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MICROSTRUCTURE OF CONTACT MATERIAL MODIFIED BY HIGH-CURRENT VACUUM ARC

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The paper presents research results into the microstructure of Cu–Cr *composite material affected by the high-current vacuum arc. The investigation of the electrode cross-sections allows us to emphasize two zones both for anode and cathode: 1) the exposure zone of the vacuum arc and 2) the virgin material. The first zone locates on the surface of electrodes and is just a zone that crystallizes after the electrode melting due to the exposure to the high-current vacuum arc. It is interesting that on anode there appears a narrow, transition layer enriched with chromium nearby the virgin material and with copper in the exposure zone of the vacuum arc. The formation of such a layer on cathode is not observed.*

Keywords: high-current vacuum arc, microstructure, composite material.

INTRODUCTION

Copper chromium (Cu–Cr) composite materials are widely used as copper–chromium contacts in vacuum arc-quenching chambers. Much research has been carried out into Cu–Cr composite materials [1–3] which, however, mostly concerned the arc resistance of these materials, their mechanical properties, abrasive wear resistance, *etc*. Less attention has been paid to the state of the surface and the internal structure of copper–chromium electrodes after the exposure to the high-current vacuum arc [4, 5]. It was shown that contact opening in a vacuum arc-quenching chamber initiated the arc discharge which burnt in vapor of the electrode material. At the same time, heating, melting, evaporation, crystallization and other processes were observed. All these processes strongly affected the surface and the internal structure of electrodes which, in turn, modified their electrical and mechanical properties. In previous research [6, 7] it was found that the increase in the contact opening capacity depended not only on the surface of electrodes but on their internal structure also.

The aim of this work is to study what effect the high-current vacuum arc has on the surface morphology, the distribution of elements in anode and cathode made of Cu–Cr composite material and the structure formation in the exposure zone of the vacuum arc.

EXPERIMENTAL TECHNIQUE

In this experiment we employed 20 mm diameter solid electrodes, without the generation of a magnetic field. Powder metallurgy was used to manufacture the electrode pad from Cu–Cr composite material containing ≈40 wt.% Cr.

Electrodes were placed in a vacuum arc-quenching chamber [8, 9] and exposed to the high-current vacuum arc. That vacuum arc-quenching chamber was dynamically pumped. The vacuum level of about 10^{-5} Pa was kept by

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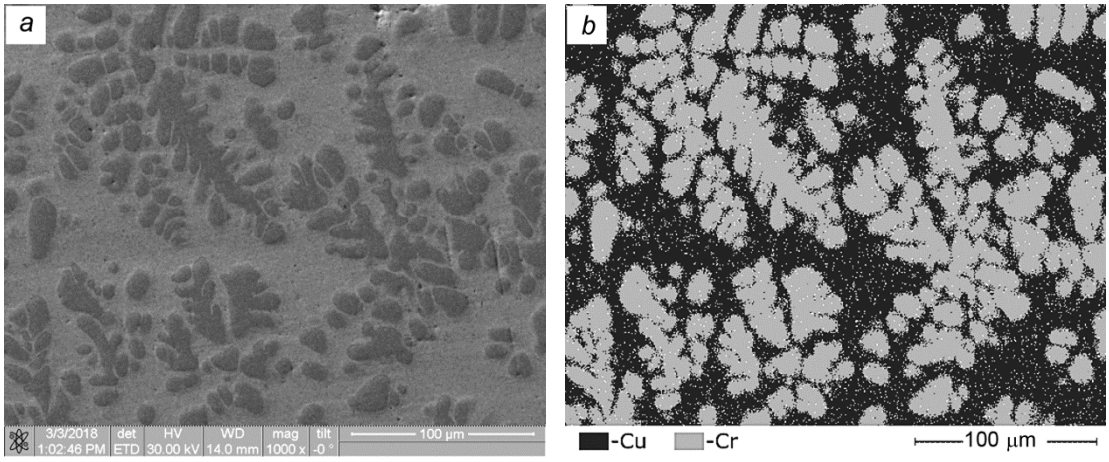

Fig. 1. Original microstructure of Cu–Cr composite material: *a* – SEM image; *b* – EDS mapping of copper and chromium distribution.

a Penning-type pump. The arc discharge was initiated by contact opening at a speed of 1 m/s. The arc discharge parameters included 8–12 kA current amplitude, 10 ms pulse duration, and ~100 pulse discharges. After a series of experiments, the electrode pad was cut off from electrodes for further investigations. It is important to note that the location of the last anode spot was clearly identified and investigated.

After the exposure to the high-current vacuum arc, the morphology of electrode surface was observed on a Quanta 200 3D scanning electron microscope with energy dispersive X-ray spectroscopy (SEM-EDS), FEI Company, USA. The investigation of the structure and element distribution in the exposure zone of the vacuum arc was performed on the electrode cross-sections.

RESULTS AND DISCUSSION

SEM-EDS images of the copper–chromium composite material are presented in Fig. 1. According to these images, the microstructure of this material represents approximately 50 μm coral-like chromium precipitates in the copper matrix. The weight content of copper and chromium in original electrodes is respectively 58.6 and 39.8% including 1.6% of oxygen which is observed mainly in chromium precipitates.

Figs 2 and 3 show SEM images of Cu–Cr electrode surface after the exposure to the high-current vacuum arc. SEM observations show that during burning of the arc discharge, the melt travels over the electrode surface from the centre of the burn area to its periphery. This is proved by characteristic signs left on the surface and solidification of the electrode material on the side surface. Optical profilometry measurements show that the surface of anode is smoother than of cathode. After the exposure to the high-current vacuum arc, the average surface roughness is 7 and 14 μm respectively for anode and cathode.

As shown in Fig. 2, cathode is characterized by two types of the surface. The surface morphology of the first type (Fig. 2*a*) is coral-like and appears mainly due to the material evaporation caused by the electric arc [10, 11]. In this case, the elemental composition of the surface contains 52.5 wt.% Cu, 45.7 wt.% Cr and 1.8 wt.% O. The surface morphology of the second type shown in Fig. 2*b* consists of small cavities, craters and droplet fractions overlapping each other. Its elemental composition includes 71.1 wt.% Cu, 28.5 wt.% Cr and 0.4 wt.% O.

After ~100 pulse discharges, the whole electrode surface becomes coral-like, as presented in Fig. 3. There are also such defects as voids, cracks and droplets saturated with chromium. The elemental composition of the anode surface after the exposure to the high-current vacuum arc is enriched with chromium and consists of 47.7 wt.% Cu, 50.3 wt.% Cr and 2 wt.% O.

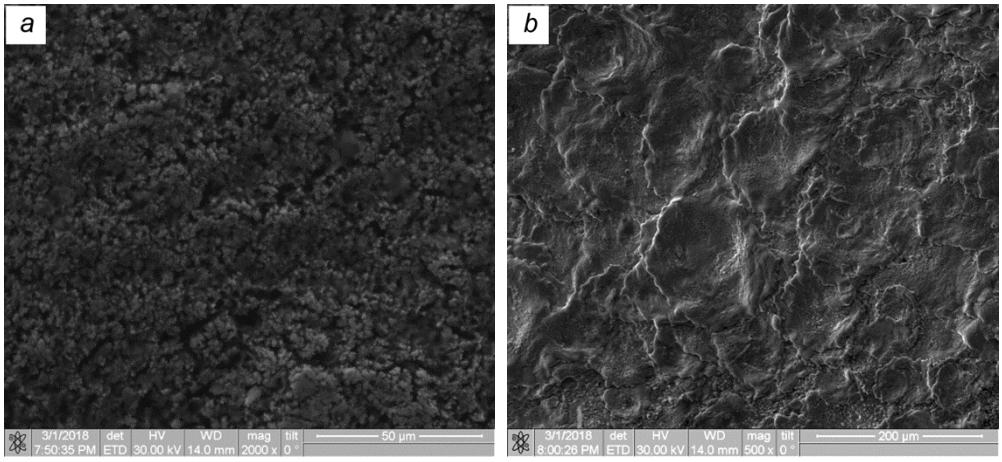

Fig. 2. SEM images of Cu–Cr cathode surface after ~100 pulse discharges: *a* – coral-like surface; *b* – cavities, craters and droplet fractions.

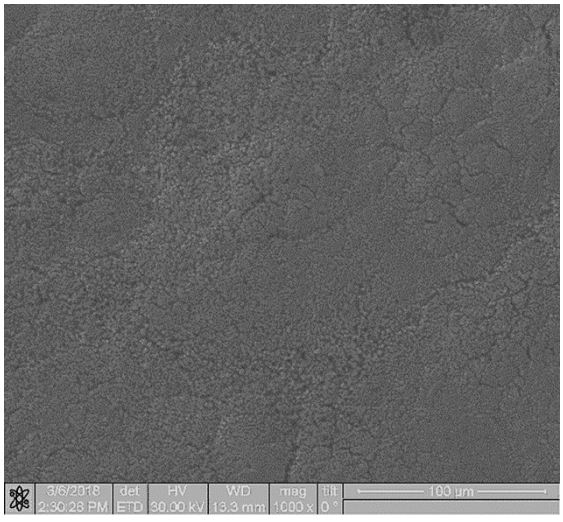

Fig. 3. SEM image of Cu–Cr anode surface after ~100 pulse discharges.

A study of the electrode cross-sections allows us to identify two zones both for anode and cathode: 1) the exposure zone of the vacuum arc and 2) the virgin material. This is shown in Fig. 4. The first zone locates on the electrode surface and is just a zone that crystallizes after the electrode melting caused by the high-current vacuum arc. Within the exposure zone, Cu–Cr composite material is a finely dispersed mixture of copper and chromium or respective solid solutions with a uniform distribution of elements. The average size of chromium precipitates is ~1 μm. It is worth mentioning that such a finely dispersed structure of Cu–Cr composite material is also observed in solidified electrode material on the side surface. In this case, the elemental composition is similar to the original, *i.e*. 58.6 wt.% Cu, 39.8 wt.% Cr and 1.6 wt.% O.

As can be seen from Fig. 4*a*, the depth of the exposure to the high-current vacuum arc varies between 10 and 150 μm. The elemental composition in this case is close to the original: 65.9 wt.% Cu, 33 wt.% Cr and 1.1 wt.% O.

According to Fig. 4*b,* the depth of the exposure to the high-current vacuum arc ranges from 20 to 300 μm and is the lowest nearby the last anode spot and the highest outside this zone. The elemental composition in this case is almost similar to the original: 59 wt.% Cu, 39.6 wt.% Cr and 1.4 wt.% O. It is interesting that in addition to the two

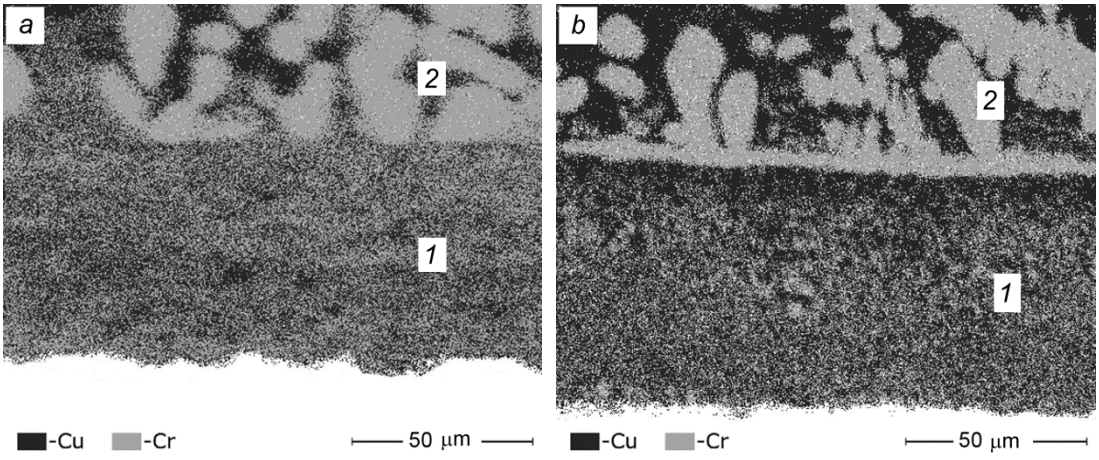

Fig. 4. EDS elemental mapping in Cu–Cr cathode (*a*) and anode (*b*) after ~100 pulse discharges: *1* – exposure zone; *2* – virgin material.

zones, a narrow, ~10 μm thick transition layer appears on anode, enriched with chromium nearby the virgin material and with copper in the exposure zone. The formation of such a layer on cathode is not observed. This is probably because a transfer of cathode material to anode and temperature conditions of the latter. The following fact supports this proposal. The cathode pad erodes stronger due to the high-current vacuum arc, wears out due to the cathode glow and is then carried away from the surface. And the formation of the transition layer is therefore impossible.

CONCLUSIONS

We investigated the microstructure of Cu–Cr composite material affected by the high-current vacuum arc and the elemental distribution in anode and cathode made of Cu–Cr composite material with ≈40 wt.% Cr, and the structure formation in the area subjected to the vacuum arc discharge. After ~100 pulse discharges, the surface morphology of electrodes contained such defects as voids, cracks and droplets. For both cathode and anode, the structure of Cu–Cr composite material formed in the exposure zone was identical, whereas its composition differed. Thus, the structure represented a finely dispersed Cu–Cr mixture or respective solid solutions with a uniform elemental distribution. The average size of chromium precipitates was observed to be about 1 μm. It was found that on anode there appeared a narrow, transition layer enriched with chromium nearby the virgin material and with copper in the exposure zone of the vacuum arc.

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