Study on Gas-Tungsten-Arc Electrode (Report 1)†

– Comparative Study of Characteristics of Oxide-Tungsten Cathode –

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Abstract

A comparative study has been made of characteristics of gas-tungsten-arc (GTA) cathodes, consisting of tungsten mixed with a small quantity of La-, Y-, Ce-, Th-, Zr- and Mg-oxides respectively and pure-tungsten. Arc starting characteristics, arc pressure, electrode consumption, change in shape due to long term operation and incompleteness of inert gas shielding, and electrode temperature are compared in direct current electronegative polarity, and it is shown the superiority of La-oxide, Y-oxide and Ce-oxide electrodes in those characteristics.

Direct observation of cathode tip by microscope during arc burning is carried out and important phenomena concerning the formation of tungsten "rim" at the periphery of cathode area, which governs the durability of electrode and the stability of arc, are studied.

KEY WORDS: (Tungsten) (Oxide Tungsten) (GTA Welding) (Nonconsumable Electrode) (Refractory Metals)

1. Introduction

The recent welding technology, automatic and robotic weldings, demands the superior stability and reliability both in long term operation and many times on-off operation of gas-tungsten-arc (GTA) welding electrode. As the cathode in GTAW, the sinterd tungsten electrode containing thoria (ThO_2) has fine characteristics in arc starting operation[1),2)], but insufficient properties in arc stability and consumption of electrode materials. It is necessary to develop the new electrode to satisfy the technical requirement.[3)]

Required features for the electrode are, the easiness on arc starting and its completely successful operation, non of deformation in cathode tip shape and consumption of electrode materials which ensure the stability of arc heat transfer characteristics, the superiority in response for the change in electric power parameter, and so on.

The aim of this investigation is to produce various types of tungsten-oxide electrode and compare the operational characteristics, namely, arc starting performance, arc voltage-current relationship, arc pressure, electrode temperature, consumption and deformation due to heavy current loading, effect of oxygen mixed into argon shielding gas on the characteristics of electrode.

Following electrodes are used in the experiment; pure tungsten electrode and tungsten-oxide electrodes containing magnesium-oxide, zirconium-oxide, thorium-oxide, cerium-oxide, yttrium-oxide and lanthanum-oxide.

2. Electrode Produced

Various types of tungsten-oxide electrode were produced by the conventional powder metallurgy process, which are tabulated in **Table 1**. These are 1.6 mm, 2.4 mm and 3.2 mm in diameter, centerless ground. The shape of electrode tip is a cone angled at 45°. Direct current is applied in electrode negative polarity.

Table 1 Electrode produced and its oxide content.

Electrode material		Oxide content (%)
Pure – Tungsten	(P-W)	0
Magnesium oxide – Tungsten	(MgO-W)	1 – 3
Thorium oxide – Tungsten	(ThO_2-W)	1 – 3
Zirconium oxide – Tungsten	(ZrO_2-W)	0.5 – 3
Yttrium oxide – Tungsten	(Y_2O_3-W)	1 – 3
Cerium oxide – Tungsten	(CeO_2-W)	0.5 – 2
Lanthanum oxide – Tungsten	(La_2O_3-W)	0.5 – 2

3. Experimental Results and Discussions

3.1 Arc starting characteristics

In order to evaluate the arc starting characteristics, a comparison of the percentage of successful start as a function of open circuit voltage for the various electrodes was made with high-frequency starting method.

Follow-up arc current was adjusted 20–30 A in each case. Electrode tips were ground conically with 45° in

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cone angle. Conventional high frequency current was applied in 10 seconds and during the time if the successful arc starting was followed or not was examined. 30 times operation were carried out in each case and starting performance was classified into three groups, that is, successful arc starting, incomplete arc starting showing apparent crimbing up and erratic motion of arc root, and failure in arc following. Obtained results are illustrated in **Fig. 1**.

La_2O_3-W, Y_2O_3-W, CeO_2-W and ThO_2-W electrodes have superior arc starting characteristics.

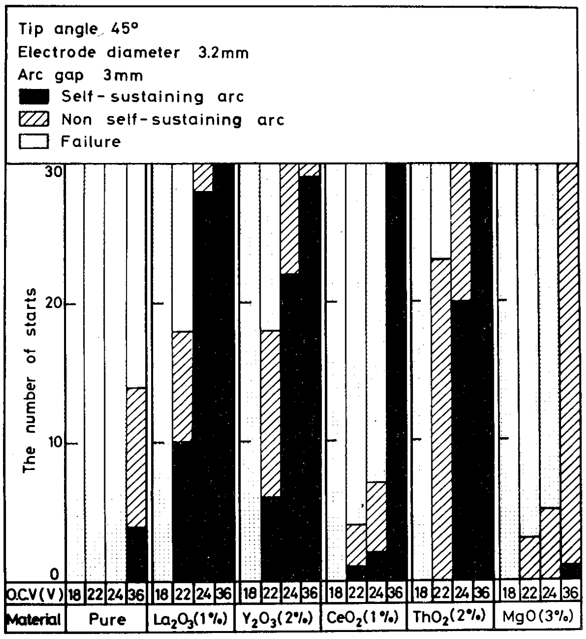


Fig. 1 Arc starting characteristics. O.C.V. shows open circuit voltage.

3.2 Arc voltage-current characteristics

An example of arc voltage-current characteristics is shown in **Fig. 2**. The characteristics curves of tungsten-oxide electrodes differ from that of pure-tungsten electrode. The difference among the arc voltage-current characteristics of various tungsten-oxide electrodes are negligible small without that of zirconiated one showing comparatively large deformation due to melting.

3.3 Arc pressure

Figure 3 shows the arc pressure distribution at the water-cooled copper anode measured by a semiconductor transducer. Arc pressure as a function of arc current is illustrated in **Fig. 4**. And, **Fig. 5** shows the maximum arc pressure at various radii of electrode truncation related with arc current, in which the curve of pure-tungsten appeared in Fig. 4 is also plotted with a dotted line.

Arc pressure is originated mainly by the induced flow of plasma gas due to the expansion of current path near the cathode. The truncation or deformation due to melting changes the thermal state of electrode and the impedance for induced flow of plasma gas, consequently leads to a change in the arc pressure. The results represent the CeO_2-W, Y_2O_3-W and La_2O_3-W electrodes have little deformation of electrode tip.

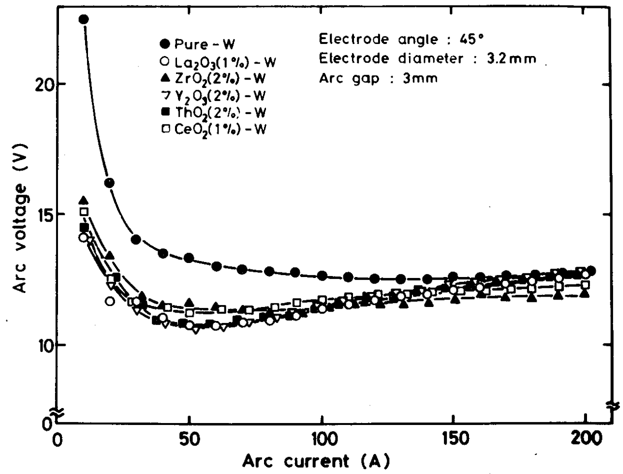


Fig. 2 Arc voltage-current relationship.

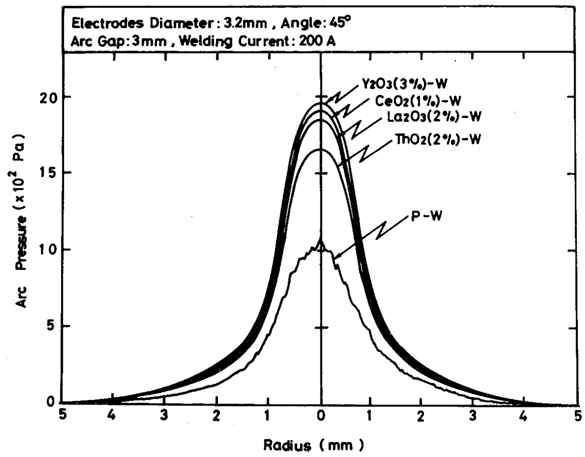


Fig. 3 Arc pressure distribution.

3.4 Electrode temperature

Electrode temperature just above the conical zone of cathode was measured by the use of a thermo-couple, as shown in **Fig. 6**. Measured value is not the temperature of the working area (spot area) as the cathode, but, it should reflect the thermal state of cathode.

La_2O_3-W, Y_2O_3-W and CeO_2-W electrodes showed the lowest temperatures. It may suggest the operation temperatures of the working area of above cathodes are rather low compared with those of other electrodes.

3.5 Electrode tip melting and structure

Figure 7 shows the appearance of electrode tip after one-hour burning at 180 A with 1.6 mmϕ in diameter (heavy loading). Metallurgical structure of the electrodes are also shown in **Fig. 8**.

La_2O_3-W electrode showed the least change in shape and structure. Y_2O_3-W electrode has also little melting at

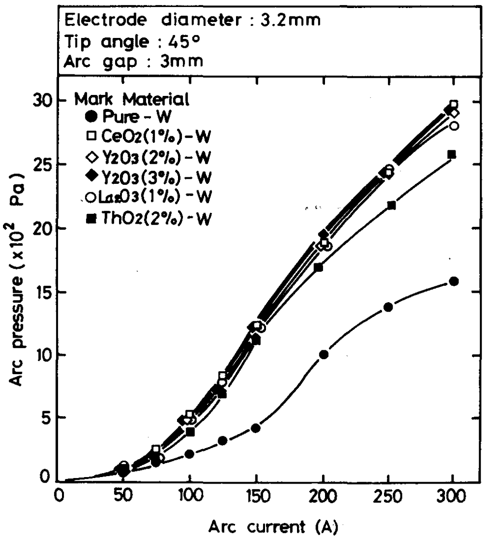


Fig. 4 Effect of current on maximum arc pressure.

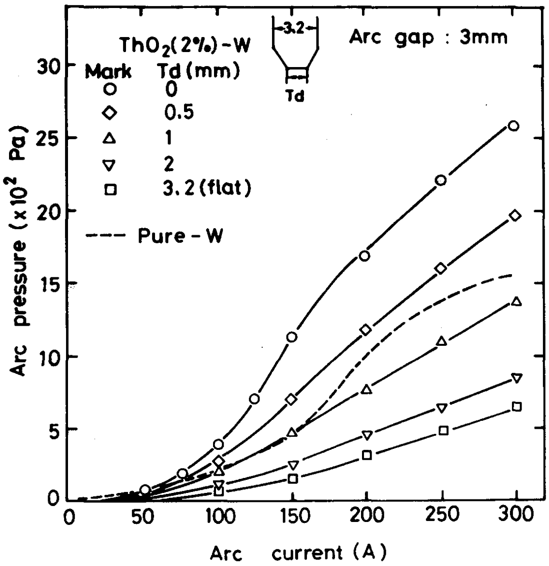


Fig. 5 Effect of truncated diameter of electrode tip on arc pressure.

the surface but some small holes appeared. CeO_2-W electrode was a little molten. On the otherhand thoriated-tungsten electrode has a large melting and production of many gas hole. ZrO_2-W one has a large consumption at the tip. Pure-W and MgO-W electrodes displayed serious melting.

3.6 Observation of cathode surface

Observation of cathode tip surface after operation was made by using SEM. **Figure 9** shows the microstructure of CeO_2-W cathode after the arc burning of 10 minutes at 200 A in argon shielding gas. Melting of very thin layer of the surface and the growth of tungsten dendrite at the periphery just behind the cathode area was observed.

The behavior of oxide contained in the electrode was examined by EDX-ray analysis using thoriated-tungsten

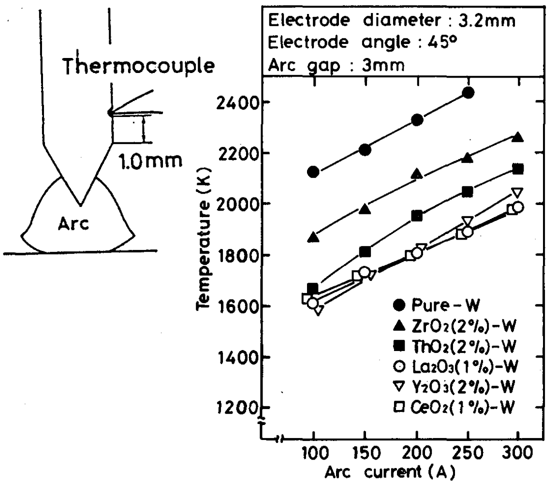


Fig. 6 Electrode temperature measurement by thermocouple.

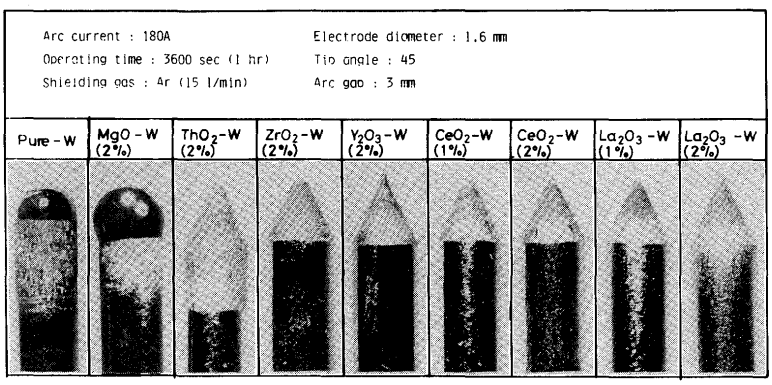


Fig. 7 Change in shape of electrode tip due to heavy loading.

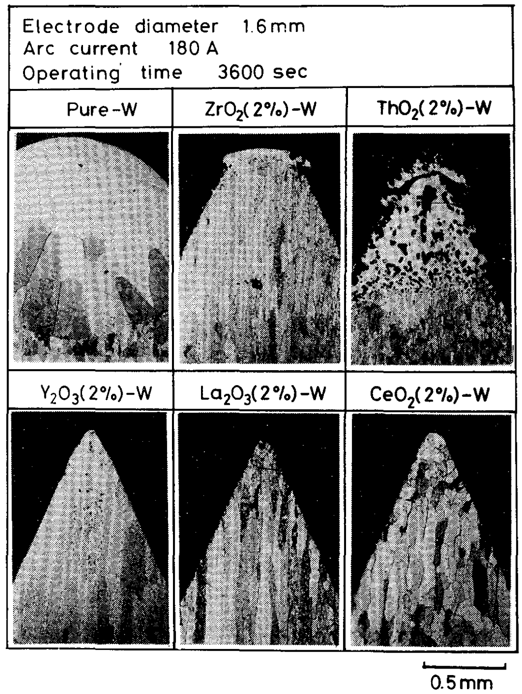


Fig. 8 Metallurgical structure of electrode after heavy loading.

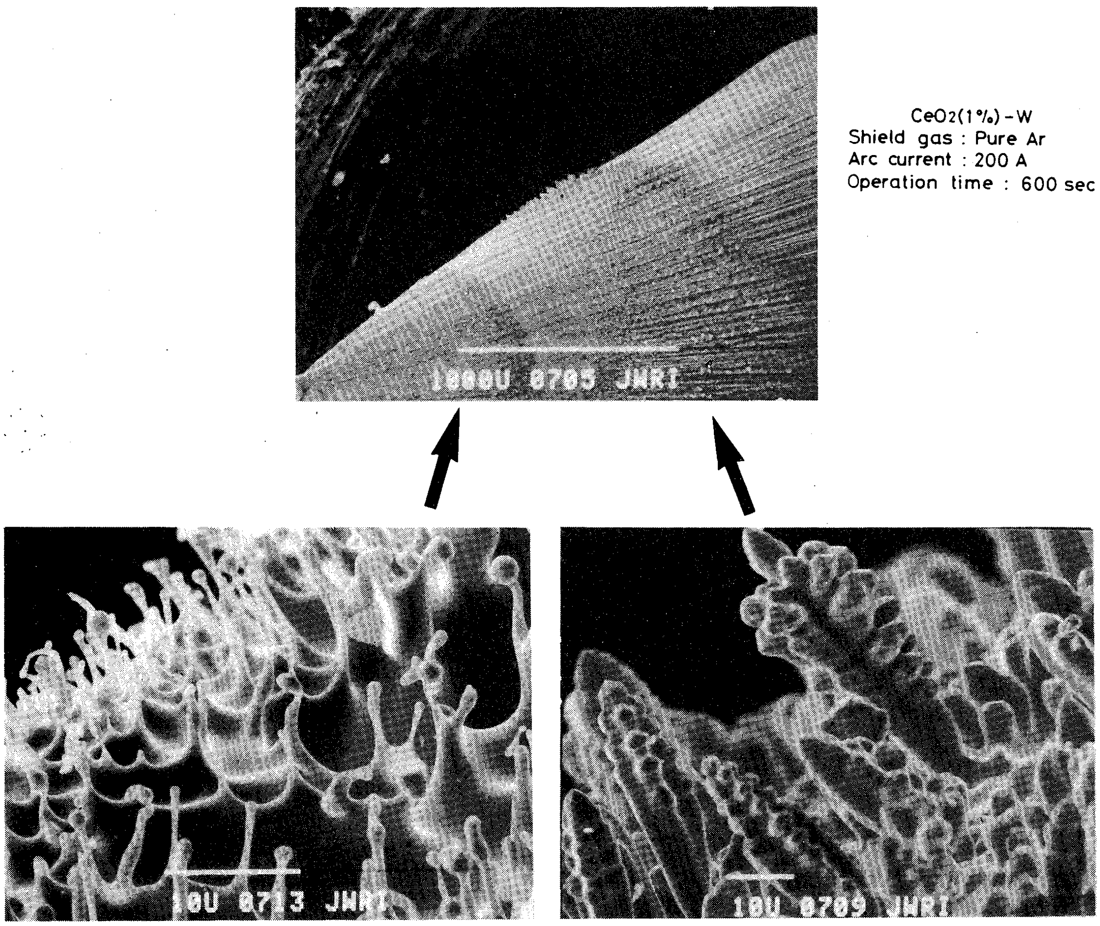


Fig. 9 Microstructure of electrode surface after heavy loading.

electrode. It disappears at the tip after the long time operation as shown in **Fig. 10**. But, at the boundary zone which is just outside of the melt zone, the concentration of thorium can be seen.

3.7 Electrode consumption and formation of "rim"

A simple measurement on electrode consumption in steady state was made with DCEN polarity. Decrease in weight of electrode after 5 minutes arc burning were plotted as a function of arc current, which is illustrated in **Fig. 11**. Tungsten-oxide electrodes displayed very little consumption compared with puretungsten electrode. This consumption increases extremely with increase in content of oxygen mixed into argon shielding gas, while nitrogen has no effect on it. **Figure 12** shows the effect of oxygen or nitrogen contents in the argon shielding gas on the consumption of electrode.

The mixing oxygen into argon shielding gas promoted the growth of tungsten dendrite mentioned in the preceding subsection, which was formed at the periphery just behind the cathode area, and resulted in shaping "rim" as shown in **Fig. 13**. It is consisted of the build up of the dendritic tungsten, according to the examination by

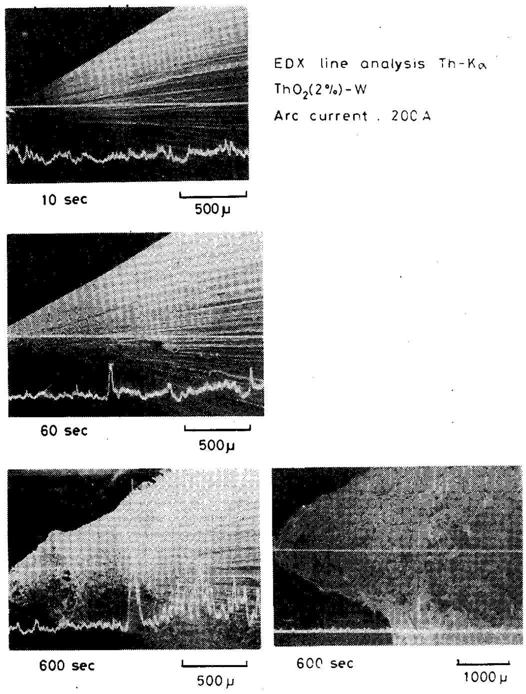


Fig. 10 EDX analysis of Th-K_α line with various operation terms.

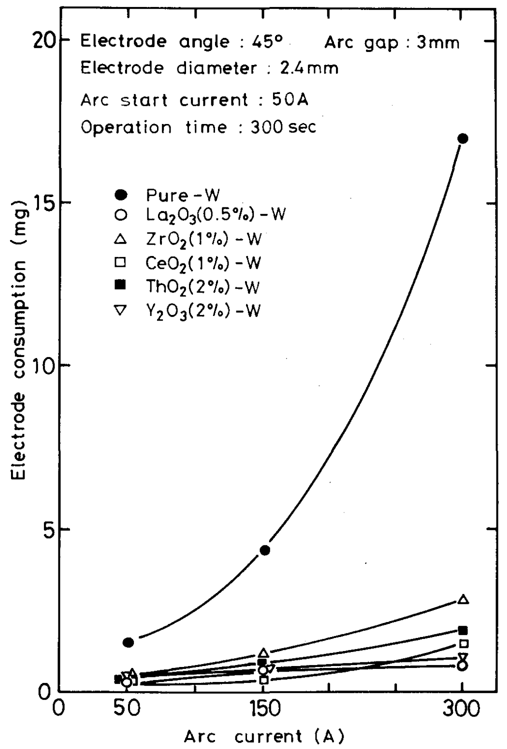


Fig. 11 Effect of arc current on electrode consumption.

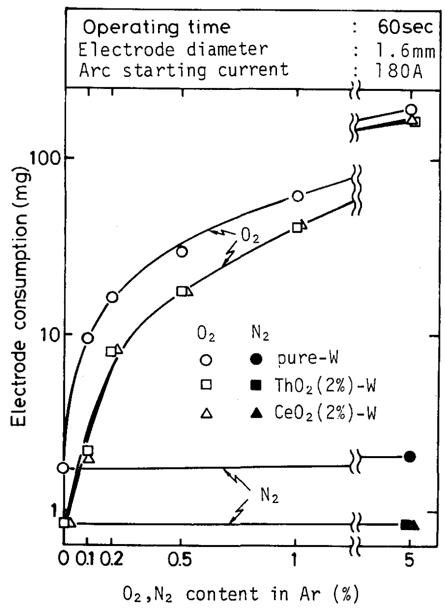


Fig. 12 Effect of oxygen and nitrogen introduced in argon shielding gas on electrode consumption.

X-ray diffraction analysis. The speed of formation of this "rim" is very high when content of oxygen in argon shielding gas is as high as 1% (**Fig. 14**).

The formation of the "rim" changes the arc configuration and causes the arc instability. **Figure 15** shows the appearances of unstable behavior in arc voltage and arc pressure in the very short time from the instance of

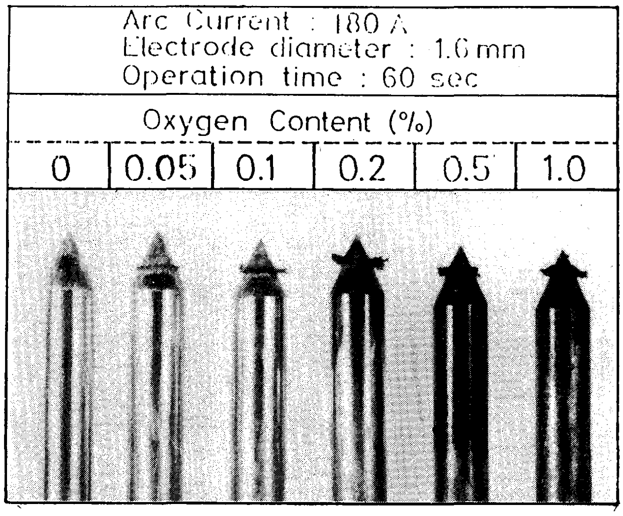


Fig. 13 Change in electrode shape due to oxygen mixing into argon shielding gas.

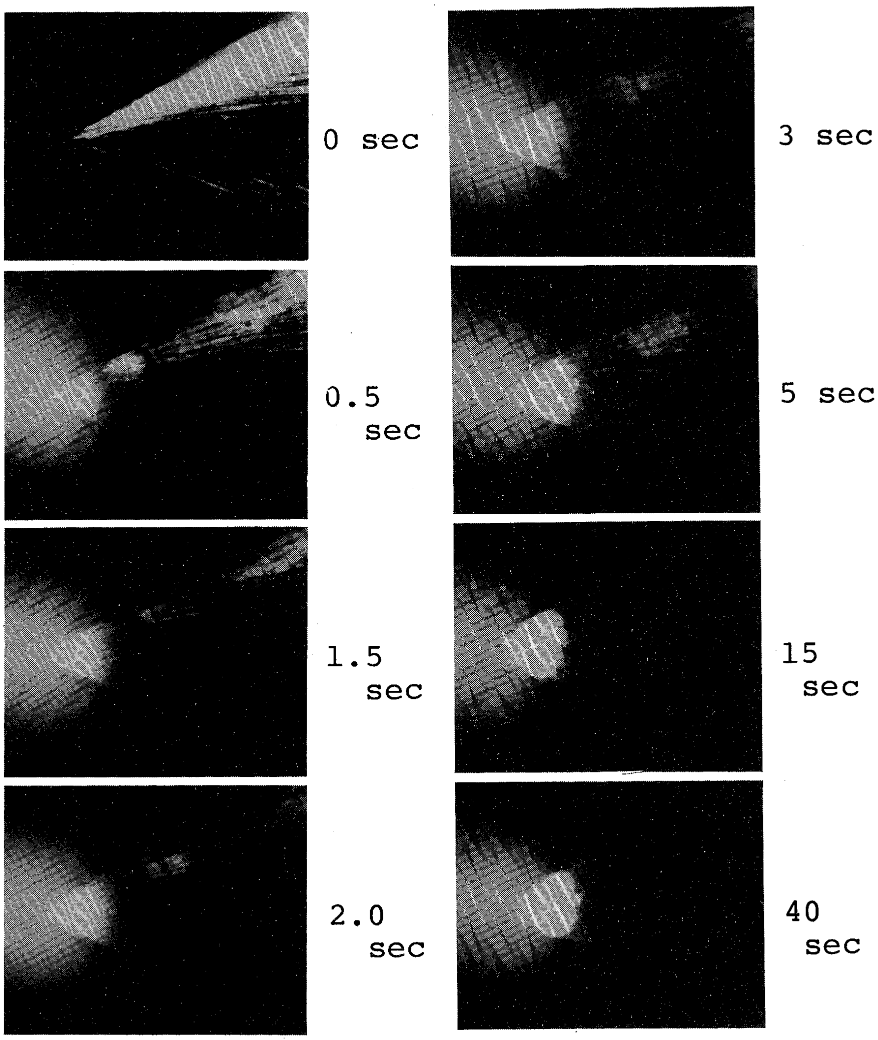
introduction of oxygen into argon shielding gas. The unstable behavior is caused by rise-up and its assymmetry of the obstacle "rim" for plasma and gas flow near the cathode.

Above these phenomena changes the physical situation of the cathode working area. The continuous feed of oxygen to the cathode tip also makes the working area narrower (Fig. 13). Consequently is accelerated the erosion and consumption at the cathode tip extremely.

Material of the "rim" is considered to originate mainly from the electrode surface through oxidization of tungsten. Electrode diameter of the rod part just behind the conical part, is greatly reduced. Tungsten is very easy to oxydize and its products can evaporate and decompose with comparatively low temperature. The vapor of oxydized tungsten may travel along the gas flow which follows to the induced plasma flow, and through decomposition pure tungsten may deposit on the surface where the situation is suitable for crystal growth.

4. Conclusions

Various types of tungsten-oxide electrodes were produced, which contained Magnesium, Zirconium, Thorium, Yttrium and Lanthanum in small quantities as oxide, respectively. Through the comparative study of characteristics such as starting performance, arc pressure, electrode consumption, change in electrode shape due to long term operation and incompleteness of inert gas shielding, and electrode temperature, with above various types of tungsten-oxide cathodes, it is shown that the superiority on the characteristics is provided by La-oxide tungsten, Y-oxide tungsten and Ce-oxide tungsten electrodes. Particularly La-oxide tungsten electrode represented the best property among them.



ThO_2(2%)-W

Electrode Diameter : 2.4 mm

Arc Current : 30 A

Shielding Gas : Ar + O_2 (1%)

Fig. 14 Progress of "rim" formation.

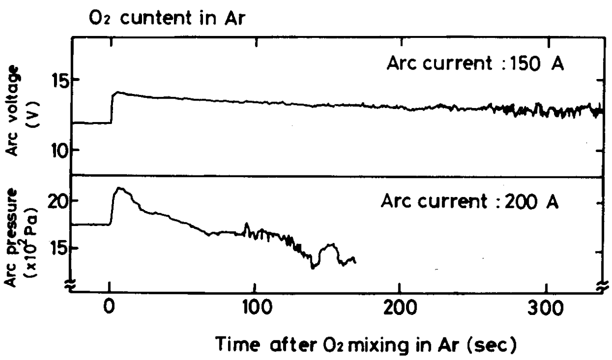


Fig. 15 Time-variation in arc voltage and pressure due to production of "rim" due to introduing Ar-CO_2 mixture gas as shielding gas.

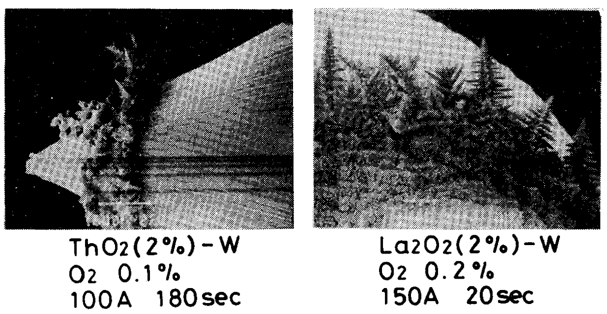


Fig. 16 SEM picture of the "rim".

The formation of the "rim" at the periphery of the cathode working area has a serious problem on the stability of the arc in long term operation and it governs the durability of the electrode. It is consisted of tungsten dendrite and may originate from the oxidation of tungsten electrode.

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