Voltage Fluctuation of Vacuum Arc on the Boundary between Oxide and Bulk Layer

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Abstract: A remarkable characteristic of a cathode spot in a vacuum arc is that the cathode spot moves around the metal surface. A cathode spot can remove an oxide layer. However, the influence of an oxide layer on cathode spot movement remains unclear. This paper elucidates the voltage fluctuation of vacuum arc with brightness and spectrum of the cathode spots. Experiments were performed using a SS400 cathode and a cylindrical copper anode. A high-speed video camera recorded the cathode spot movement. Then, the obtained images were analyzed using plasma image processing. The cathode spot movement was generated mainly on the boundary between oxide and bulk layer, however, sometimes on the processed surface. Conductance of arc decreases because of contamination of oxide vapor into cathode spot. In addition, electrical conductivity is changed because the oxide vapor is ionized, i.e. the electron is generated from the oxide vapor. Therefore, the voltage fluctuation and intensity of the cathode spot are occurred by the contamination of oxide vapor into cathode spot.

Keywords: Vacuum arc, cathode spot, oxide layer, boundary, voltage fluctuation.

1. Introduction

Recently, our society has promoted a circulating production, which embraces the so-called three Rs of reducing waste (Reduce), reusing components and structures (Reuse), and collecting discarded materials for remanufacturing (Recycle). It is necessary for decontamination technology to conform to and serve those social needs. Decontamination technology of the blast and chemical processing is used. However, those processing present numerous secondary waste. Some researchers have been researched the cathode spot in vacuum arc, because few secondary waste is generated. Recently, the models of oxide layer removal have been proposed, such as the work function between oxide and bulk layer [1], blowing away and evaporation from oxide layer [2]. However, these models have not elucidated with the mechanism theoretically. It is considered that the temperature of cathode spot is to be several thousand K, and it moves in a random with removing the oxide layer. Processing with a vacuum arc cathode spot can rapidly evaporate an oxide layer [3] [4] [5].

Because processing is done in a closed space, it scarcely generates dust or noise; the evaporated material is collected using a filter, which enables recycling of the material by melting the filter. Thereby, vacuum arc processing with a cathode spot is expected to comply with and support the social goal of 3R. The authors have been researched the mechanism of oxide layer removal by cathode spot, and clarified the contribution of the oxide layer causes to cathode spot stay time, its continuing, and its occurring between oxide layer and bulk. However they have not elucidated the removal mechanism. This study measures the voltage and spectra during the oxide layer removal in order to elucidate the mechanism of oxide layer removal with cathode spot. In addition, the pictures of cathode spots are taken by the high speed video camera in order to elucidate the position on cathode spots, and the relation between voltage fluctuation and vapor from oxide layer.
2. Experimental Procedure

Experimental arrangement was shown in Fig.1. A cathode work piece and a cylindrical copper anode were set in a vacuum chamber. A pulsed power supply was used for the processing, and the chamber has an evacuation system using a rotary pump. There are a vacuum chamber with the cathode work piece, a cylindrical copper anode, a power supply for the arc, and an evacuation system using a rotary pump. The SS400 with an oxide layer, which serves as a cathode, is connected to the negative line of the power supply. The anode is separated 10 mm from the cathode. The chamber was evacuated to 10 Pa. Argon gas was introduced into the chamber at 0.1 MPa; it was evacuated again to 100 Pa. This operation was repeated. Adjusting the gas-inlet needle valve controlled the chamber pressure. The pressure was adjusted to 100 Pa. A transferred arc was ignited using a wire trigger. Then, the arc current was adjusted to 10 A. The spectrum during the oxide layer removal was measured by spectroscope. The voltage during the oxide layer removal was measured. And the pictures of cathode spots are taken by the high speed video camera. The exposure time is the 30,000 frames/s.

3. Results and Discussion

3.1 Spectra on only bulk and boundary between oxide layer and bulk

The spectra when the cathode spot exists on only bulk is shown in Fig.2. The spectra when the cathode spot exists on the boundary between oxide and bulk layer were shown in Fig.3. When the cathode spot exists on only bulk, Ar I and Fe II spectrum are only observed. However, when it exists on the boundary between oxide layer and bulk, the various spectra were observed, such as, Fe I(741.1, 744.1, 749.2 nm), Ar I (750.0, 751.7 nm), O I (777.4 nm), C I (768.3 nm), Fe II (738.4, 763.6, 772.1 nm), O II (764.2, 765.3, 767.0 nm), Ar II (758.7 nm).
Therefore, the oxide layer is evaporated from the bulk with the heat of energy of cathode spot and sheath region. It is considered that the spectrum of Fe, Ar, O and C atom were generated. In addition, they while the species are ionized, obtain more energy. The atom excites and emits the electron. The cathode spot obtains this electron and it maintained.

3.2 Voltage fluctuation of cathode spot

Fig.4 shows the model of cathode spot moves. This model has 4 modes that classified by cathode spot moves. Mode A shows the cathode spot exists on only the bulk. Mode B shows the cathode spot moves on only the bulk to on the boundary between the oxide layer and bulk. Mode C shows the cathode spot exists on the boundary between the oxide layer and bulk. Mode D shows the cathode spot moves on the boundary between the oxide layer and bulk to on only the bulk.

Fig.5 shows the voltage and picture of cathode spot as a function of processing time. A, B, C and D in Fig.5 are corresponded to Fig.4. Fig.6 shows the relation of the cathode spot mode and voltage. The voltage is fluctuated with increasing the time. In the case of the mode A, the mean voltage is 27.9 V and cathode spot brightness is low.

In the case of the mode B, its voltage is 28.5 V and cathode spot brightness becomes high. In the case of the mode C, its voltage is 28.9 V and cathode spot brightness is high. In the case of the mode D, its voltage is 28.1 V and cathode spot brightness becomes low. Therefore, the voltage depends on the cathode spot mode. It is considered that the contamination of vapor from oxide layer as mention in section 3.1.
Fig. 7 shows the arc voltage and image of cathode spot between 674.5-675 ms. In these case of mode X, C' and Z, the voltage fluctuates even though the cathode spot exists on near-by oxide layer. This is different from A to D mode as shown in Figs. 5 and 6. In the case of mode X, its voltage increases, because the cathode spot ionizes the O_2 atom and iron vapor. In the case of mode C', its voltage is high, because the cathode spot ionizes the O_2 atom and iron vapor as well. In the case of mode Z, its voltage decreases, because the electrical conductivity increases by the electron of ionized O_2 atom and iron vapor.

Therefore, the cathode spot movement was generated mainly on the boundary between oxide and bulk layer, however, sometimes on the processed surface. The conductance of arc decreases because of contamination of oxide vapor into cathode spot. In addition, the electrical conductivity is changed because the oxide vapor is ionized, i.e. the electron is generated from the oxide vapor. Therefore, the voltage fluctuation and intensity of the cathode spot is occurred by the contamination of oxide vapor into cathode spot.

4. Summary

The voltage, spectra, pictures during the oxide layer removal was measured in order to elucidate the mechanism of oxide layer removal with cathode spot and the relation between voltage fluctuation and vapor from oxide layer. The main results are shown below:

(1) The bulk and the oxide layer are evaporated with the heat energy of the cathode spot. Therefore, the spectrum of Fe, Ar, O and C atom and ion are measured.

(2) The ionized atoms obtain the energy and emit the spectrum. The atom excites and emits the electron. It would indicate that the cathode spot obtained this electron and it maintained.

(3) The voltage fluctuation and intensity of the cathode spot are occurred by the contamination of oxide vapor into cathode spot. This is the reason why the electrical conductivity is increased by the electron of ionized O_2 atom and iron vapor.

References


