumption of cathode electrode. In previous papers[1), 2)], it is shown that tungsten electrodes activated with La_2O_3, Y_2O_3, and CeO_2, respectively, have superior characteristics in their operation. These electrodes and also the one with combined additives of these oxides have long life compared with Thoriated-tungsten electrode, but all of tungsten electrode are severely consumed in oxidizing atmosphere. Thus, the use of tungsten electrode should not be used in oxidizing atmosphere and also in higher current [3)].

The operation stability of these electrodes are strongly related with the behavior of oxide included in the electrode during arcing. In order to apply these tungsten electrode properly, it is necessary to understand the mechanism affecting upon the stability of operation and consequently the electrode life. In this paper, the behavior of oxide, the electrode temperature, the effects of grain shape on those phenomena are discussed. Moreover the good characteristics of new cathode materials is shown here.

2. Experimental Procedures

The electrodes used in the work were produced by the conventional powder metallurgy[4)]. Four types of rod electrode whose diameters are 2.4, and 3.2 mm are prepared. The electrode contained La_2O_3, Y_2O_3, CeO_2 and LaB_6 are abbreviated as La-W, Y-W , Ce-W and LB-W, respectively. The additional material content of the electrodes are listed in **Table 1**

The power source is a constant current type, and a welding torch is used in the experiment with a negative direct current in the electrode and a water cooled anode made by copper. The tip angle of electrode was set as 45~180 degrees. The distance between the electrode and the anode was adjusted at 3mm, and the electrode was oriented perpendicular to the anode throughout the series of test.

3. Experimental Results

3.1 Electrode consumption

Figure 1 shows the electrode weight losses measured after one hour arc discharge with various arc currents. In the small current region the weight losses are very low. However above critical current of 300A, the weight loss

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Table 1 The additional material content of electrode used in this study.

Electrode		Content of additives(%)
Thoriated tungsten	ThO_2-W	2.0 (ThO_2)
Yttriated tungsten	Y_2O_3-W	2.0 (Y_2O_3)
Ceriated tungsten	CeO_2-W	2.0 (CeO_2)
Lanthanized tungsten	La_2O_3-W	2.0 (La_2O_3)
Lanthanum borided tungsten	LaB_6-W	0.1 (LaB_6)

increases with high rate.

The time dependence of weight loss is shown in **Fig.2**. Within one hour the consumption rate is almost constant. (The slightly higher erosion occurs in the early stage associated with arc starting.)

Figure 3 shows the electrode weight loss of new electrode which contains the LaB_6(0.1w%). This electrode consumes lower than any other electrode.

3.2 Redistribution of oxide

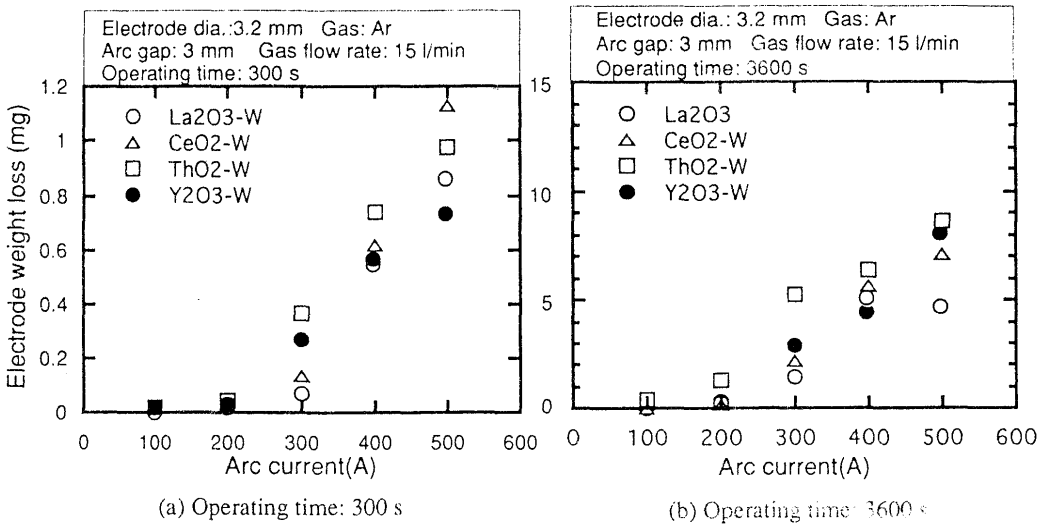
During arc discharge, the oxide contained inside the electrode changes its morphology owing to melting and moves toward the higher temperature zone near the arc root area, as shown in **Figs.4~5**. Figure 4 shows the oxide distribution after arcing on the surface. The concentration of oxide just outside of arc root area is clear. The result of X-ray diffraction analysis of oxide particle inside and near the electrode surface showed the rare earth metal oxides react generally with tungsten and form tungstate or oxytungstate. The melting points of those tungstate and oxytungstate are lower than that of oxides or tungsten.

In the case of Th-W electrode, no tungstate and oxytungstate is detected. Thus the ThO_2 is believed to react with tungsten forming only Th during arcing. The collected data for thermodynamic properties and estimated behavior of the oxide are listed in **Table 2.** Note that only CeO_2 was reduced to Ce_2O_3 after sintering in hydrogen atmosphere.

Figure 5 shows the difference between the rare earth metal oxide distribution inside the electrode in low current arc and that in higher current arc. It is obvious that in higher current case the quantity of migrated oxide is much and they concentrates in the tip and surface.

From above observations and measurement of temperature distribution along electrode surface (see **Fig.6**), we can consider the behavior of oxide as follows:

The tungstates or oxy-tungstates melt and migrate from the lower temperature zone to the higher temperature zone along the grain boundaries (which usually have a longitudinal shape) due to capillary action. The migration rate increases considerably with increasing temperature gradient and depends upon the melting point of the tungstates or oxy-tungstates. Also,



(a) Operating time: 300 s (b) Operating time: 3600 s

Fig.1 Electrode consumption as a function of arc current after arc discharge.

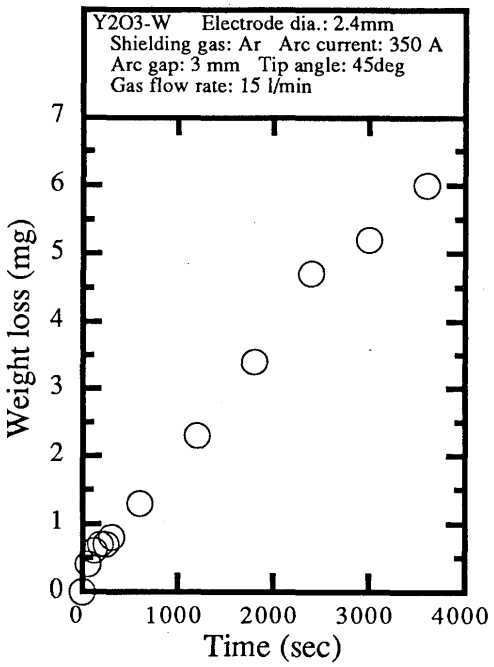


Fig.2 Electrode consumption as a function of operating time of arc discharge.

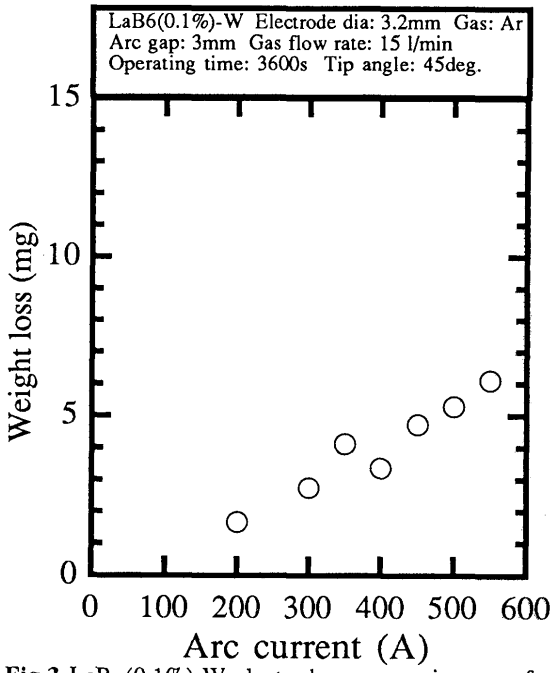


Fig.3 LaB_6(0.1%)-W electrode consumption as a function of arc current after arc discharge.

as the migrated particles travel up the temperature gradient, they are accelerated and increase in size.

At the tip, vaporization of the rare earth metals occurs. And the balance between the evaporation of rare earth metal or its oxide and their feed from inside the electrode is most important to achieve the stable and long life operation.

In the case of rather high current (300A for La-W in Fig.5), much rare earth metal oxide concentrates excessively at the tip, and sometimes it occurs the formation of vacant holes (see **Fig.7**). It is inferred that the cause could be attributable to the decomposition of oxides and their compounds.

Under the lower current conditions, the feed and evaporation of above rare earth metal oxide is well balanced in cases of La-W, Y-W and Ce-W. However, in Th-W, according to the high melting point of ThO_2 and the temperature range at which ThO_2 is reduced by tungsten, the feed and diffusion rates are much lower than the vaporization rate. Thus the electrode tip will eliminate the ThO_2 and work as pure tungsten.

3.3 Electrode temperature

Electrode temperature during arcing was determined by measuring the radiant energy from electrode. In order to eliminate the effect of arc radiation and the change in emissivity, the electrode containing a V groove was used for calibration. V groove was filled with graphite powder under extreme pressure and the radiant energy from the graphite is referred. The effect of inserted graphite on the measured temperature and electrode current density within sensible limits was assessed and found not to alter the general trend of results.

Figure 6 shows the change in temperature distribution with changes in arc current and also in shape

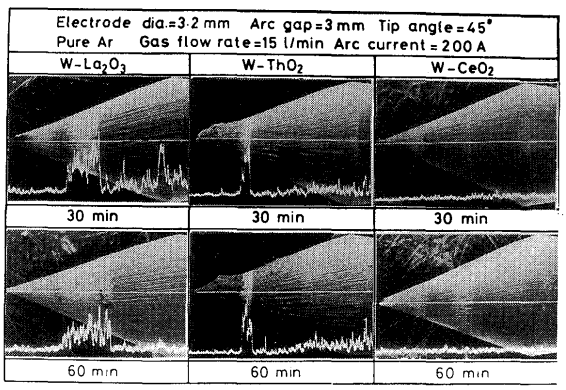


Fig.4 Appearance of electrode surface and EDX line analysis of La, Th, Ce, respectively.

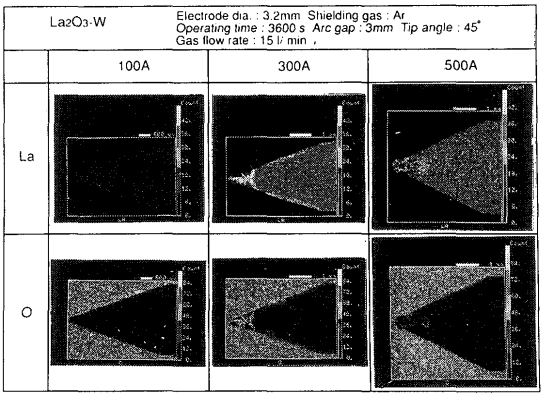


Fig.5 EPMA analysis results of cross-section of La_2O_3-W after arc discharge for 3600 s.

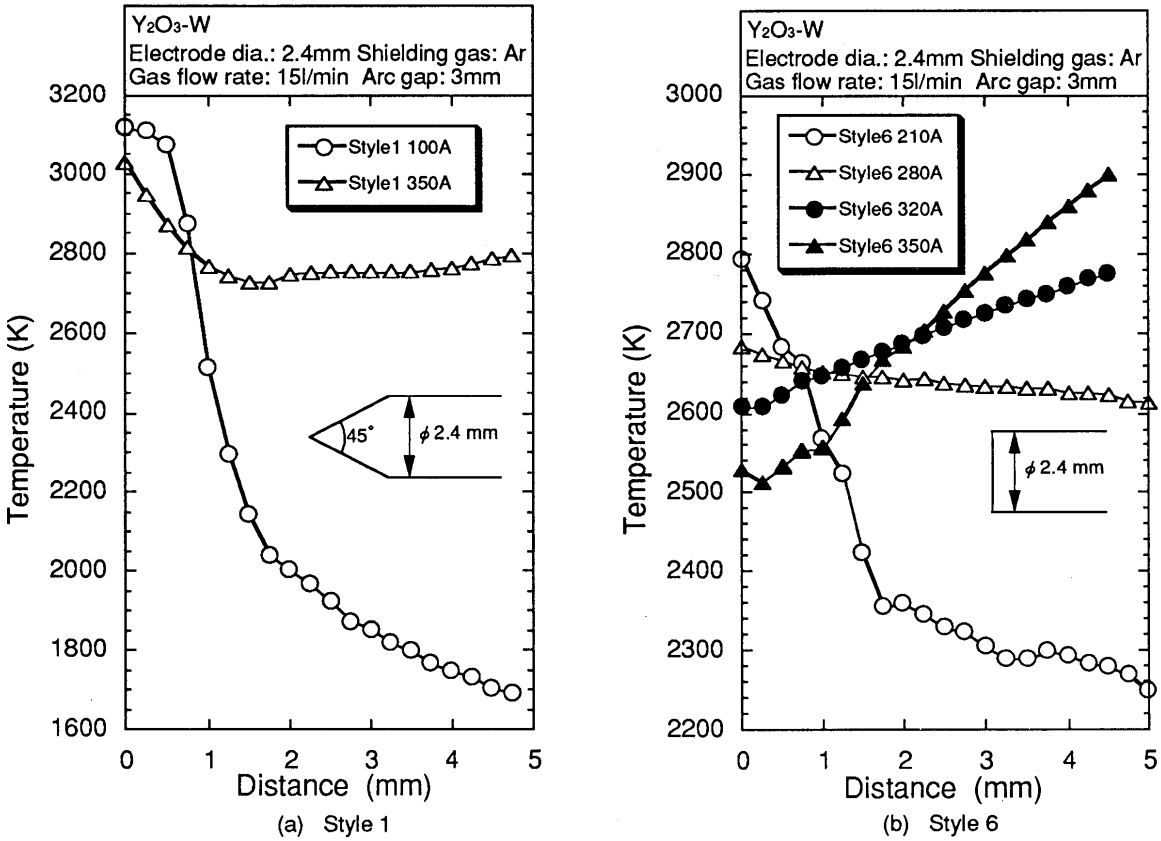


Fig.6 Electrode surface temperature along electrode axis for various arc current. Distance means the one from the electrode tip. (a) style 1 (b) style 6

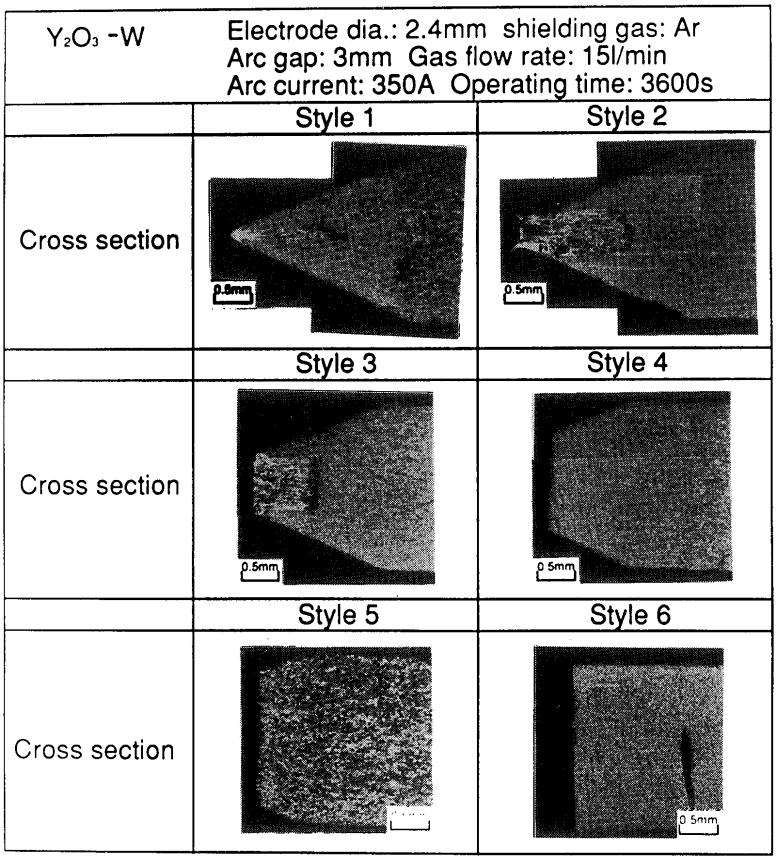


Fig.7 Cross-sectional microstructure of various electrodes tip shape after arc discharge.

Table 2 Summary of oxide and rare earth metals behavior.

Type of oxides	ThO_2	La_2O_3	CeO_2	Y_2O_3
Melting point (m.p.) K	3323 (Th: 2028)	2490 (La: 1193)	2873 (Ce: 1071)	2708 (Y: 1799)
Heat of decomposition, kJ	1227.6	1244.7	(523.4)	1271.1
Type of oxides after sintering	ThO_2	La_2O_3	Ce_2O_3 (m.p.: 1963 K)	Y_2O_3
Reaction with tungsten	reduction of ThO_2 by W occurs forming pure Th	forms tungstate (m.p.: 2073 K) and oxytungstate (m.p. > 1773 K)	forms tungstate (m.p.: 1363 K)	forms tungstate (m.p.: 1743 K) and oxytungstate (m.p. > 2473 K)
Oxide behavior	1. diffusion of Th atoms to the electrode surface 2. vaporization of Th from the electrode surface	1. migration of La_2O_3 occurs from the center to the electrode tip 2. vaporization of La_2O_3 from the electrode surface	1. migration rate throughout the electrode edge is higher than from the center to the electrode tip 2. vaporization of CeO_2 from the electrode surface	1. very low migration and vaporization rates
Stability of oxides	lower stability	higher stability	reasonable stability	high stability

of electrode. The electrode fused with 360A at around 8mm from the tip.

3.4 Effect of shape of electrode tip

Figure 7 shows metallurgical structure of various shapes of electrode after severe loading of arc discharge. Electrodes of styles 4~6 have no obvious change in metallurgical structure, though the one of style 5 shows a little grain growth. On the other hand, style 1~3 show severe damages at the tip. From the consideration of the results shown in Fig.6, it will be deduced that the temperature field near the tip has decisive effect on the metallurgical structure including the distribution of oxide. The weight losses of these electrodes (style 1~6) were nearly equal within 1 hour.

4. Discussion and Conclusions

Originally the addition of rare earth metal oxide to the tungsten electrode was developed to ensure the long life and the stable operation. This is because of low work function of the rare earth metal and their oxides. And it also made the ignition of arc very easy. Thus the operation properties of the electrode is improved as the oxide content was increased, but the oxide contents employed are generally less than 2%, since the electrode containing oxide more than 2% is very difficult to produce by sintering.

Our experimental results showed that in lower current the oxide migrated and diffused to the higher temperature zone and lower the work function.

It decreased the electrode temperature and consequently reduce the consumption.

However in higher current, the temperature increased and severe concentration of oxide occurred at the tip. Since these oxide has comparatively low melting point, the excess oxide might be decomposed and gasified.

The behavior of oxide was governed by the temperature and its distribution, which are different for various shapes of tip. When the evaporation of oxide from surface and its feed from inside was well balanced, the formation of vacant hole did not occur. These phenomena suggest the optimum amount of oxide is determined by considering the temperature field of electrode. The amount of oxide, electrode shape and geometrical structure are of importance in the design of plasma torch.

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