PLASMA OF ELECTRIC ARC BETWEEN COMPOSITE ELECTRODES ON SILVER BASE

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The investigations of the processes of the mass transfer in a discharge gap of electric arc and peculiarity of interactions of discharge plasma with composite electrode surface were carried out. The optical spectroscopy and metallographic techniques were used. It was found that qualitative change of electric erosion mechanism of electrodes components are realized with increasing of arc current up to 30 A.

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1. INTRODUCTION

Composite materials on a base of copper and silver are widely used as electrode or contact materials in electric industry applications (e.g. relays, commutators, circuit breakers etc.) [1,2]. The principal contact materials on a silver base are described and classified up today. In silver – oxide of metal system oxides either of cadmium or stannum either copper or zinc at mass concentrations in the range from 8 to 20% are used. Such materials are obtained either by powder metallurgy techniques or by an internal oxidation of silver and cadmium (either stannum or copper) alloy. Electro- and heat conductivities of such materials decrease with increasing of oxide content. Materials of silver – cadmium oxide system are characterized both by an excellent erosion resistance and a significant welding resistance as well as a least contact resistance in comparison with other materials of silver – metal oxide system. As an industrial application of cadmium leads to the environmental pollution the more regard must be paid to the development of those materials, which contain alternate materials, in particular, *Ag–CuO* or $Ag–SnO_2$.

The operation efficiency of switching devices is defined by the intensity of mass transfer processes in a discharge gap. Obviously such processes are depended both on the surface structure of electrodes (contacts) and plasma parameters of an arc discharge as well. The composition optimization of an appropriate composite material requires the detail metallographic investigations of such electrodes surface and plasma parameters in a discharge gap too. Naturally, silver is a main component in a composite system of silver – metal oxide. Most probably parameters of electrodes surface as well as arc discharge plasma are determined just by this element.

There are an insignificant number of experimental and theoretical papers, which deal with an investigation of surface condition, plasma parameters and arc discharge between single-component silver electrodes in the up-to-date literature. Unfortunately there are no complex investigations both surface and plasma parameters of arc discharge between composite electrodes on silver base in a literature as well. The probable reason is “the inconvenience” of silver atom in spectroscopy investigations, in particular in optical emission spectroscopy. The matter is that spectral lines of this element, which wave lengths are located in preferable from the point of view of diagnostics visible range, correspond to transitions from closely spaced upper levels. This leads to the low accuracy of a plasma temperature determination in particular. The additional problem is a large variety of available in a nowadays literature spectroscopic data for these lines (transition probability, oscillator strength etc.).

The main aim of this paper is a complex investigation both surface and plasma parameters of arc discharge between fabricated by a powder metallurgy technique composite electrodes *Ag–CuO* (90/10).

2. EXPERIMENT

The arc was ignited in air between the end surfaces of the non-cooled electrodes. The diameter of the rod electrodes was 6 mm, the discharge gap was 8mm, and the arc current was 3.5 and 30 A. To avoid the metal droplet appearing a pulsing high current mode was used: the current pulse 30 A was put on the "duty" weak-current (3.5A) discharge. The pulse duration ranged up to 30 ms.

The spatial distribution of metal vapours in a discharge gap we measured by techniques of optical emission spectroscopy (OES) [3-5] and laser absorption spectroscopy (LAS) [3,4] as well.

The structural changes in the working layer of electrodes were investigated by the optical microscope "Neophot-2" and the scanning electron microscope (SEM) with the X-ray microanalyzer "JSM Super Probe-733", JEOL.

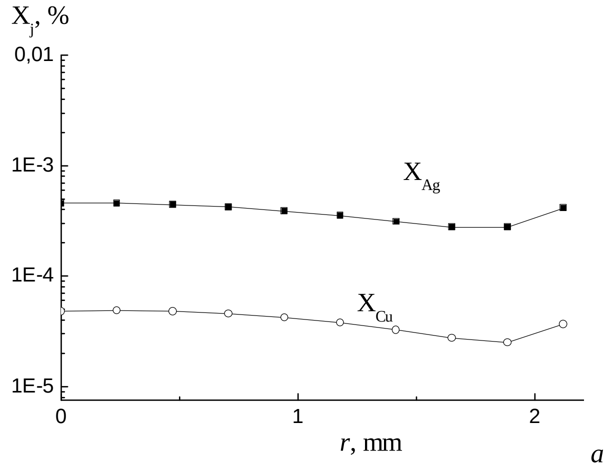
3. RESULTS AND DISCUSSIONS

3.1. MASS TRANSFER IN A DISCHARGE GAP

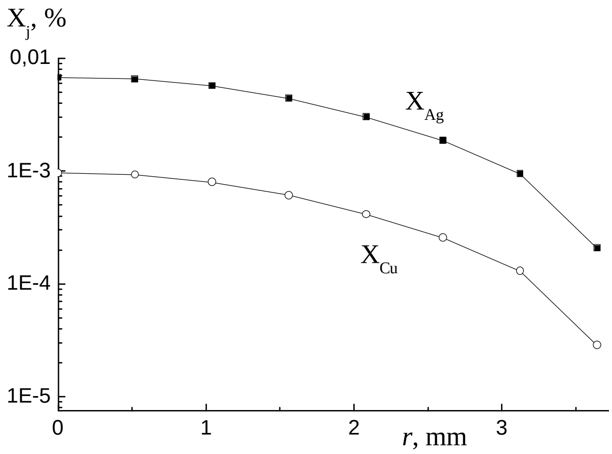
Two independent spectroscopy techniques in a study of the spatial distribution of metal vapours were used. In OES the temperature profiles T(r) in electric arc between composite electrodes were obtained from relative intensities of spectral lines *AgI* 405.5 and 768.8 nm as well as by the Boltzmann plot techniques. In the last case intensities of spectral lines *AgI* 405.5; 447.6; 466.8; 520.9; 546.5; 547.2; 768.8; 827.4 nm and *CuI* 427.5; 465.1; 510.5; 515.3; 521.8; 570.0; 578.2; 793.3; 809.3 nm were used. Spectroscopic data of these spectral lines were carefully analyzed and examined. The radial profiles of electron densities $N_e(r)$ in discharge at 30 A are obtained from width of spectral lines *CuI* 448.0; 515.3 nm and *AgI* 447.6; 466.8 nm in a case of prevail quadratic Stark broadening. The ratio of atom concentrations *AgI* and *CuI* in plasma was calculated from radial profiles of intensities of spectral lines *AgI* 405.5 and *CuI* 465.1 nm in the assumption of the equilibrium of the energy level population.

The obtained electron density and the temperature in plasma as initial parameters were used in the calculation of the plasma composition in the local thermal equilibrium (LTE) assumption. So, it can be possible to calculate the concentration of any considered plasma particle in a discharge gap and the content of silver and copper vapours as well.

In Fig. 1 the radial distributions of content of silver and copper vapours in discharge gap between composite *Ag-CuO* electrodes at arc currents 3.5 (a) and 30 A (b) are shown. Such content of metals in plasma is determined traditionally as X_{Ag}, % = $(N_{Ag}+N_{Ag+})\cdot 100/\sum N_j$ and X_{Cu}, % = $(N_{Cu}+N_{Cu+})\cdot 100/\sum N_j$.



a



b

Fig. 1. Radial profiles of content of silver and copper vapours in discharge between composite Ag–CuO electrodes at arc currents 3.5 A (a) and 30 A (b)

One can conclude that silver content in plasma is more than copper content by a factor of 12 at discharge current 3.5 A. The value of this factor is 7 with current increasing up to 30 A. Obviously it means that mechanism of electric erosion of electrode components is changed.

One another technique of copper vapours visualization is LAS.

The absorption coefficient at the centre of the spectral line *CuI* 510.5 nm in arc plasma volume was measured [3]. From this coefficient of absorption it is possible to calculate the population of the lower level of such spectral transition. So, in this manner we could realize the visualization of copper vapours in a discharge gap at least. Moreover, we can be able to calculate the spatial distribution of copper atom concentration N_{Cu} in the assumption of the equilibrium of the energy level population.

In Fig. 2 the radial distributions of N_{Cu} in discharge gap between composite *Ag–CuO* electrodes obtained by optical emission and laser absorption spectroscopy at arc currents 3.5 and 30 A are shown.

As one can see the concentration of copper atom is naturally raised with increasing discharge current. Good agreement is observed with values obtained by different techniques. There is one more conclusion can be made in this case. Namely, it means that investigated plasma in considered arc discharge modes can be properly described within model of LTE.

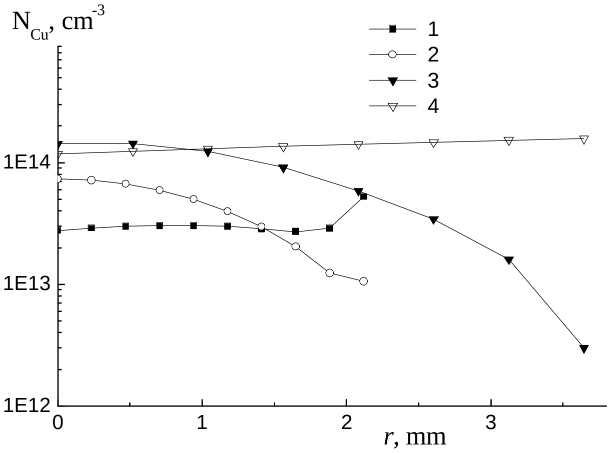


Fig.2. Radial distributions of copper atom concentration in discharge gap between composite Ag–CuO electrodes obtained by OES (1,3) and LAS (2,4) spectroscopy at arc currents 3.5 A (1,2) and 30 A (3, 4)

To clarify the efficiency of the mass transfer processes in a discharge gap and peculiarity of interactions of electrode surface with arc plasma we carried out additional surface investigations by metallographic technique.

3.2. PLASMA-SURFACE INTERACTIONS

The structural changes in a working layer of electrode were studied by metallographic analysis of microvolumes of a working layer.

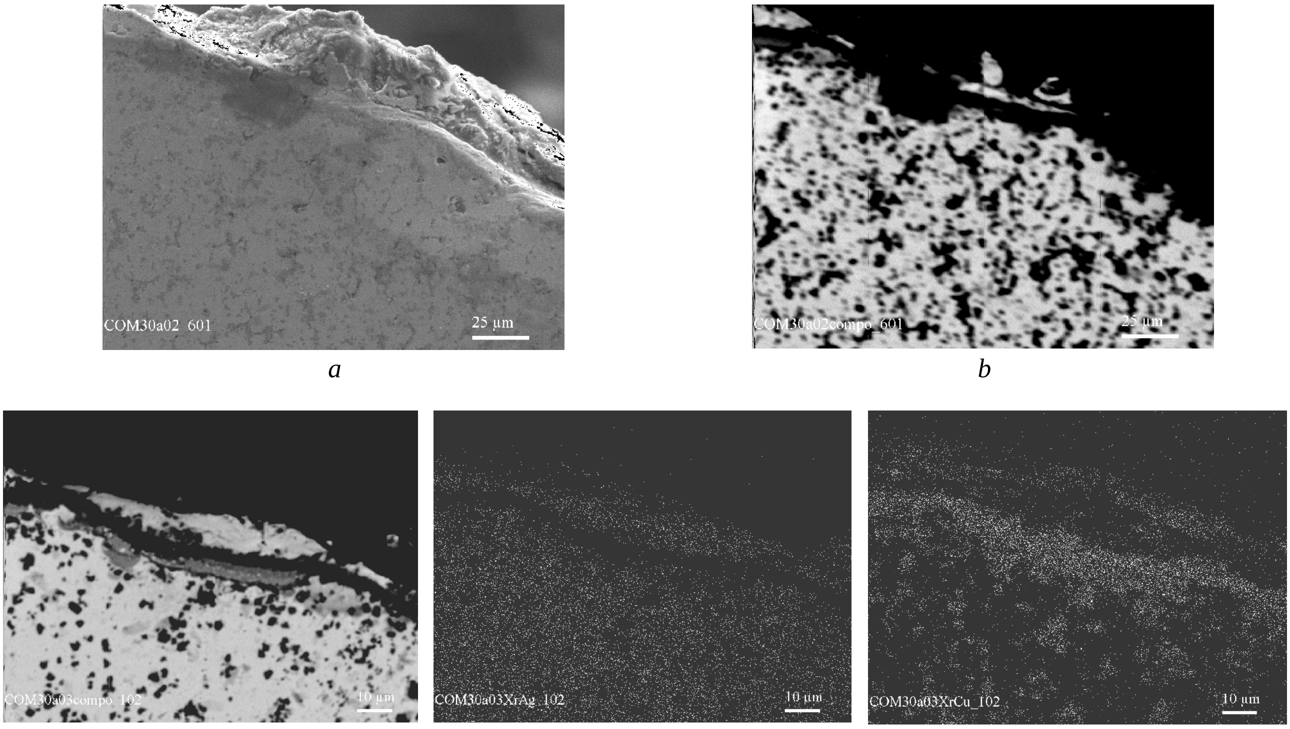
Usually, such secondary modified surface of composite electrode has a complicated unique structure in air arc discharges [3].

The carried out analysis testified that the electrical erosion of *Ag–CuO* electrodes under influence of the free burning in air electric arc occurs mainly in a vapour phase at discharge current of 3.5 A. Both silver and copper as well are evaporated in accordance with their stoichiometric relationships in the electrode composition in this mode of arc operation. The quantitative confirmation of such mechanism of metals evaporation one can observe in Fig.1, a.

It was found as well that the electric erosion increases with increasing current up to 30A. But the condition of silver and copper evaporation is changed at once.

In Fig. 3 the secondary structure on the surface of electrode treated by 5 single 30 A pulses of current (the duration of each is 30 ms) is shown. Fragments of normal surface section in silver and copper X-rays are shown too (see Fig. 3, d, e).

The segregation of silver and copper component in the working layer is clearly observed in this mode of arc operation. It led to the different kind of evaporation mechanism of silver and copper components. It was found that the electrical erosion of *Ag-CuO* electrodes under influence of the free burning in air electric arc can be in addition realized in a solid phase too at discharge current of 30 A. Therefore, it is not surprising that silver/copper ratio in plasma in the discharge gap is changed.



a *b*

c *d* *e*

Fig. 3. The normal surface section of working layer of composite Ag–CuO anode treated by arc current of 30 A

4. CONCLUSIONS

It was found, that the current increasing up to 30 A causes the metals content increasing by factor 10 in plasma in discharge gap between composition *Ag–CuO* electrodes. The ratio of silver/copper in plasma in the discharge gap is decreased in this mode of arc operation. The metallographic investigations confirmed that with increasing of the input power into discharge the qualitative electrodes surface modifications are realized which are caused by change of electric erosion mechanism of each component.

REFERENCES

1. R.V. Minakova, A.P. Kresanova, M.M. Churakov, E.V. Khomenko. The development tendencies of manufacturing technologies of composite materials and their contacts // *Electric Contacts and Electrodes*. Kiev: "IPM NANU", 1998, p. 5-19 (in Russian).
2. G.V. Butkevich, G.S. Belkin, et al. *Erosion of electric contacts and electrodes.* Moscow: "Energia", 1978.
3. I.L. Babich, D.V. Chukhalenko, N.I. Grechanyuk, et al. Plasma of electric arc discharge between Cu-Mo electrodes // *Problems of Atomic Science and Technology. Series "Plasma Physics" (11).* 2007, N 1, p. 139-141.
4. I.L. Babich, V.F. Boretskij, A.N. Veklich. Plasma of electric arc discharge between copper electrodes // *Contr. papers of the XVIIth Symp. on Phys. of Switching Arc (FSO 2007).* Brno, 10-13 Sept., 2007 / Univ. of Techn., Brno. , 2007, v. I, p. 13-16.
5. I.L. Babich, A.N. Veklich, V.Ye. Osidach. Investigation of the electric arc discharge plasma between composition electrodes on the copper base //*Bull. of the Univ. of Kiev. Series "Phys.&Math."* 2006, N 4, p. 265-268.

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ПЛАЗМА ЭЛЕКТРИЧЕСКОЙ ДУГИ МЕЖДУ КОМПОЗИЦИОННЫМИ ЭЛЕКТРОДАМИ НА ОСНОВЕ СЕРЕБРА

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Металлографическими методами и методами оптической спектроскопии исследованы процессы массопереноса в разрядном промежутке электрической дуги. Изучена особенность взаимодействия разрядной плазмы с поверхностью композиционных электродов. Установлено качественное изменение механизма электрической эрозии компонент электродов при увеличении силы тока дугового разряда до 30 А.

ПЛАЗМА ЕЛЕКТРИЧНОЇ ДУГИ МІЖ КОМПОЗИЦІЙНИМИ ЕЛЕКТРОДАМИ НА ОСНОВІ СРІБЛА

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Металографічними методами та методами оптичної спектроскопії досліджені процеси масоперенесення у розрядному проміжку електричної дуги. Вивчена особливість взаємодії розрядної плазми з поверхнею композиційних електродів. Виявлена якісна зміна механізму електричної ерозії компонент електродів при збільшенні сили струму дугового розряду до 30 А.