Effect of Grain Morphology on Consumption of GTA Electrode†

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Abstract

This work was made on tungsten electrodes activated with ThO_2, La_2O_3, Y_2O_3, and CeO_2. The phenomena of electrode consumption were investigated from the point of view of those oxides' behavior during arc discharge. The results indicated that ThO_2-W electrode has inferior characteristics among those electorodes at low arc current, but at high arc current all electrodes exhibit insufficient properties.

The morphology of tungsten grain has an influence on the stability and life time of electrode of gas-tungsten arc. Two types of tungsten electrode, whose grain have a longitudinal shape and a granular shape were compared experimentally, and it was shown the longitudinal type has a superior properties than the granular type. To clarify the effect, the behaviors of oxide during arc discharge were reviewed and discussed. And based on the theory of oxide behavior deduced from the review, the effects of tungsten grain shape on the temperature and consumption were discussed.

KEY WORDS : (Gas-Tungsten-Arc)(Electrode Consumption)(Tungsten)(Rare-Earth Metal Oxides)

1. Introdution

One of the issues to be solved in plasma torch technology is the serious consumption of cathode electrode. In a previous paper[1),2)], it is shown that tungsten electrodes activated with La_2O_3, Y_2O_3, CeO_2 respectively have superior characteristics in their operation. These electrodes and also the one with combined additives of these oxides have long life times compared with thoriated electrode, but all of tungsten electorode are severely consumed in oxidizing atmosphere. Thus, the use of tungsten electrode should be limited in the inert atmosphere.

The life time 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 life time. In this paper, the behavior of oxide, the electrode temperature, the electrode consumption and behavior of oxides at high arc current, the effects of grain shape on those phenomena are discussed.

2. Experimental Procedures

The electrodes used in the work were produced by the conventional powder metallurgy. Four types of rod electrode whose diameters are 2.4, 3.2 and 4.8 mm are prepared. Oxides, ThO_2, La_2O_3, Y_2O_3, and CeO_2 are included in 2 % in weight. Those are expressed as Th-W, La-W, Y-W and Ce-W respectively. Additional two types of electrodes are prepared, which have different grain structure of tungsten. One has a longitudinal grain structure whose morphology is long in axial direction and the other has a granular grain boundaries. These electrodes are listed in **Table 1**[3)].

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 degrees. The distance between the electrode and the anode was adjusted at 3 mm, and the electrode was oriented perpendicular to the anode throughout the series of test.

Specimens were prepared for metallographic examination by means of hand grinding through No.1500 emery papers and polishing with fine alumina. Polished specimens were electrolytically etched in a solution consisting of NaOH-10 % normal, for SEM observation. During the electorolytic etching, the voltage was set at 5 V for 30 s. This aids in the delineation of the morphological changes of the oxide shape after arcing. To

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Table 1 Oxide content in tungsten electrode produced.

Electrode		Oxide content (%)
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)
Mixed oxide tungsten	(U-W)	1.2 (Y_2O_3) 0.4 (CeO_2) 0.4 (La_2O_3)

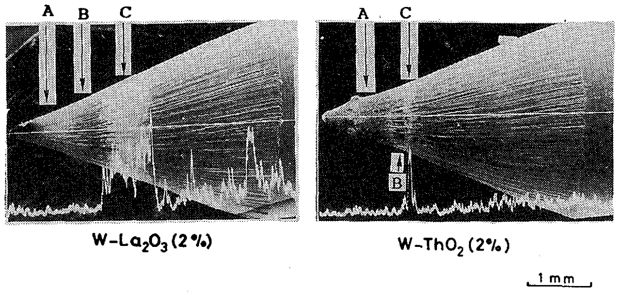

Fig. 1 Appearance of electrode surface and oxide distribution throughout the electrode tip of W-La_2O_3 and W-ThO_2.

observe the microstructure and the recrystallized grains after arcing Murakami's reagent (a solution of 10 g $K_3Fe(CN)_6$, 10 g KOH and 100 ml water) was used. It was applied by swabbing for 5-10 s.

Electrode temperature duing operation were determined by measuring the radiation from the graphite pyrometrically which was inserted in electrode. In the measuring, electrodes, 4.8 mm in diameter, were machined to contain a V shape groove, which was then filled with graphite powder under extreme pressure to avoid its loss during arcing. The graphite powder has a known emissivity. 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.

The temperature of the electrode was measured using Infrared Thermometer. This type of infrared thermometer collects the infrared radiation with a wave length range of 1.8-5.0 microns from a target area of 0.25 mm in diameter and converts it to a temperature reading for the same target area.

3. Experimental Results

3.1 Behavior of rare-earth metal oxides during arc discharge

During arc discharge, the oxide contained inside the electrode changes its morphology due to melting and moves to the higher temperature zone like the arc root area, as shown in **Fig. 1-3. Figure 1** shows the oxide distribution after arcing on the surface. The concentration of oxide just outside of arc root area is clear. In **Fig. 2**, the result of X-ray diffraction analysis of oxide particle inside and near the electrode surface is shown. The rare-

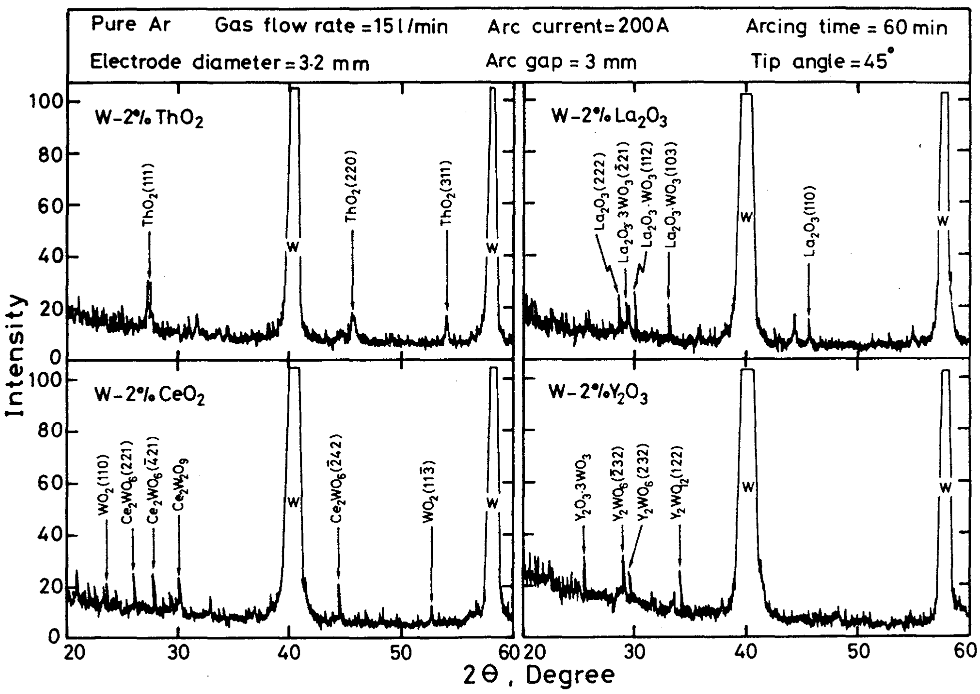

Fig. 2 X-ray analysis of the migrated particles through the several electrodes.

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 **Table 2** and **Fig. 3**. Note that only CeO_2 was reduced to Ce_2O_3 after sintering in hydrogen atmosphere.

Schematic illustration of the suggested migration and the different behavior of oxides accompanied with the temperature distribution are shown in **Fig. 3**. In the case of rare earth metal oxides their tungstates and oxytungstates 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 oxytungstates. Also, as the migrated particles travel up the temperature gradient, they are accelerated and increase in size. A detailed investigation and analysis of the migrating particles throughout the electrode tip was made clear that there is a concentration gradient of W and La set up throughout the migrated particles as folows; At the bulk of the electrode and far from the tip, the ratio between W concentration and La concentration is almost the same (1: 1 oxy-tungstate), but when moving in the tip direction the relative La concentration becomes higher. At the tip, vaporization of La_2O_3 occurred. It is inferred from this observation that the rate-limiting process is probably dissolution kinetics at the leading interface of the particles.

According to the high melting point of ThO_2 and the temperature range at which ThO_2 is reduced by tungsten, the feeding and diffusion rates are much lower than the vaporization rate. Thus the electrode tip will eliminate the ThO_2 and work as pure tungsten.

From above observation, it was deduced that the balance between the evaporation of the oxide at the surface and its feed from inside the electrode is most important to achieve the stable and long life operation.

3.2 Electrode consumption and behavior of oxides at high arc current

To investigate the phenomena of electrode consumption at high arc current, the electrodes which have a longitudinal grain structure were arced for 1 hr. **Figure 4** shows the result of this consumption test. As shown in previous paper[4], the consumption rate of Th-W was highest below 400 A. But there was not much difference among Th-W, La-W, and Y-W at 500 A, and the consumption rate of Ce-W was much higher than

Table 2 Summary of oxides 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

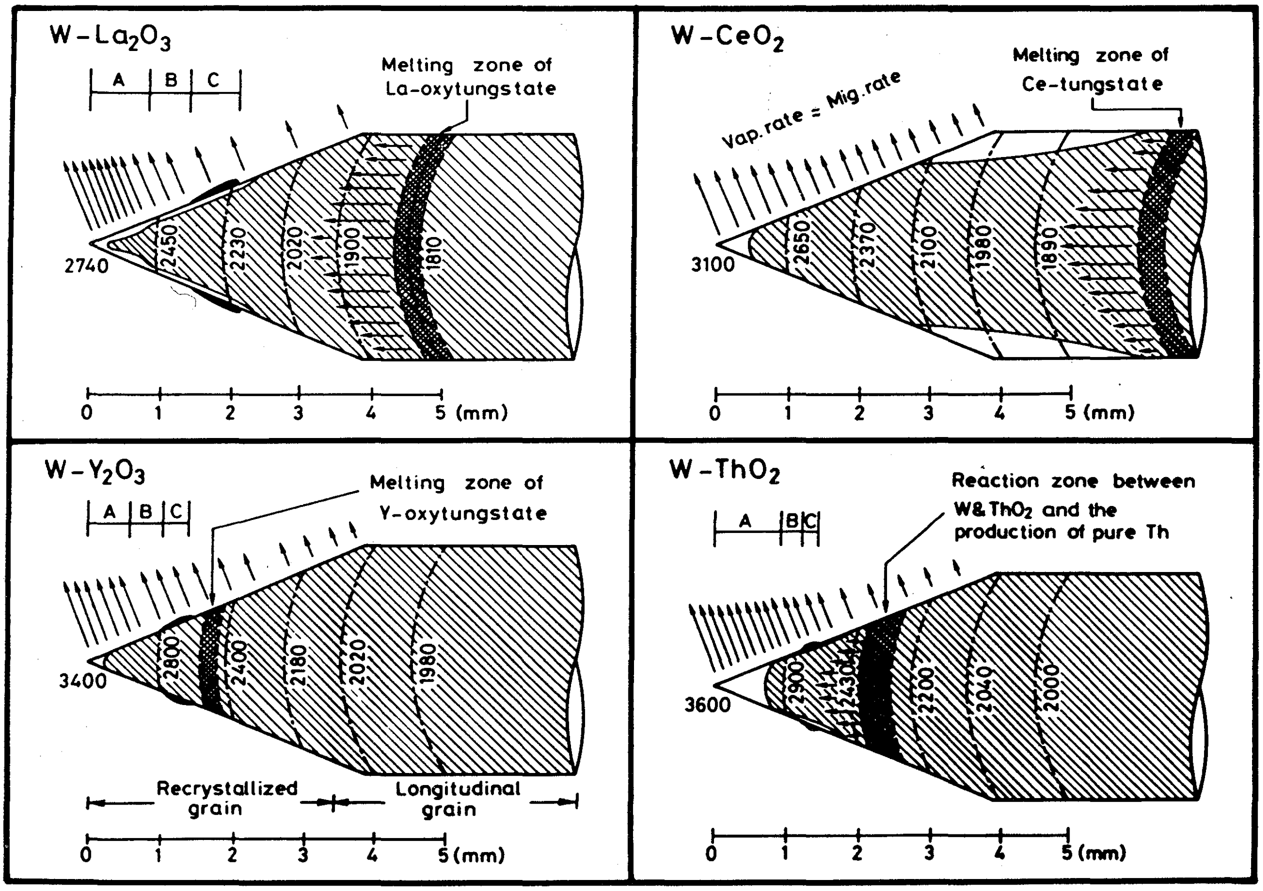

Fig. 3 Schematic illustration of the oxide distribution and behavior accompanied with the temperature distribution along the electrode axis. Dashing areas represent the oxide remaining after operation, and the arrows represent the oxide vaporization.

these electrodes. The consumption rate begins to increase rapidly from 300 A about all electrodes.

Figure 5 shows the appearance of electrodes after 1 hr of arcing. At 300 A the formation of rim occurred except La-W, but above 400A the rim disappeared. Below 200A the electrode tip of Th-W was most transformed and the other electrodes relatively retained their pointed tip. Above 300 A the tips of all electrodes were extremely transformed.

Figure 6 shows metallurgical structures of the cross section of the electrodes. In the case of Th-W, the oxides decreased near the tip surface below 300 A, and many porosities were created above 400 A. In the cases of La-W, Y-W, and Ce-W, many porosities were created and the oxides almost disappeared at the tip side from the porosities above 200 A.

From **Table 2** these phenomena are deduced as follows: In the case of Th-W, the migration of ThO_2 dose not occur. The ThO_2 is believed to react with tungsten forming Th during arcing, and these pure Th atoms diffuse to the tip surface. At the area where the oxides disappeared, the temperature is enough to react ThO_2

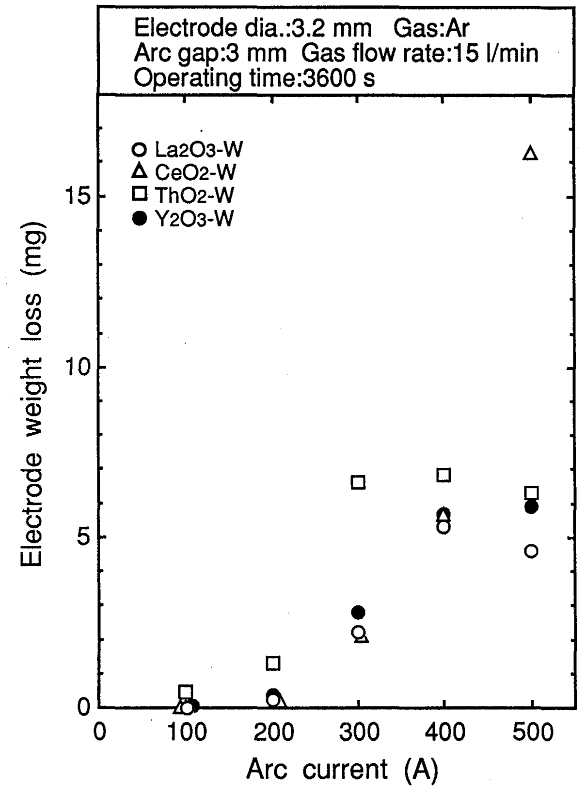

Fig. 4 Electrode consumption as a function of arc current.

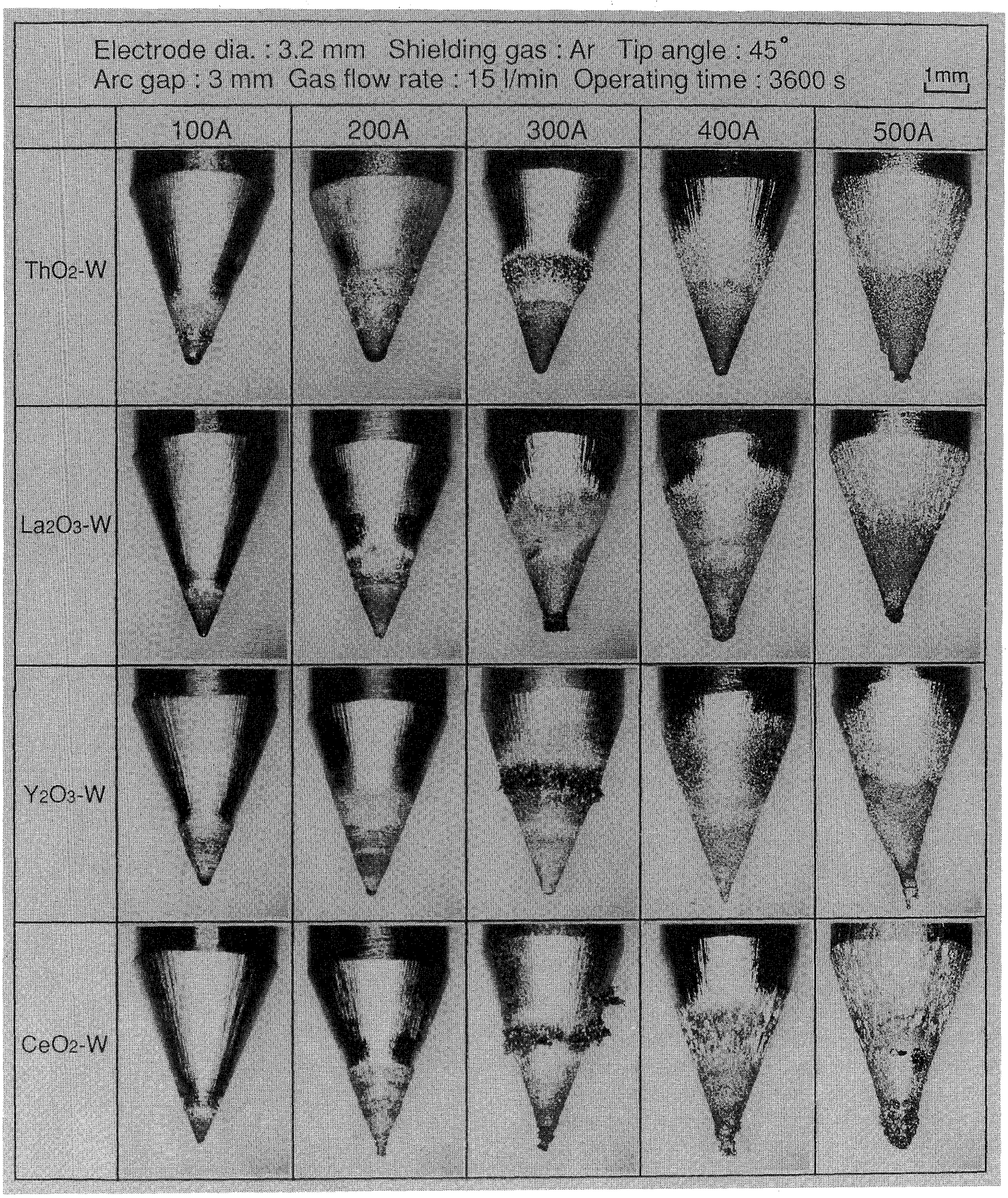

Fig. 5 Appearance of electrode tip shape after 60 min of arcing.

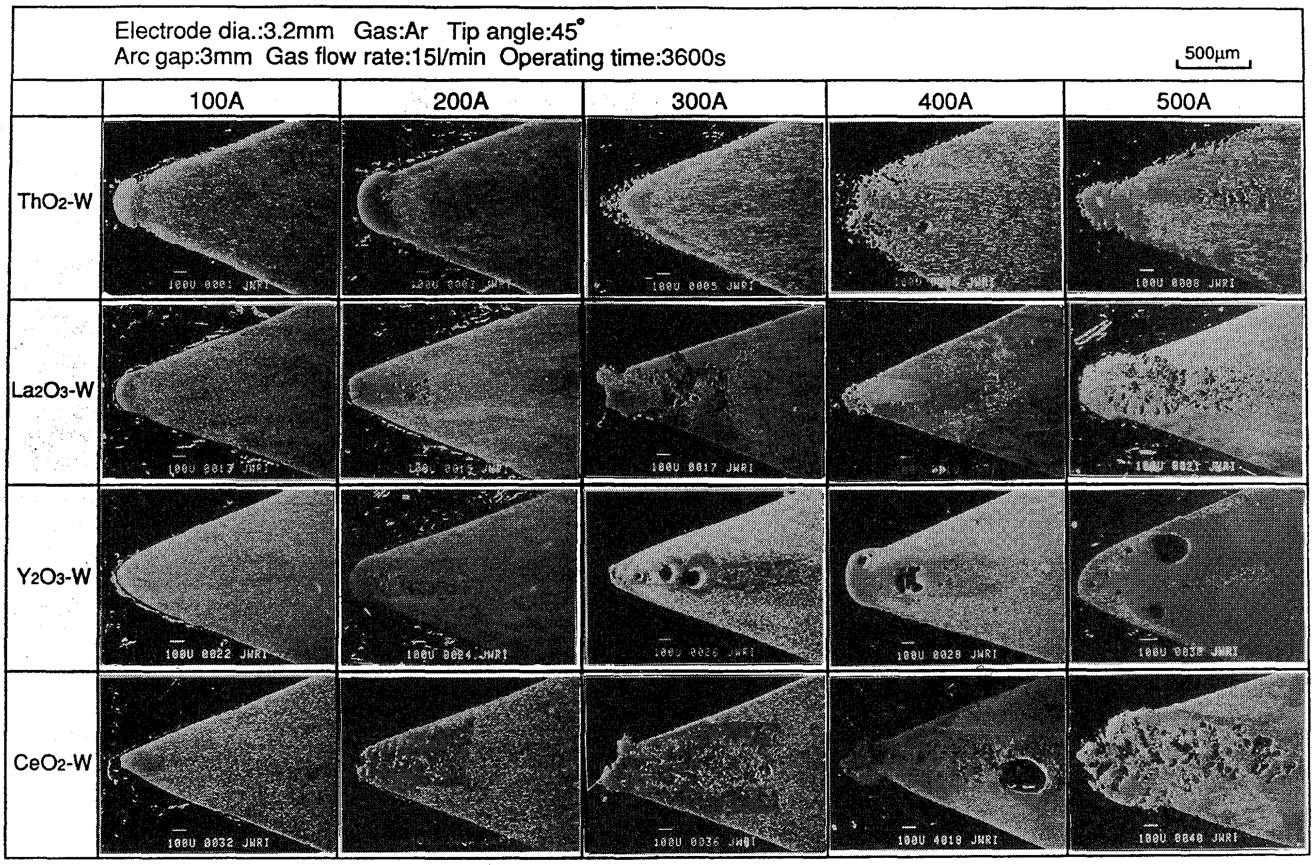

Fig. 6 Microstructure of the several electrodes after 60 min of arcing.

with tungsten. On the contrary, the oxides remained in the area where the temperature is not enough to react ThO_2 with tungsten. Thus the boundary of the oxide distribution is very clear. In the cases of La-W, Y-W, and Ce-W, the oxides migrate to the tip surface, but this migration is disturbed by the porosities. Thus there were no oxide at these electrode tip.

3.3 Effect of shape of tungsten grain on the behavior of oxides and consumption

The electrodes were applied for arcing with a constant arc current (300, 500 A) for various time intervals from 10 min to 6 hr of arcing in pure argon to observe the metallurgical changes and the behavior of oxides. **Figure 7** shows the appearance of electrodes after 1 hr of arcing with 500A, as example, for La-W and Ce-W electrodes respectively. It is noted the surface of granular structure elecrtodes was rougher than that of longitudinal structure electrodes. In the case of La-W, the difference in surface morphology is very clear, though the Ce-W is not the case.

Figure 8 shows metallurgical structures of the cross section of the electrodes. In the case of longitudinal structure type La-W electrodes, the oxides remained near the surface, but in the case of granular structure type La-

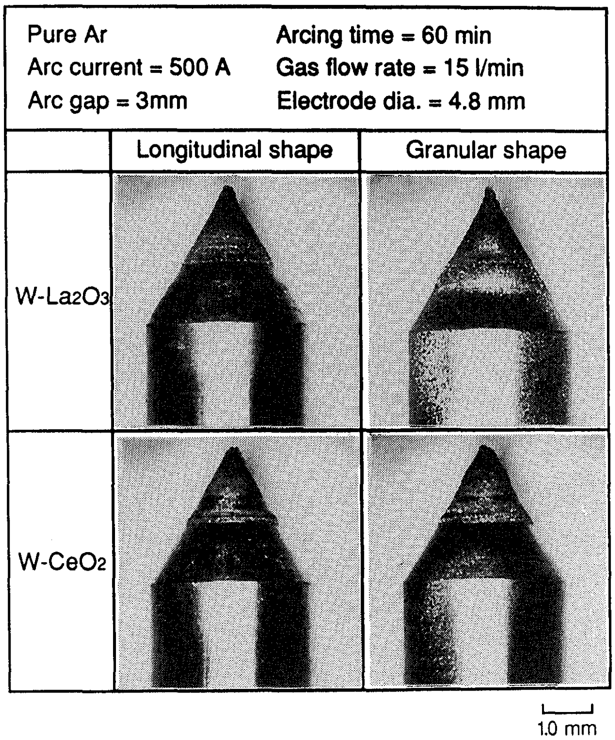

Fig. 7 Appearance of electrode tips after 60 min of arcing at 500 A in pure Ar.

W electrodes the oxides decreased near the surface.

The time-development of temperature of electrode tip is shown in **Fig. 9**. The electrode of longitudinal grain structure kept roughly constant, but the electrode of granular grain one has gradual increase in temperature. All of these results above mentioned can be attributable to the imbalance between the evaporation of oxide from surface and its feed by migration from inside the electrode to the surface. When the shape of grain boundaries is granular, the oxide (tungstate, oxytungstate) takes much time to migrate along the grain boundaries and reach the electrode surface.

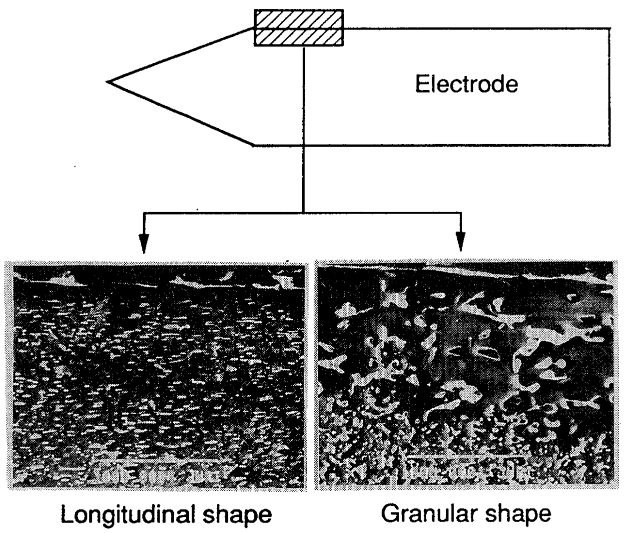

Fig. 8 Microstructure of La-W electrode after 60 min of arcing at 500 A in pure Ar.

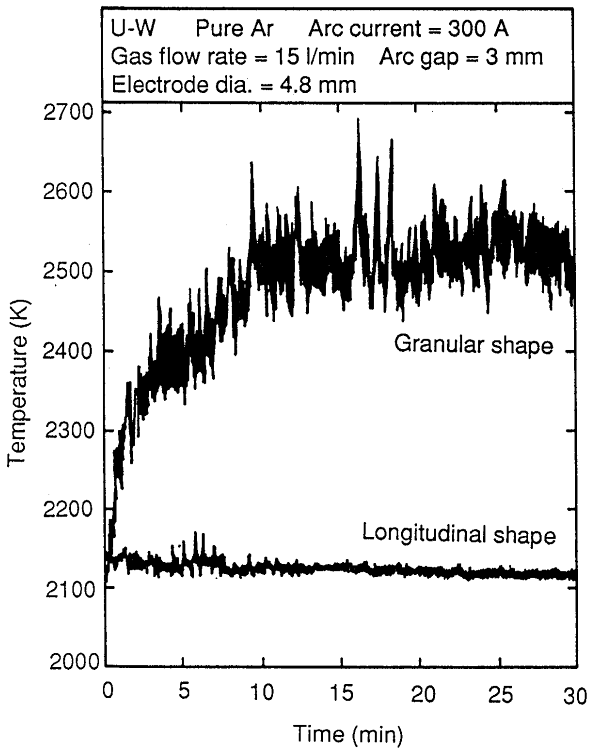

Fig. 9 Changes in temperature of electrode tip during arcing.

Table 3 Electrode consumption after arc discharge.

Pure Ar Arc gap = 3 mm	Gas flow rate =15 l/min Electrode dia. =4.8 mm		
	La2O3-W	CeO2-W	U-W
Arc current	500 A	500 A	300 A
Arcing time	1 hr	1hr	6hr
Granular shape	0.43 mg	0.70 mg	0.40 mg
Longitudinal shape	0.24 mg	0.24 mg	0.13 mg

The highest migration rate among those oxides is shown by Ce_2O_3, which has a lower melting point (even for the oxide itself and for the tungstate). This oxide tungstate easily migrates and it is continuously fed to the electrode tip. Thus the consumption rate of the oxide is much higher.

Table 3 is the results of electrode consumption test confirmed the mechanism above mentioned. If the feed of oxide to the surface from inside is not sufficient, it increased the working temperature of electrode tip and consequently results in higher consumption.

4. Conclusion

At low arc current (below 200 A) superior characteristics are provided by the La_2O_3-W, Y_2O_3-W, and CeO_2-W electrodes, but at high arc current (above 300 A), all electrodes exhibit insufficient properties.

The difference of shape of tungsten grain affects the behavior of oxide and the stability and the consumption of tungsten electrode.

The longitudinal shape grain provide better characteristics than that of granular shape.

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